Brazil: A Country Profile on Sustainable Energy Development

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BRAZIL: A COUNTRY PROFILE ON SUSTAINABLE ENERGY DEVELOPMENT

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FOREWORD

This publication is the product of an international project led by the IAEA to develop an approach suitable for the comprehensive assessment of national energy systems within a sustainable development context. The completion of the first country profile on Brazil focusing on sustainable energy development is the result of an intensive effort conducted by Brazilian experts, primarily from the Energy Planning Programme, Graduate School of Engineering (COPPE), Federal University of Rio de Janeiro (UFRJ); the Brazilian Reference Centre on Biomass (CENBIO) of the University of São Paulo; and the São Paulo State Environmental Secretariat, jointly with the IAEA and the United Nations Department of Economic and Social Affairs (UNDESA).

The framework, systematic approach and guidelines proposed in this study represent an attempt to move forward with the practical implementation of effective mechanisms that permit the incorporation of sustainable development concepts. The assessment is directed specifically to one of the most important sectors affecting economic and social development — energy. This initiative, officially registered as a ‘Partnership’ with the United Nations Commission on Sustainable Development, contributes to Agenda 21, the Johannesburg Plan of Implementation and the Millennium Development Goals. The study is, to a certain extent, a continuation and implementation at the national level of two worldwide undertakings: the World Energy Assessment undertaken by the United Nations Development Programme (UNDP), UNDESA and the World Energy Council (WEC); and the Energy Indicators for Sustainable Development (EISD) undertaken by the IAEA, the International Energy Agency (IEA), UNDESA, Eurostat and the European Environment Agency (EEA).

No study of a national energy system within the context of sustainable development can be final and definitive. To be useful, the assessment process must evolve over time to fit ever-changing conditions, priorities and national sustainable energy development criteria. This publication proposes one approach for consideration and use in the assessment of energy systems by energy specialists and decision makers at the national level. This approach serves as a starting point for the development of more suitable and universally accepted methods for comprehensive sustainable energy development assessments. It is hoped that other countries will use the experience and lessons learned from this Brazilian study in the assessment of their own energy systems and in evaluating their progress towards nationally defined sustainable development goals and objectives. It is also hoped that users of this publication will contribute to refinements in the process by adding their own unique perspectives to what is presented herein.

The work of devising country profiles on sustainable energy development was initiated in 2002 by the IAEA. The effort to develop the first country profile for Brazil started that same year with the creation of the joint partnership with participating Brazilian organizations, UNDESA and the IAEA. Under this partnership, an ad hoc expert committee was created to direct the study and to monitor the progress of implementation. This committee was led by two Co-Chairpersons: J. Goldemberg (São Paulo State Environmental Secretariat) and H.H. Rogner (IAEA). Other members include R. Schaeffer (Team Leader, COPPE), J.R. Moreira (Team Leader, CENBIO), K. Abdalla (Scientific Secretary, UNDESA) and I. Vera (Scientific Secretary and Project Coordinator, IAEA). The committee met on three occasions with experts from the participating Brazilian teams and from other Brazilian organizations, including Eletrobras, Petrobras, the Ministry of Mines and Energy, the Ministry of Science and Technology, the Brazilian Nuclear Energy Commission and the Brazilian National Development Bank, and also with representatives of international and regional organizations, including WEC–Brazil, the Latin American Energy Organization (OLADE) and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC).

The IAEA and other participating organizations would like to express their gratitude to all the experts involved in the preparation of this report. The IAEA officer responsible for this publication was I. Vera of the Department of Nuclear Energy.

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Chapter 1

INTRODUCTION

F. TOTH, J.R. MOREIRA

Energy has been a central concern to humankind throughout its long history. The adequate provision of energy services has become especially important for economic development since the Industrial Revolution. In recent decades, energy issues have been a fundamental component of the conceptual and strategic discussions on sustainable development worldwide. This chapter introduces the project 'Brazil: A Country Profile on Sustainable Energy Development' within this recent political context. The chapter starts with a concise overview of the energy related aspects of international sustainable development programmes and declarations, followed by a short summary of events and documents explicitly devoted to energy matters (Section 1.1). Recent arguments in the theoretical debate on sustainability are presented in Section 1.2 in order to provide the conceptual background for the sustainability assessment of Brazil's energy sector. The background, objectives and scope of the project are summarized in Section 1.3. Finally, in Section 1.4 a road map to the report is provided, drawing the attention of different audiences to chapters of interest to them.

1.1. PRIMER ON SUSTAINABLE ENERGY DEVELOPMENT

1.1.1. Sustainable development: From Stockholm to the WSSD

The United Nations Conference on the Human Environment (UNCHE) in Stockholm in 1972 was the first major United Nations conference devoted entirely to environmental issues. At that time, it was recognized that "The protection and improvement of the human environment is a major issue which affects the well-being of peoples and economic development throughout the world" [1.1]. The product of this conference, the Declaration of the United Nations Conference on the Human Environment, known as the Stockholm Declaration, is dominated by the reciprocal concerns about the environmental implications of socioeconomic development and the repercussions of environmental degradation for the development prospects of present and future generations. It concludes with a commitment to respond to the worldwide problem of environmental deterioration, setting out the principles, guidelines and recommendations that should guide citizens, communities, and local and national governments in shaping their actions with "a more prudent care for their environmental consequences" [1.1].

The energy sector is not explicitly mentioned in the Stockholm Declaration, but several items hold messages for energy production and use. Principle 5 of the document declares that "non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that benefits from such employment are shared by all mankind" [1.1]. This presages the (still unresolved) sustainability dilemma of using non-renewable resources and the equity element of sustainable development. Principle 6 speaks to the environmental implications: "The discharge of…substances…in such quantities or concentrations as to exceed the capacity of the environment to render them harmless…must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems" [1.1]. These are early indications of the critical load concept and the precautionary principle that have become key concerns in the environmental dimension of sustainable development.

Much has been accomplished over the past three decades, but today the world recognizes that protection of the environment has to be linked to social and economic development to secure what has been termed 'sustainable development'. The report on 'Our Common Future' by the World Commission on Environment and Development [1.2] defines sustainable development as "progress that meets the needs of the present without compromising the ability of future generations to meet their own needs". The report further describes sustainable development as "a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potentials to meet human needs and aspirations" [1.2]. The term sustainable development has become a buzzword since the publication of this report.

The commission's report describes the challenges involved in meeting these goals and recognizes the importance of energy in sustainable development by devoting one of the six 'challenges' chapters to this issue. Starting from the premise that development crucially depends on the long term availability of energy "in increasing quantities from sources that are dependable, safe, and environmentally sound" [1.2], the commission defines four elements of sustainability for energy use: sufficient growth of supplies to meet human needs, energy efficiency and conservation measures, public health concerns and environmental protection (at all scales, from the biosphere to the local level). After investigating resource, economic, environmental and safety aspects of fossil fuels, nuclear energy, fuelwood and other sources of renewable energy, and contemplating issues of energy efficiency and energy conservation, the commission concludes that a "safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative" [1.2].

In 1992, the United Nations Conference on Environment and Development (UNCED) resulted in the adoption of the global programme entitled Agenda 21 and the Rio Declaration on Environment and Development. Both identify actions to be taken to achieve the objectives of sustainable development. Neither document mentions energy issues explicitly. Principle 5 of the Rio Declaration asserts that eradicating poverty is an indispensable requirement for sustainable development and that the provision of energy services is a precondition for poverty eradication. Principle 8 calls for eliminating "unsustainable patterns of production and consumption" and has clear implications for energy production and use in developed countries with high energy intensity and in poverty stricken developing countries. Finally, Principle 15 stipulates the wide application of the precautionary approach that is often cited in the context of climate change, where carbon dioxide (CO_2) emissions from fossil fuels are considered a possible cause of potentially serious or irreversible environmental damage.

The Millennium Summit in 2000 confirmed that progress towards sustainable development and poverty eradication has top priority for the global community. The Millennium Development Goals, derived from agreements and resolutions of relevant United Nations conferences in the post-Rio years, are rather ambitious. Some goals are only very remotely related to energy provision and use — for example, Goals 4, 5 and 6 focus on human health concerns. Other goals have important indirect implications for energy development: Access to electricity could foster universal primary education (Goal 2) in many regions of the world. Availability and affordability of commercial energy for cooking would drastically reduce the time and effort needed for fuelwood collection and thus promote gender equality and empowerment of women (Goal 3).

At the macro policy level, Goal 7 calls for integrating the principles of sustainable development into country policies and mentions, among others, energy intensity and per capita carbon emissions as indicators for measuring progress. Ample opportunities exist to make progress on this goal, and many economists suggest that eliminating perverse subsidies that distort the energy sector in many countries could be a good start. Ironically, some energy related measures aimed at poverty alleviation would likely have a negative effect on the sustainability indicators related to energy intensity or emissions in the short term, because they would increase energy use per unit of gross domestic product (e.g. providing electricity to promote education, increased industrialization and urbanization) and CO_2 emissions per capita (e.g. replacing fuelwood with commercial fossil energy in households). However, once these investments in infrastructure and human capital (education, gender equality) start paying off, the energy and carbon intensity indicators should improve as well.

The World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002 recognized that, although some progress has been made, major challenges still must be overcome to implement the vision of sustainable development. Paragraph 18 of the Johannesburg Declaration on Sustainable Development lists energy among the essential needs and suggests rapidly increasing the "access to such basic requirements as clean water, sanitation, adequate shelter, energy, health care, food security and the protection of biodiversity" [1.3]. Point 9 of the Plan of

Implementation of the WSSD makes the direct link between access to reliable and affordable energy services and facilitating the Millennium Development Goals in general and eradicating poverty in particular. Actions to this end range from improving access to modern biomass technologies and cleaner use of liquid fossil fuels to developing national energy policies and regulatory frameworks and enhancing international financial and technical assistance.

An important outcome of the WSSD that has proved to be an effective implementation mechanism is the 'non-negotiated partnership' in sustainable development. These partnerships supplement the commitments agreed to by governments through the intergovernmental process. The project presented in this report is an example of such a partnership.

1.1.2. Energy

Energy is generally recognized as a central issue in sustainable development. Several high level conferences and declarations have confirmed that the provision of adequate energy services at affordable costs, in a secure and environmentally benign manner, and in conformity with social and economic development needs is an essential element of sustainable development. Reliable energy services are the precondition for investments that bring about economic development. They facilitate the learning and study that are crucial for developing human capital. They also promote equity by giving a chance for the less well-off to study, and thus provide a possible escape from poverty. Therefore, energy is vital for alleviating poverty, improving human welfare and raising living standards. However, the provision of energy services also raises other crucial sustainability concerns. The socially optimal depletion of non-renewable energy resources has been at the centre of the sustainability debate for decades. The environmental impacts of different energy forms and their repercussions for society (ranging from the damage imposed on socioeconomic and material assets to risks to human health) can undermine the sustainability of the development.

Many current patterns of energy supply and use are unsustainable. About a third of the world population relies on the use of non-commercial fuels that have negative impacts on health and the environment. Between 1.7 and 2 billion people have no access to electricity. Many regions of the world have no reliable and secure energy supplies, limiting economic development. The challenge is to design and implement sustainable energy development that will support these societies on the long term path of sustainable development.

In 1997, the United Nations General Assembly formally recognized the need for more sustainable energy use patterns, and, for the first time, an intergovernmental process was created to elaborate a common approach to the sustainable energy development agenda. The World Energy Assessment (WEA) [1.4] thoroughly analyses the relationships among energy, social issues, health and the environment; addresses issues of energy security, resource availability, end use efficiency, and renewable and advanced supply technologies; pays special attention to the fundamental problem of rural energy in developing countries and to the role of energy in economic prosperity; and depicts three energy scenarios for the 21st century. The study pays special attention to unsustainable features of the current energy system: problems related to equity (accessibility), reliability and affordability, and environmental impacts. The report concludes that sustainable energy policies should meet overall national sustainability goals and should:

- Rely on markets where they function properly and correct market failures by using suitable regulatory mechanisms where possible market failures (monopolies, externalities) and other obstacles (lack of technological knowledge, diverging interests of investors and users) exist;
- Complement measures of energy sector restructuring with regulations that encourage sustainable energy;[1]
- Provide incentives for mobilizing additional investments in sustainable energy and technological innovation in transition and developing countries by fostering reliable commercial legislation and regulation;
- Encourage enhanced international cooperation;
- Support technological leadership and capacity building in developing countries.

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[1] The WEA defines sustainable energy as "energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions" [1.4].

The development efforts of the international community and most developing countries have increasingly focused on poverty reduction in recent years. The World Bank [1.5] has distinguished three main domains of poverty reduction strategies (promoting opportunity, facilitating empowerment, enhancing security) and identified a series of actions for implementation. In the 'opportunity' domain, provision of energy services is among the key factors, with cascading effects in other areas: "improving poor people's access to energy or transport can increase their access and returns to education" [1.5]. Similarly, providing electricity is a core element of the strategy to provide infrastructure and knowledge to poor areas.

In April 2001, the 9th Session of the Commission on Sustainable Development (CSD-9) recognized the need for a movement towards sustainable patterns of production, distribution and use of energy. In establishing the multi-year programme of work of the CSD, the Special Session underscored that, in line with the objectives of Agenda 21, the CSD-9 should "contribute to a sustainable energy future for all". The IAEA and the International Energy Agency (IEA) [1.6] presented a preliminary report on indicators for sustainable energy development (ISED) as part of the deliberations of CSD-9. In 2005, the IAEA, in cooperation with the United Nations Department of Economic and Social Affairs (UNDESA), the IEA, the Statistical Office of the European Communities (Eurostat) and the European Environment Agency (EEA), published a report on guidelines and methodologies of Energy Indicators for Sustainable Development (EISD) [1.7]. Table 1.1 presents the list of energy indicators included in that publication. To the extent possible, these indicators are used in this report to characterize Brazil's past and present energy development and to assess alternative future scenarios and strategies.

The project presented in this report draws heavily on the concepts, procedures, analytical frameworks and modelling tools of the above activities, especially those of the WEA and the ISED programme of the IAEA. In fact, it is the first in-depth analysis of sustainable energy development at the national level.

1.2. THE ONGOING DEBATE: 'SUSTAINABILITY VERSUS DEVELOPMENT' OR 'DEVELOPMENT VERSUS SUSTAINABILITY'

1.2.1. Conceptual foundations and political debates

Endless debates over the past 15 years have been trying to make out the practical implications of the sustainability concept. Dozens of alternative definitions, hundreds of sustainability indicators and numerous criteria and implementation strategies have been proposed. The reason why it is difficult to define precise criteria for sustainability is that doing so involves value judgements. What would one consider sustainable? For whom? By whom? In what context?

Considering the widely diverging views about sustainability even within individual economic sectors (What is sustainable agriculture or sustainable forestry?), it will take a long time and much debate before consensus may emerge about its more specific definition and practical implications. An important part of the problem is that the term is politically heavily loaded. It is widely used and often misused. This study is one attempt to examine sustainability in a national context, to apply the EISD to describe the current situation of Brazil and to explore future development options for the national energy system.

As nations have been exploring strategies to reach sustainable development, it has become evident that the emphasis on what is needed depends on the country's level of development. Developing countries are more concerned with 'development', and in particular with economic and social development, since major priorities include improving incomes and standards of living while achieving full satisfaction of basic needs and high levels of employment. Developed countries, which have reached industrialization and high living standards, emphasize 'sustainability', consequently their policies are formulated to stress the need to protect the environment. In a classic argument, developing countries see environmental restrictions as imposing constraints on their development that were not imposed on the developed countries as they went through the equivalent stages of the development process. Developed countries, in contrast, assert that the global character of environmental protection requires commitments from all

TABLE 1.1. ENERGY INDICATORS FOR SUSTAINABLE DEVELOPMENT [1.7]

Social

Theme	Sub-theme	Energy indicator		Components
Equity	Accessibility	SOC1	Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy	Households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy Total number of households or population
	Affordability	SOC2	Share of household income spent on fuel and electricity	Household income spent on fuel and electricity Household income (total and poorest 20% of population)
	Disparities	SOC3	Household energy use for each income group and corresponding fuel mix	Energy use per household for each income group (quintiles) Household income for each income group (quintiles) Corresponding fuel mix for each income group (quintiles)
Health	Safety	SOC4	Accident fatalities per energy produced by fuel chain	Annual fatalities by fuel chain Annual energy produced

Economic

Theme	Sub-theme	Energy indicator		Components
Use and production patterns	Overall use	ECO1	Energy use per capita	Energy use (total primary energy supply, total final consumption and electricity use) Total population
	Overall productivity	ECO2	Energy use per unit of GDP	Energy use (total primary energy supply, total final consumption and electricity use) GDP
	Supply efficiency	ECO3	Efficiency of energy conversion and distribution	Losses in transformation systems including losses in electricity generation, transmission and distribution
	Production	ECO4	Reserves-to-production ratio	Proven recoverable reserves Total energy production
		ECO5	Resources-to-production ratio	Total estimated resources Total energy production
	End use	ECO6	Industrial energy intensities	Energy use in industrial sector and by manufacturing branch Corresponding value added
		ECO7	Agricultural energy intensities	Energy use in agricultural sector Corresponding value added
		ECO8	Service/commercial energy intensities	Energy use in service/commercial sector Corresponding value added

TABLE 1.1. ENERGY INDICATORS FOR SUSTAINABLE DEVELOPMENT [1.7] (cont.)

Economic

Theme	Sub-theme	Energy indicator		Components
Use and production patterns	End use	ECO9	Household energy intensities	Energy use in households and by key end use Number of households, floor area, persons per household, appliance ownership
		ECO10	Transport energy intensities	Energy use in passenger travel and freight sectors and by mode Passenger-km travel and tonne-km freight and by mode
	Diversification (fuel mix)	ECO11	Fuel shares in energy and electricity	Primary energy supply and final consumption, electricity generation and generating capacity by fuel type Total primary energy supply, total final consumption, total electricity generation and total generating capacity
		ECO12	Non-carbon energy share in energy and electricity	Primary supply, electricity generation and generating capacity by non-carbon energy Total primary energy supply, total electricity generation and total generating capacity
		ECO13	Renewable energy share in energy and electricity	Primary energy supply, final consumption and electricity generation and generating capacity by renewable energy Total primary energy supply, total final consumption, total electricity generation and total generating capacity
	Prices	ECO14	End-use energy prices by fuel and by sector	Energy prices (with and without tax/subsidy)
Security	Imports	ECO15	Net energy import dependence	Energy imports Total primary energy supply
	Strategic fuel stocks	ECO16	Stocks of critical fuels per corresponding fuel consumption	Stocks of critical fuel (e.g. oil, gas) Critical fuel consumption

Environmental

Theme	Sub-theme	Energy indicator		Components
Atmosphere	Climate change	ENV1	GHG emissions from energy production and use per capita and per unit of GDP	GHG emissions from energy production and use Population and GDP
	Air quality	ENV2	Ambient concentrations of air pollutants in urban areas	Concentrations of pollutants in air
		ENV3	Air pollutant emissions from energy systems	Air pollutant emissions
Water	Water quality	ENV4	Contaminant discharges in liquid effluents from energy systems including oil discharges	Contaminant discharges in liquid effluents

TABLE 1.1. ENERGY INDICATORS FOR SUSTAINABLE DEVELOPMENT [1.7] (cont.)

Environmental				
Theme	Sub-theme	Energy indicator		Components
Land	Soil quality	ENV5	Soil area where acidification exceeds critical load	Affected soil area Critical load
	Forest	ENV6	Rate of deforestation attributed to energy use	Forest area at two different times Biomass utilization
	Solid waste generation and management	ENV7	Ratio of solid waste generation to units of energy produced	Amount of solid waste Energy produced
		ENV8	Ratio of solid waste properly disposed of to total generated solid waste	Amount of solid waste properly disposed of Total amount of solid waste
		ENV9	Ratio of solid radioactive waste to units of energy produced	Amount of radioactive waste (cumulative for a selected period of time) Energy produced
		ENV10	Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste	Amount of radioactive waste awaiting disposal Total volume of radioactive waste

countries and in particular those undergoing intense industrialization processes.

Recent debates and practical programmes have focused increasingly on the complementary characteristics of development and sustainability. Many unsustainable forms of resource use (fuelwood, water) and many practices harmful to human health and the environment (low quality fuel causing indoor air pollution and smog) are rooted in poverty, hence development would help alleviate poverty and simultaneously protect resources and nature. Further up the affluence ladder, there is ample evidence that societies pursuing environmentally benign development paths improve their overall welfare in ways that are superior to those following behind them on the environmental degradation–rehabilitation path. This is largely a function of affluence — having choices beyond survival and more income to spend on a higher quality of life.

Sustainability is an intriguing concept for scholars and politicians alike. Serious efforts have been made to quantify and/or model the economic–non-economic balances that are struck in the process of charting a sustainable development course, taking into account national and regional differences. There is a general understanding that the term involves normative aspects and therefore defies ‘objective’ scientific treatment. The reason is that the notion of sustainability goes beyond biophysical limits and the efficient allocation of scarce environmental resources. It involves choices about social, value and technological options made under circumstances characterized by severe uncertainties. It is worth reviewing here some of the well known efforts in this area.

The book *The Limits to Growth* [1.8] could be considered the opening salvo to the current round of debate on sustainability. Based on one of the first global models that tried to accommodate worldwide problems in the context of global economic integration, the book anticipates a rather bleak future for the world: scarcity, degradation, poverty, crisis and collapse. The core concept of the underlying model is exponential growth, considered to be the root of all evil. Subsequent studies refuted both the model and its conclusions by pointing to conceptual, methodological, economic and resource accounting problems. Nonetheless, the report triggered an enormous debate about economic growth and general socioeconomic development, and their implications for natural resources and the environment. Part of the debate focused on zero growth. Not surprisingly, zero growth was totally unacceptable to poor countries — in fact, to any country. A new concept has emerged in the debate based on the principle that development (and economic growth as its basis) is indispensable but must be environmentally benign.

Hussen [1.9] examines three more recent conceptual approaches to defining sustainable development (Hartwick–Solow, ecological economics and safe minimum standards) and finds several common features: recognition of biophysical limits, the desirability of sustainable development, the non-declining total (natural and human) capital stock and the importance of efficiency and equity criteria. The two main issues on which these sustainability concepts diverge are the relationship between natural and human capital (considered to be substitutes by the Hartwick–Solow approach but thought of as complements by the ecological economics and safe minimum standards approaches) and the relative importance of equity and efficiency (the Hartwick–Solow approach focuses on intertemporal efficiency, ecological economics emphasizes intergenerational equity, while the safe minimum standards approach is centred on irreversible environmental implications). The Hartwick–Solow approach gives more credit to technological innovation for embarking on environmentally benign development paths, while the safe minimum standards approach tends to discount this proposition. There are various corollaries for sustainable energy development, the most important being that if one takes the verbatim interpretation of non-declining natural capital proposed by the ecological economics position, the use of non-renewable energy sources is problematic until their technologically feasible and economically affordable replacements from renewable sources are demonstrated.

But even if one disregards the normative aspects, it is impossible to define absolute criteria for sustainability. One of the key points in the debate concerns the difference between what economists call ‘weak’ and ‘strong’ sustainability. The fundamental criterion for weak sustainability is that the total amount of capital (natural and social) available to any generation should be non-declining, whereas the principal criterion for strong sustainability is more restrictive: the total amount of natural capital must not decline over time. (The implications for sustainable energy are the same as those under the Hartwick–Solow versus ecological economics approaches above.) Neumayer [1.10] presents an in-depth analysis of the conceptual foundations of the two sustainability paradigms (neoclassical versus ecological economics), the key difference between the two sustainability definitions (substitutability of natural capital, especially non-renewable resources), the analytical and policy making circumstances (risks, uncertainties, ignorance), and the attempts to measure sustainability (indicators ranging from the Hartwick rule concerning genuine savings on the weak sustainability side to the physical measures of sustainability standards and gaps in the strong sustainability realm).

Neumayer’s key conclusions include the following: Science cannot unambiguously support either paradigm, because they differ fundamentally in their presumptions about future possibilities for substitution and technological development. The future, in turn, is inherently uncertain. A disaggregated approach towards natural capital is required because some forms of natural capital are more compatible with the weak sustainability definition (natural resources as input to the production of goods and services), while other forms are more congruent with the strong sustainability assumption (natural capital as pollution absorber and neutralizer, and provider of direct utility). A somewhat simplified conclusion of this treatise for the energy sector is that, according to these definitions, depletions of fossil fuel sources are less of a problem from the sustainability perspective than are the risks that the resulting emissions raise for the environment, like climate change.

1.2.2. Prospects for sustainable development in the energy sector

Section 1.1.2 above presents several reasons why energy is at the heart of sustainable development. One additional reason is the pervasive nature of energy in societies: it is required for all production, consumption, service and investment activities, albeit in different forms and quantities. This is illustrated in Fig. 1.1 (see also Refs [1.4, 1.12]). Depending on their geographical (climate, location), social (values, customs, preferences) and economic (affluence, access to technologies) situation, people choose a set of goods and services to satisfy their needs, ranging from food to comfortable living conditions, from mobility to cultural needs, from survival to convenience or luxury. Accordingly, among the selected consumer goods, one finds cooking, lighting, air conditioning, communication and entertainment devices, and vehicles and other equipment providing the services people want. The manufacture of consumer goods

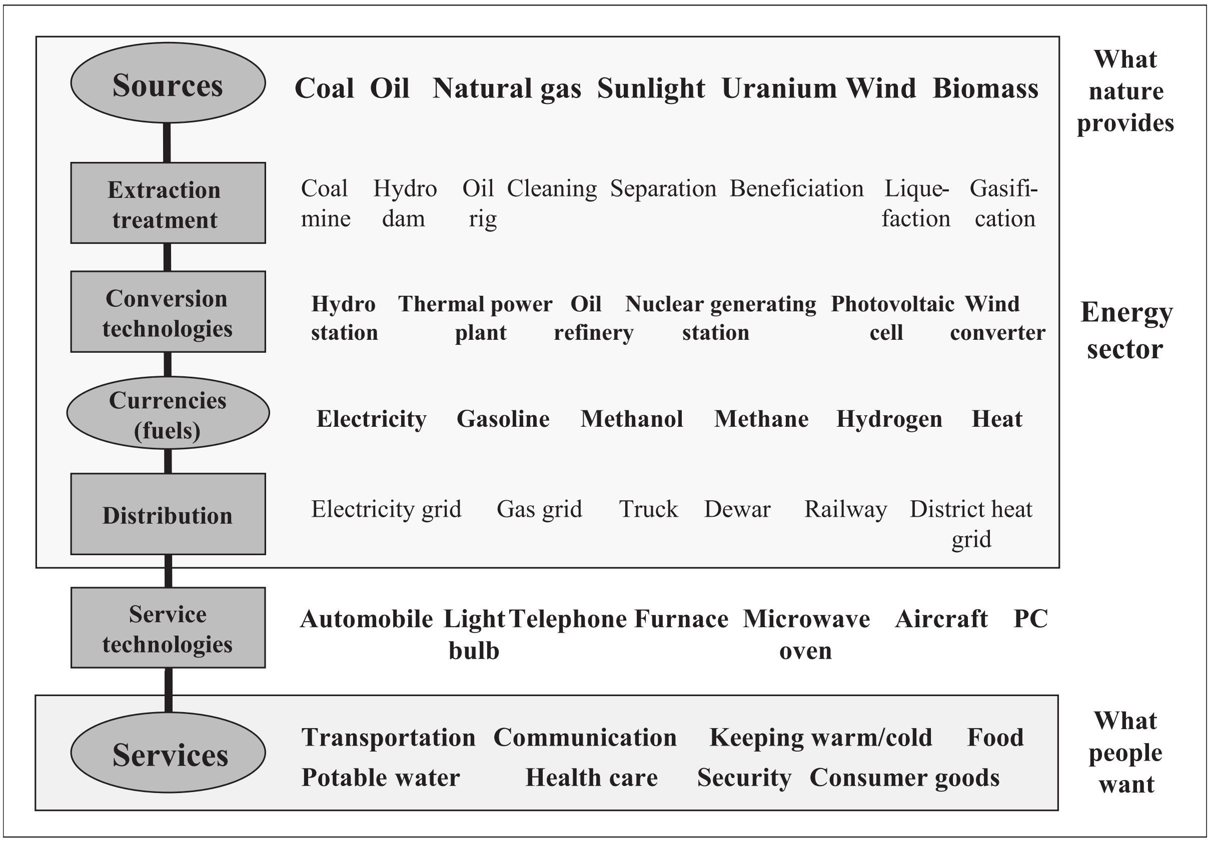

FIG. 1.1. Architecture of the energy system (after Ref. [1.11]).

and the provision of services, in turn, require another large array of tools and equipment (like metal smelters, automobile and video assembly plants, and medical instruments manufacturers), and their operation also requires energy. The hardware used by final consumers and producers is called service technologies in energy systems analysis. Such technologies perform the local conversion of final energy into useful energy required to provide services (light, heat, mobility). In modern societies, a complex web of equipment and activities delivers final energy to the users, as depicted in Fig. 1.1.

The process starts at locations (coal mines, hydropower dams, oil wells, windy areas, forests) of energy sources (coal, oil, gravity, jet streams, fuelwood). Depending on the nature of the source, some extraction and treatment operations are required to obtain what is called primary energy. Conversion sites (hydropower stations, thermal and nuclear power plants, oil refineries, coal gasification plants) apply a range of conversion technologies (turbines, cracking, chemical reactors) to turn energy sources (coal, oil, uranium, sunlight, wind, biomass) incorporating primary energy into secondary energy. Secondary energy takes different forms called currencies (electricity, gasoline, hydrogen, heat) and is fed into distribution networks (electricity and gas grids, vehicles, heat grid pipes) that transmit it (and, in some cases, store it) from the conversion sites to the user. The final energy received by the user drives the service technologies in the process of local conversion into useful energy.

It is important to note that the technologies applied in the production sectors and in final energy use include both the equipment and the process of converting final energy into useful energy. Energy related concerns (costs, efficiency, form, dependability, convenience) constitute only a subset of the many criteria considered by users and operators of the local conversion technologies. That is why highly efficient technologies often fail in the market because consumers ignore them for economic (large investment), technical (frequency of maintenance needs), aesthetic (unattractive appearance), comfort (noise level), convenience (ease of operation) or religious (rules or taboos) reasons, or simply as a matter of taste.

Nevertheless, the framework in Fig. 1.1 is useful for illustrating the scope for sustainable energy development within the energy system and in energy–economy–society interactions. Steps in the long process from primary to useful energy are plagued by conversion and transmission losses, as measured by different efficiency indicators within the energy system. The range and the relative weight of energy sources are almost fixed in the short term but can be changed drastically in just a few decades. Consumer tastes and preferences may alter spontaneously or can be influenced by economic incentives (relative prices) and moral persuasion (ethical arguments), including environmental concerns.

Recent estimates of resources and reserves of non-renewable energy sources are supported by broad consensus (see Ref. [1.13]). Depending on one's stance on their substitutability by human-made capital (recall Section 1.2.1), they can be extracted at faster or slower rates. Extraction technologies for non-renewable energy sources might become more efficient, and this is likely to increase the total amount of primary energy gained from these sources. There is a larger scope for efficiency improvements in primary conversion, although different conversion technologies are in different phases of their technology life cycles and thus have different potentials for improvement. Conventional power plants and oil refineries rely on mature technologies with modest room for additional improvements in conversion efficiency. Solar heat and photovoltaic (PV) technologies, in contrast, are in an earlier phase and are rather far from the theoretical maximum of their conversion efficiencies. Further down on the conversion pathways, one finds more or less possibility of loss reduction (gas leakage, power transmission losses) depending on the energy form, distance, transmission technology and other factors. Finally, it is generally recognized that a large potential for reductions in energy use exists in efficiency improvements in local conversion technologies (from final to useful energy), in lifestyle changes (energy intensity of the goods and services consumed) and, partly as a result of the latter, in economic structural changes (energy intensity of producing the goods and services).

The message of the energy systems framework shown in Fig. 1.1 for sustainable energy development is twofold. First, the scope for efficiency improvements and corresponding resource savings and reduced environmental impacts increases as one proceeds from primary to secondary, final and useful energy. Second, the relative weight of energy and efficiency concerns in the decisions declines along the same path: technical efficiency and economic costs carry a significant weight in decisions on primary conversion and secondary transmission technologies, but the choice of final conversion technologies (typically integrated into production equipment and consumer goods) depends on numerous factors and is thus more difficult to influence on energy grounds.

1.2.3. The state of the sustainable development debate in Brazil

Brazil is internationally recognized as a centre of major environmental events. In 1992, Rio de Janeiro hosted the UNCED, which produced Agenda 21, a comprehensive set of terms of reference for sustainable development into the 21st century. Rio de Janeiro was also where the United Nations Framework Convention on Climate Change (UNFCCC) was opened for signature. Later, at the WSSD in Johannesburg in 2002, Brazil proposed the Brazilian Energy Initiative (BEI) stipulating a global target of 10% of all energy to be derived from renewable sources [1.14].

Economic development is a major issue in Brazil. Since the 1970s, when significant growth was observed, the country has achieved only modest rates of growth of gross national product owing to external and internal obstacles. Modest economic growth has not been sufficient to create job opportunities for the growing population; at the same time, technological progress has reduced the size of the workforce necessary to generate the same amount of goods and services. This means that significant effort is needed for new development growth carried out under sustainable conditions. In other words, it is desirable to take advantage of technological leapfrogging, since following the path of industrialized countries would create undesirably high energy demand and pollution levels. As Brazil needs to reduce regional and social inequalities, socioeconomic development and employment creation are major concerns for policies in all major sectors of the economy, including the energy sector.

In Brazil, energy policies and policy frameworks for sustainable development focus on guaranteeing universal access to energy and encouraging energy efficiency and the use of renewable sources. Universal access to energy is being pursued through recently implemented programmes like the Energy Programme for Small Communities (PRODEEM), through the 'Light for All' Programme and through policy efforts practised for decades, like subsidies for liquefied petroleum gas (LPG) used for cooking purposes and low cost electricity for low level consumers. Energy efficiency has been officially promoted since 1985, which marked the creation of the National Electricity Conservation Programme (PROCEL), and since 1992 through the creation of the Brazilian National Programme for Rationalization of Oil Products and Natural Gas Use (CONPET). These two programmes have been reasonably promoted by the Government and are well accepted by society, but they have yielded modest results, especially CONPET. Private participation is increasing through the flourishing of energy service companies (ESCOs), mainly since the establishment of a compulsory Federal programme requiring investments by utilities in energy conservation at the clients' facilities. The concept of electricity efficiency was tested during most of 2001, with considerable public engagement when electricity shortages affected most of the country's population.

Energy systems based on renewables were strongly facilitated by Government initiatives in favour of hydropower and alcohol fuel promotion. The Brazilian energy matrix has a significant share of renewable energy: 14% from mostly large hydropower plants,[2] plus 27% from biomass (sugar cane, charcoal and fuelwood, most of it exploited in a sustainable way). Thus the situation in Brazil is quite different from that in developed countries (see Fig. 1.2). The Brazilian Alcohol Programme (PROALCOOL), the world's largest commercial renewable energy effort, was launched in 1975; sugar cane ethanol is now competitive with gasoline without subsidies (in 2002 it replaced about 200 000 bbl of imported oil per day). Its importance has been increased by activities in the electricity supply market through the operation of thermal plants using sugar cane bagasse. These power units, initially designed to produce heat and power for sugar mills, are selling surplus electricity to the grid. Private initiatives were important in the development of alcohol fuel and for industrial charcoal use. The country is also the world's largest charcoal producer and consumer, and the only country with a significant research and development (R&D) programme dedicated to charcoal; consequently, its charcoal technology has efficiencies of about 30–35%, compared with 12–25% in many other countries. Social acceptability and participation, as well as political support, have been important elements for the success of such renewable energy schemes. Nevertheless, since the 1990s public

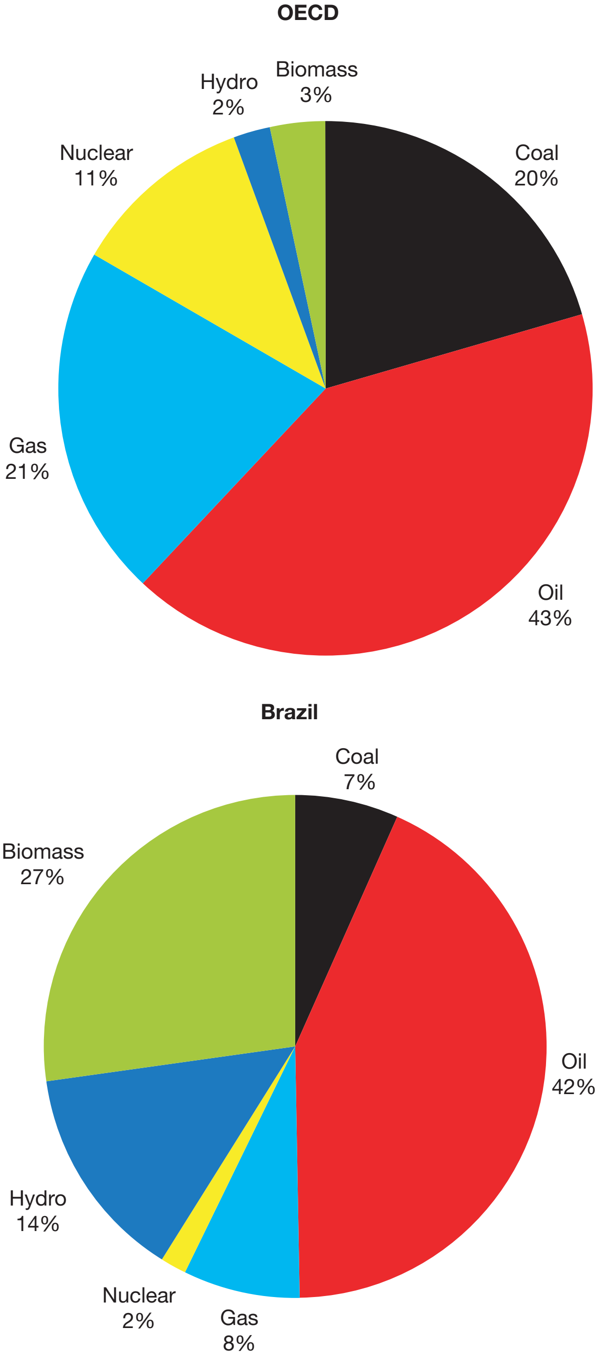

FIG. 1.2. Total primary energy by fuel share in the OECD and Brazil, 2002 [1.15, 1.16].
Note: *Data for the OECD are from Ref. [1.15]; data for Brazil are from Ref. [1.16].*

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[2] Including hydroelectricity imports.

debate on large hydropower has increased and environmentalists have successfully slowed its implementation. Small hydropower is once again considered an option for electricity supply, but it is well understood by society that large hydropower plants might still be constructed, provided attention is paid to the displaced population. A recent Government energy programme — the Alternative Energy Sources Incentive Programme (PROINFA) — intends to address simultaneously the issues of universal access to energy and increased use of renewable sources.

The relationship between cumulative implementation of a given technology and unit cost reductions is captured by the concept of a learning curve. The case of the alcohol programme in Brazil has proved that the creation of a large market for renewable energy depends on several conditions: developing dispersed markets, extending financial services to the retail level, building business and maintenance infrastructure and scaling up manufacturing. Governmental interventions were crucial to fostering this brand new market in the early 1980s, but today the supply continues without any subsidies.

Together with developing technology, a way to establish a new renewable energy market is to induce demand for it. Through Government programmes in Brazil, market development contributes to boosting the development and application of renewable energy technologies as an essential step towards future large scale use.

Sustainable development cannot be achieved without fundamental changes in the way industrial societies produce and consume, and it is necessary to adopt policies and measures that support such changes. Eradicating poverty and hunger and promoting sustainable livelihoods are central to achieving sustainable development. This has been well understood by Brazil’s past two Federal Governments, and since 1992 several social programmes have been implemented to mitigate poverty and hunger. Unfortunately, limited economic growth and the large amount of financial resources absorbed by external and internal debt have prevented social actions in some years.

Another aspect of the sustainable development attitude in the country — that regarding air pollution in large cities — is demonstrated by the considerable importance attributed to it in legislation and its acceptance by society. Water pollution through deliberate action or through accidents results in severe criminal and financial punishment and is presented as major news in important daily newspapers. The increasing power of environmental organizations, either official ones or non-governmental organizations, is noticeable and has even been criticized as excessive by the private sector and other forces of the Government. Almost all new energy production facilities require special permission from such authorities. Other sectors of the economy are also subject to environmental legislation if the activity has some potential impact on the environment. Currently, all automobiles in the city of Rio de Janeiro are subject to emissions inspections, and the fulfilment of minimum standards is compulsory for automobiles built in recent years. Similar rules are expected to be implemented in the city of São Paulo in 2006.

Regarding global pollution, Brazilian society reacts very favourably to the UNFCCC and to the Kyoto Protocol. As early as 1999, the Brazilian Government created an interministerial commission to take care of global environmental issues, and the private sector has made significant efforts to identify Clean Development Mechanism (CDM) projects. Brazil has been a leader in submitting CDM projects to the World Bank and the CDM Executive Board.

One of the country’s few significant environmental problems is related to deforestation, mainly in the Amazon region (Amazonia); however, deforestation resulting from energy use is limited. Reasonably effective legislation exists, but it has been poorly enforced. Deforestation is a major issue, and it is well understood by society that it must be controlled and greatly mitigated.

1.3. MOTIVES AND OBJECTIVES OF THE STUDY

1.3.1. Background and justification

Sustainable development requires integrated economic development based on social responsibility and respect for the environment while keeping in mind the impact on future generations. Energy supply has a significant bearing on all the dimensions of sustainability: social, economic, environmental and institutional. Proper management of the energy sector in developing countries is indispensable to reducing poverty and advancing sustainability. There is a need among developing countries for a variety of tools and integrated evaluation methods that permit the formulation of comprehensive sustainable energy development strategies, as well as the monitoring of their successful implementation. Ideally, countries should be able to construct a profile of their own progress towards a sustainable energy future. A country profile for energy constitutes a vital road map for establishing priorities and optimizing the allocation of limited resources.

Brazil is an ideal candidate for demonstrating the feasibility and merits of constructing the first country profile on sustainable energy development. It is the fifth most populous country in the world, the third largest energy consumer in the Western hemisphere (behind the United States of America and Canada) and the largest emitter of CO_2 in the region. Brazil enjoys a broad mix of energy resource endowments and technologies and valuable environmental assets. The Amazon rainforest of Brazil, for instance, represents 30% of the planet's remaining tropical forests. In addition to acting as a mechanism for absorbing CO_2 from the atmosphere, the Brazilian Amazon forest provides shelter to at least one tenth of the world's plant and animal species. In summary, the country has energy and environmental characteristics of great importance worldwide.

A major priority for Brazil is to satisfy growing energy demand fuelled by population and economic growth, and to balance this effort with environmental priorities and other issues such as energy affordability, accessibility, security and efficiency. Energy policies now being implemented and the formulation of future policies should be monitored and evaluated in the light of both sustainable development needs and their effectiveness in ensuring efficient expansion of energy services.

This project aims to fill the need for more comprehensive energy policies at the national level for the advancement of sustainable development goals and in accordance with the outcome of the WSSD. The project is, to a large extent, a continuation and implementation at the national level of two CSD-9 undertakings: the WEA undertaken by the United Nations Development Programme (UNDP), UNDESA and the World Energy Council (WEC); and the ISED programme undertaken by the IAEA in cooperation with the IEA, UNDESA, Eurostat and the EEA.

1.3.2. Objectives

The primary objective of this study is to develop the first country profile in relation to sustainable energy development. It represents the first attempt to produce a comprehensive, systematic and forward looking approach for the formulation of such a profile. The methodology can be replicated in other countries seeking to define a national plan for a sustainable energy future. A team of national and international experts has performed an overall assessment of the energy sector in Brazil using the proposed approach. This approach allows the assessment of alternative strategies that Brazilian policy makers might consider in formulating energy policies according to their priorities in pursuing different dimensions of sustainable development — social, economic, environmental and institutional. The final goal is to provide an assessment to foster progress towards a sustainable energy future.

The study demonstrates the practical application of this approach. It comprises quantitative and qualitative assessments of energy demand, supply and security; domestic resources; technology and trade; and scenarios of energy sector evolution under different policy assumptions to permit national decision makers to chart and monitor a course of sustainable energy development.

The report summarizes the analyses and findings and explores policy options useful to decision makers and energy and environmental specialists. The analysis provides a comprehensive assessment of the overall energy situation and the status of the major energy priority areas.

1.4. IMPLEMENTATION AND SCOPE

1.4.1. Conduct of the study

The project was completed in about three years. Most of the research activities and analyses were conducted by experts from the Energy Planning Programme, Graduate School of Engineering (COPPE), Federal University of Rio de Janeiro (UFRJ); the Brazilian Reference Centre on Biomass (CENBIO) of the University of São Paulo; the São Paulo State Environmental Secretariat; and the Planning and Economic Studies Section of the IAEA. Experts from COPPE and CENBIO were in charge of collecting the statistics, implementing simulations for the energy system and providing the technical support necessary to build the country profile.

An ad hoc expert committee coordinated the overall effort. The committee consisted of approximately 10–15 members from Brazil and from international organizations. The Brazilian experts were from COPPE/Federal University of Rio de Janeiro, CENBIO/University of São Paulo, the São Paulo State Environmental Secretariat, the Ministry of Mines and Energy, and the Ministry of Science and Technology. The international experts were from the IAEA, UNDESA, WEC–Brazil, the Latin American Energy Organization (Organización Latinoamericana de Energía — OLADE) and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). The expert committee provided guidance for the analysis and participated in the formulation of the approach followed in this study.

1.4.2. Road map

The study considers data from the past 20–25 years in formulating the corresponding indicators for sustainable energy development for Brazil. The data allow a comprehensive assessment of the sustainability of historic trends. The effort includes an extensive energy supply and demand modelling endeavour conducted using two IAEA simulation tools — MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) and MAED (Model for Analysis of Energy Demand). Alternative paths have been developed for the period ending in 2025.

To allow a better understanding of sustainable energy development, a complete review of the energy supply and demand sector is presented. The detailed overview of the sector provided by this approach reveals that, independent of the significant contribution of large hydropower and other new and renewable energy sources, the country still relies on large amounts of fossil energy. This should be expected and is also one motivation for this study. Under the current economic globalization, economic competition requires low production costs for goods and services, and fossil fuels are still among the cheapest sources of energy for most activities and regions. Brazil alone cannot undertake a fully environmentally friendly path before its commercial competitiveness with fossil fuels is demonstrated. Economic actors base their decisions on private cost accounting. It is now well understood that external costs are significant and should be internalized by appropriate Government action. Some well established environmentally and socially friendly energy programmes have become real competitors to established fossil fuel programmes, either because of their lower private cost or through society's acceptance of the need to incorporate some external costs of other energy sources into their prices. Some of these programmes are examples of leapfrogging. Examples from the first category are alcohol fuel production and cogenerated electricity in sugar mills. Examples from the second category are the extensive use of liquefied natural gas (LNG), PV electricity generation in remote areas and the 'Light for All' Programme.

The principal outcome of this extensive investigation of the energy sector is a better understanding of the sustainability features of different energy strategies, their benefits and shortcomings, and trade-offs, including the identification of ways to increase the share of renewable sources of energy in an economically feasible way. This includes efforts in R&D and in learning by doing, as well as the distribution of information to society to increase the acceptance of the external cost concept and the inclusion of externalities in the evaluation of the real costs of new and renewable sources. Another expectation covers the buildup and dissemination of information on the country's energy costs computed by the energy demand model and derived from the aspirations of the society. Economic development can be achieved through several paths. Some paths are more energy intensive than others and may look easier to pursue considering the existence of less international competition. Nevertheless, strong demand for energy is an obstacle to further increases in the share of clean energy, since there are limits to the availability of clean alternatives and the initial financial disbursement is usually high for such alternatives compared with that for fossil fuels. An extensive discussion of the advantages of a less energy intensive development path is presented in the text and is aimed at convincing decision makers to give importance to the definition of future development routes, since some are more compatible with sustainable development than others. Associated with such a conclusion is the necessity to improve human and institutional capacity building, since less energy intensive routes require better technologies and a better educated society.

This report presents a comprehensive appraisal of sustainable energy issues in Brazil's past, present and future. The assessment starts with a retrospective analysis of the Brazilian energy sector and its implications for sustainable development. Past energy balances and time series indicators as well as the social, economic, environmental and institutional dimensions of sustainable development are reviewed and priority issues for securing a sustainable energy future are identified in Chapter 2. The starting point for developing a national sustainable energy strategy is to take stock of available natural energy resources. Brazil's conventional and unconventional energy resources and reserves are assessed in Chapter 3, including oil, hydropower, biomass, agricultural residues and other renewable energy resources, as well as traditional versus modern applications of bioenergy and the potential use of fuelwood, charcoal and agricultural residues. Brazil is a leader in the use of a number of sustainable energy technologies appropriate for developing countries, including sugar cane conversion, ethanol production and use as a transport fuel, electricity generation from sugar cane bagasse, charcoal production, production of vegetable oils and biodiesel fuel, combustion of agricultural and wood residues, and deepwater oil production. These technologies and associated technology costs, efficiencies and energy infrastructure requirements are analysed in detail in Chapter 4.

Brazil's choices for promoting economic development have shaped its energy use in notable ways. This is demonstrated in Chapter 5 with the analysis of past energy use and its driving forces, such as changes in energy intensities, demographic factors and economic activity (especially shifts in the structure of the economy), and changes in technology efficiency. One needs to draw lessons from the past concerning the environmental impacts of energy production and use them to guide strategies for the future. Environmental impacts are reviewed at the household, workplace, city/town, regional and global levels in Chapter 6. Particular attention is given to unsustainable practices of the past related to hydropower, coal mining, unsustainable use of biomass and deforestation. Health effects resulting from urban pollution and from the use of non-commercial fuels in rural areas are also discussed. Strategies are formulated to reduce negative environmental effects produced by energy systems.

Social and energy security concerns place additional demands on sustainable energy development. First, energy plays an important role in poverty eradication by allowing improvements in education, employment, health and sanitation (Chapter 7). Therefore, current problems of affordability, accessibility and disparity in energy use need to be alleviated through the adoption of appropriate strategies. Second, energy security risks in Brazil with respect to changes in the national and international markets for primary energy sources (strategic and economic security) and vulnerability to accidents, disruptions and attacks (physical security) need to be addressed (Chapter 8). Currently, security risks in Brazil are mainly related to economic (lack of sufficient capital resources) and strategic (the concentration of energy sources in a particular region or for a particular sector) issues. Detailed analyses of earlier security incidents (the oil crisis of the 1970s, the alcohol shortage for automotive fuel in the 1980s and the electricity shortages in 2001 and 2002) provide the basis for evaluating future strategies.

The value of the above 'lessons learned' from the past and the success of strategies formulated for the future crucially depend on the policies and measures available to decision makers and the effectiveness of their implementation. Therefore, major energy policies adopted by Brazil to increase natural gas use, improve energy efficiency and increase renewable energy utilization are reviewed in this report. In Chapter 9, policy options are identified in major priority areas for Brazil, including fuel conservation and substitution, energy efficiency, financing, electricity conservation, use of renewables, technology transfer, and international trade and cooperation.

The main objective of the project is to assess possible paths towards sustainable energy development for Brazil. Drawing on the lessons learned from the evaluation of the relationships among socioeconomic development, energy use and environmental implications, a scenario analysis was conducted (Chapter 10). Building on the material presented in Chapters 2–9, the future is explored by developing and using scenarios in two main steps and by producing two types of output. In the first step, an overall socioeconomic scenario is constructed on the basis of recent dynamics, existing assets (installed physical capital, available human capital) and generally agreed objectives and directions for medium term (15–25 years) strategic development. In the second step, energy modelling, the energy demand associated with the macro level scenario is calculated using MAED and other tools. Several options to satisfy the energy requirements are then explored using MESSAGE, resulting in several variants of energy strategies under the same socioeconomic scenario.

The main results of the study are summarized in Chapter 11. Special emphasis is given to the policy insights concerning national efforts to foster progress towards sustainable energy development.

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Chapter 2
STATUS

A. SZKLO, R. CUNHA

The energy picture of Brazil today is that of a large, rapidly growing country in the midst of economic development with a reasonable supply of indigenous resources. Its current situation reflects its attempts to satisfy and accommodate competing needs and challenging sustainable development goals. This chapter reviews the current status of Brazil's energy system and how it developed. It is divided into four major sections: Section 2.1 presents the national energy balance; Section 2.2 assesses the country's energy status according to the economic, social and environmental dimensions of sustainable development; Section 2.3 highlights the institutional dimension of Brazil's energy system; and Section 2.4 summarizes the major issues facing that system.

2.1. BRAZIL'S ENERGY BALANCE: RETROSPECTIVE AND GENERAL OVERVIEW

During the past three decades, Brazil's energy system has been characterized by a rapid increase in energy demand and an accelerated switch from traditional non-commercial fuels to indigenous commercial fuels and electricity. The emphasis on indigenous energy sources started in the late 1970s and early 1980s as a result of policies designed to replace high cost oil imports. Brazil currently depends heavily on hydropower, biomass, and domestic and imported oil to satisfy its energy requirements.

2.1.1. Total primary energy supply

Brazil's total primary energy supply (TPES) grew from 4824 PJ in 1980 to 8276 PJ in 2002, an average annual rate of 2.5% (see Table 2.1), surpassing the average annual economic growth of 2.0% for the same period. Fossil fuels in general provide more than half of Brazil's TPES. Renewable biomass and hydropower account for another 40%. Among individual fuels, oil and biomass are dominant, but they have lost shares to natural gas, hydropower, coal and nuclear. Nuclear started to play a role in the Brazilian primary energy supply in 1985. Figure 2.1 shows the fuel shares in TPES for the 1980–2002 period.

With respect to import dependence, Brazil has managed to reduce its overall imports at a rate of 2.6% per year, from 42% in 1980 to 14% in 2002. As a result of the expansion of Brazil's domestic oil production, dependence on oil imports has decreased over the past two decades, falling from 81% in 1980 to 47% in 1990 and to 10% in 2002. However, imports of coal and electricity increased during the same period. Imports of coal rose owing to the low quality of domestic coal and the need to satisfy the demand for coal from the metallurgical industry. A small fraction of electricity began to be imported when the Itaipu binational (Brazil–Paraguay) power plant started operation in 1985. Natural gas imports were initiated in 1999.

During the past two decades, the use of modern renewable energy has increased as a result of energy policies adopted in the 1970s aimed at import substitution. The Government has promoted the replacement of oil products by encouraging the use of hydropower for heating in the industrial sector and the substitution of ethanol for gasoline in the transport sector. In addition, renewable biomass use has increased with the implementation of

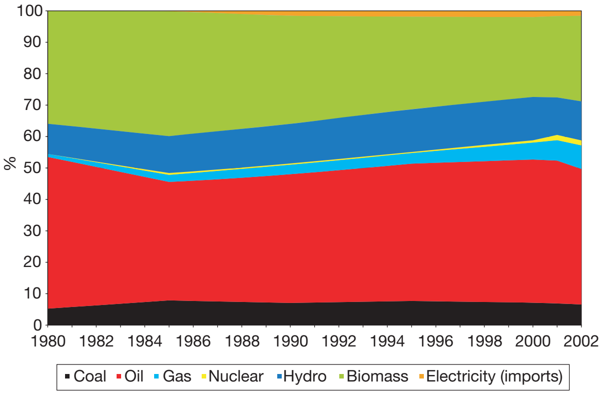

FIG. 2.1. Fuel shares in total primary energy supply, 1980–2002 [2.1].

TABLE 2.1. TOTAL PRIMARY ENERGY SUPPLY (TPES) (PJ) [2.1]

Fuel	1980	1985	1990	1995	2000	2001	2002	Annual growth rate (%)
Domestic (D)								
Coal	104	147	80	85	109	91	84	
Gas	46	123	181	227	348	355	427	
Oil	389	1168	1348	1481	2666	2793	3143	
Hydropower	464	642	744	914	1095	964	1025	
Nuclear	0	32	21	24	58	137	133	
Biomass — modern	894	1265	1293	1467	1584	1669	1800	
Biomass — traditional	833	961	733	510	399	417	450	
Total	2730	4340	4401	4709	6259	6427	7061	4.4
Net imports (Imp)								
Coal	161	262	343	431	456	449	463	
Gas	0	0	0	0	81	170	194	
Oil	1877	891	1136	1352	1041	801	360	
Electricity	–1	7	95	127	159	136	132	
Biomass	0	0	31	65	2	3	0	
Total	2037	1160	1606	1976	1740	1559	1149	–2.6
Stock variation (Stck)								
Coal	–12	20	–9	0	2	18	–2	
Oil	63	3	–80	106	–85	87	65	
Biomass	6	–53	–4	0	40	9	4	
Total	57	–30	–93	106	–43	114	67	
Total: D + Imp + Stck								
Coal	253	430	415	517	568	559	544	
Gas	46	123	181	227	429	525	621	
Oil	2329	2062	2404	2939	3623	3681	3568	
Hydropower	464	642	744	914	1095	964	1025	
Nuclear	0	32	21	24	58	137	133	
Biomass	1733	2174	2022	1977	2022	2096	2254	
Electricity (imports)	–1	7	95	127	159	136	132	
Total	4824	5471	5882	6725	7954	8097	8276	2.5
Share of total TPES (%)								
Coal	5.2	7.9	7.1	7.7	7.1	6.9	6.6	
Gas	1.0	2.2	3.1	3.4	5.4	6.5	7.5	
Oil	48.3	37.7	40.9	43.7	45.5	45.5	43.1	
Hydropower	9.6	11.7	12.6	13.6	13.8	11.9	12.4	
Nuclear	0.0	0.6	0.4	0.4	0.7	1.7	1.6	
Biomass	35.9	39.7	34.4	29.4	25.4	25.9	27.2	
Electricity (imports)	0.0	0.1	1.6	1.9	2.0	1.7	1.6	

modern commercial energy practices in the industrial sector (e.g. black liquor in the pulp and paper industries) and as a result of rapid urbanization in the residential sector.[1] It is important to note, however, that the annual growth rate of total biomass between 1980 and 2002 was only 1.2%, which is the net result of a sharp drop in the use of traditional biomass (–2.8% per year) coupled with a strong increase in modern commercial biomass use (3.2% per year).

Over the past two decades, most of the traditional biomass use has corresponded to fuelwood used to meet residential demand or used in industrial charcoal burners. This industrial demand still imposes deforestation pressures in some areas [2.3], such as in the Amazon River basin (Amazonia). In other States and for much of Brazil's steel industry output, however, the use of biomass based energy does not necessarily impose deforestation pressures, since much of the charcoal consumed is either renewable or produced from planted forests [2.4].[2] Therefore, the main cause of deforestation in Brazil is not predatory logging, as is often assumed, but the expansion of commercial agriculture and cattle ranching [2.5]. More recently, some specialists have also highlighted the problem of export oriented enterprises moving into Amazonia and the Cerrados, where they log, produce beef and grow soybeans, all with detrimental impacts on the forests [2.6]. In addition, deforestation of urban forests, such as the portion of the Atlantic forest in Rio de Janeiro State, cannot be ascribed to the use of wood biomass for energy purposes, but rather to other factors such as the settlement of urban areas by low income sectors of the population.

Domestic production of oil and natural gas has grown rapidly at about 10–11% annually since 1980. Notably, in the late 1990s the Marlim oilfield, discovered in the Campos Basin in 1984, became Brazil's most important oilfield, accounting for 35% of Brazil's total production and pushing up the domestic oil supply. The successful increase in oil and gas production (see Table 2.2) results from technological innovations developed by Petrobras, Brazil's national oil company, through specific programmes for oil exploration in ultra-deepwater fields.[3]

Development of domestic gas production is to some extent dependent on associated oil exploration and production. However, further development of the overall natural gas industry will require major investments in infrastructure to transport offshore and imported gas. As of 2003, there were only 8000 km of transport pipelines and almost 9000 km of distribution pipelines, the latter concentrated in the Southeast region of Brazil.

TABLE 2.2. OIL AND NATURAL GAS PRODUCTION (PJ) [2.7]

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
						Oil					
Onshore	410	394	387	389	428	431	459	452	459	464	475
Offshore	972	1011	1072	1124	1289	1409	1673	1957	2250	2373	2717
Total	1382	1405	1459	1513	1717	1839	2132	2409	2709	2837	3191
						Natural gas					
Onshore	114	118	117	121	136	146	156	162	217	159	256
Offshore	177	187	203	214	244	261	292	330	334	339	388
Total	291	305	320	335	380	408	448	492	551	498	644

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[1] The distinction between modern and traditional biomass sources proposed by Goldemberg and Coelho [2.2] is used in this chapter. Accordingly, biomass produced in a sustainable way, or modern biomass, includes electricity generation and heat production, as well as transport fuels, from agricultural and forest residues and from solid waste. Traditional biomass is often produced in an unsustainable way and in many countries is used as a non-commercial energy source for cooking, usually with very low efficiencies.

[2] For instance, the share of non-renewable fuelwood consumed for charcoal production decreased from 86% in 1980 to 28% in 2000 [2.4].

[3] Technological innovations related to oil exploration have resulted from Brazil's Technological Development Programme on Deepwater Production Systems (PROCAP) (see Chapters 4 and 9 for details).

Natural gas supply in the South region became available only in 2000, with pipelines bringing the fuel from Argentina and Bolivia. Since 2001, the Argentine line has transported some 2.1 million m^3/d, or 0.084 PJ/d, although it has a total capacity of 12 million m^3/d (0.48 PJ/d). Moreover, the Brazilian Regulatory Agency has already authorized the importation of some 30 million m^3/d more from Argentina, indicating that Brazil's natural gas imports from this country might increase in the short term. However, this increase depends on the expansion of Brazil's current gas pipeline capacity, which implies considerable investments.

As of 2003, the Bolivian line had a capacity of 30 million m^3/d (1.2 PJ/d). The opening of the Bolivia–Brazil gas pipeline in 1999 was a major step in introducing natural gas to Brazil, but amortization of such infrastructure investments will depend in part on the development of a critical mass of clusters of industrial demand for gas. Development of the second largest domestic natural gas reservoir in Urucu currently is limited to producing and processing a small amount of liquefied petroleum gas (LPG) for local consumers because of the lack of a distribution network. The Urucu proven reserves total 48 billion m^3 of natural gas [2.8]. Petrobras has been investing in two transport pipelines connecting the Urucu gas field to Porto Velho, the capital of Rondônia State, and to Manaus, the capital of Amazonas State.[4] Together, these pipelines will allow the transport of some 13 million m^3/d by 2007 and will likely change the power generation mix of the North region as a result of the replacement of diesel and fuel oil thermal plants with natural gas fired plants. In 2003, Petrobras announced the discovery of 419 billion m^3 (around 17 EJ) of new gas reserves in the Santos Basin in the Southeast region.

2.1.2. Final energy use

Final energy use grew at an annual rate of about 2.3% in the 1980–2002 period (see Table 2.3). This is slightly lower than the corresponding rate for TPES (2.5% per year), reflecting increased transformation losses in some areas, including electricity transmission and distribution (see Section 2.2.1.6). The use of all commercial fuels grew in absolute terms, reflecting population growth, increased industrialization, higher standards of living and urbanization. However, the use of ethanol decreased slightly over the 1995–2001 period owing to the replacement of neat ethanol with gasoline after the Government eliminated ethanol subsidies, although the use of anhydrous ethanol was not affected. Throughout the 1990s, coal and coke replaced charcoal, as wood derived from planted forests became more expensive with the elimination of subventions for reforestation.[5] In addition, the privatization of Brazil's steel sector in the 1990s and the merger of steel companies focused on integrated mills using metallurgical coke.

By 2002, the industrial sector accounted for 40%, the transport sector for 30% and the residential sector for 13% of final energy use (see Table 2.3). The agriculture and commercial sectors had shares of about 5% each, while the rest corresponded to feedstocks. Over the 1980–2002 period, the shares of energy use for the industrial, commercial and public, and transport sectors, and for feedstocks increased slightly. These increases were offset by reductions in the shares of energy use in the agricultural and residential sectors. The large decrease in the residential share reflects the reduction in the use of traditional biomass at low conversion efficiencies.

The commercial and public sectors showed the highest average energy growth rate (4.7% per year) for the period, while the industrial and transport sectors grew at about 2.5% and 2.8% per year, respectively. Most of the growth in the commercial and public sectors can be explained by their modernization and the increasing importance of larger electricity consumers, such as big hospitals, hotels and shopping centres [2.10]. The contribution of these sectors to Brazil's gross domestic product (GDP) in terms of value added and their corresponding shares are described in Chapter 5. The growth in the transport sector is due primarily to an increase in road transport of passengers and freight, and to the increased use of private automobiles. The consumption of fuels varied considerably among sectors, with the industrial, residential, and commercial and public sectors depending heavily on electricity.

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[4] The total investment in these pipelines is estimated to be US $1.3 billion [2.9].

[5] After 20 years of fiscal subventions, during which modern biomass energy technologies were developed, notably for producing charcoal and recuperating black liquor, in 1988 the Government eliminated the reforestation subventions.

TABLE 2.3. FINAL ENERGY USE (PJ) [2.1]

	1980	1985	1990	1995	2000	2001	2002	Annual growth rate (%)
					Fuel			
Oil	2131	1898	2241	2747	3352	3331	3291	2.00
Coal	184	315	303	394	439	426	451	4.15
Gas	30	65	102	130	215	255	320	11.36
Electricity	427	602	759	923	1155	1074	1114	4.46
Fuelwood	1147	1085	893	919	1024	1113	1203	0.22
Ethanol	88	242	329	389	270	253	262	5.08
Charcoal	179	259	257	206	201	184	193	0.34
					Sector			
Industrial	1583	1710	1806	2138	2561	2574	2723	2.50
Commercial and public	124	150	196	256	344	329	342	4.72
Transport	1116	1192	1441	1807	1983	2000	2028	2.75
Residential	879	777	758	760	866	843	866	–0.07
Agriculture	243	255	253	297	305	323	337	1.49
Subtotal	3945	4084	4454	5258	6059	6069	6296	2.15
Non-energy/feedstocks	241	382	430	450	598	567	538	3.72
Total	4186	4466	4884	5708	6657	6636	6834	2.25
					Share of total final energy use (%)			
Industrial	37.8	38.3	37.0	37.5	38.5	38.8	39.8	
Commercial and public	3.0	3.4	4.0	4.5	5.2	5.0	5.0	
Transport	26.7	26.7	29.5	31.7	29.8	30.1	29.7	
Residential	21.0	17.4	15.5	13.3	13.0	12.7	12.7	
Agriculture	5.8	5.7	5.2	5.2	4.6	4.9	4.9	
Subtotal	94.2	91.4	91.2	92.1	91.0	91.5	92.1	
Non-energy/feedstocks	5.8	8.6	8.8	7.9	9.0	8.5	7.9	

2.1.2.1. Regional availability of fuels

The Southeast region of Brazil is the country's most populated and industrialized, and the region with the largest share of total GDP (55% in 2001) [2.11]. It consumed 50% or more of each of the modern energy fuels sold in Brazil in 2001, with the exception of diesel (see Table 2.4). The country's oil refineries are concentrated in the South and Southeast regions, corresponding to 82% of Brazil's total primary capacity. Only two refineries are not located in this region — a large refinery in Bahia State (Relam) and a small refinery for onshore production in the Urucu field in Amazonia (Reman). Production and consumption of natural gas is also centred in the Southeast region, where reserves and production are concentrated.[6] In the Northeast region, consumers are less concentrated and natural gas availability is limited by the lack of pipeline connections from the Southeast region. This situation justifies the current projects aimed at connecting the Southeast region to the Northeast region (see Section 2.3 for details).

2.1.3. Electricity generation, use and capacity

Electricity generation in Brazil grew at an average annual rate of 4.2% between 1980 and 2002, with hydropower as the predominant generating technology (see Table 2.5). Of the next significant generating technologies — nuclear,

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[6] Almost 50% of Brazil's natural gas production is in the Campos Basin in Rio de Janeiro State.

TABLE 2.4. FUEL SHARES OF MODERN FINAL ENERGY SALES IN 2001 BY REGION (%) [2.12, 2.13]

Fuel	Region				
	North	Northeast	Southeast	South	Midwest
Natural gas	0.0	29.3	56.1	14.0	0.6
Petrol (grade C)*	4.2	13.5	53.6	19.9	8.7
Diesel	8.1	15.3	44.7	20.4	11.6
LPG	4.9	20.5	49.6	17.1	7.9
Other oil products	10.6	6.6	65.4	11.8	5.6
Neat ethanol	1.7	8.8	57.0	21.4	11.1
Electricity	5.4	15.9	56.0	17.4	5.4
Total	6.0	16.0	52.4	17.9	7.8
Total (PJ)	239.2	640.3	2101.7	720.2	311.8

* Grade C petrol is an automotive gasohol or gasoline–neat alcohol mixture (75:25 by volume).

natural gas and diesel oil — none has a share larger than 5%. Between 1980 and 1995, hydropower's share remained constant at 92%. With the introduction of biomass, nuclear and natural gas, its share was reduced to 83% by 2002, but the strong and continued rise in electricity demand has required more than a doubling of hydropower generation in absolute terms and even more robust growth, though at lower absolute levels, from other generating options.

The electricity market has seen a gradual increase in industrial self-generation and in the number of independent fossil fuel generators since 1990. Self-generation represents a significant segment of total generation (8.5% in 2002), fuelled in large part by biomass, hydropower and natural gas.

Over the past two decades, electricity use has more than doubled (see Table 2.6), corresponding to an annual growth rate of 4.5% (with a dip during the severe crisis in 2001). This strong growth reflects concomitant increases in economic growth, industrialization and mechanization of agriculture,[7] population and urbanization, in patterns traditionally consistent with economic development. Demand growth was also spurred by artificially low electricity prices, especially during the 1980s. Power demand is highest in the industrial sector, largely as a result of the electricity intensive industrial subsectors.

With respect to installed electricity capacity (see Table 2.7), the share of hydropower was 82% in 2002, and that of natural gas was 4.5%. The installed nuclear power capacity was about 2.0 GW, resulting from two nuclear reactors, Angra I and Angra II, which entered into operation in 1985 and 2000, respectively.

2.1.3.1. Hydropower

Hydropower dominates electricity generation, and large hydropower dams dominate this sector. With 433 hydropower plants in operation in the Brazilian electricity system, the 23 plants with installed capacity higher than 1000 MW accounted for more than 70% of the country's total installed power capacity [2.14] and for 50–60% of total electricity generation. There is still considerable unused hydropower potential (estimated at about 190 GW) scattered unevenly throughout Brazil, but largely located in the North region and away from the consuming centres of the Southeast region, thus entailing higher electricity transmission costs as well as environmental constraints. The potential for retrofitting Brazilian hydropower plants older than 20 years (a total installed capacity of 32 GW) is between 1 and 8 GW [2.15], at an estimated cost of US $100–300/kW.

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[7] Since 1979, the Brazilian Government has been promoting the modernization of the agricultural sector, focusing mainly on two different sets of goods: export oriented primary crops and fruits, and biomass for energy purposes. In addition, the Rural Electrification Programme launched in 1999 has also affected the use of electricity by small and medium sized farms.

TABLE 2.5. ELECTRICITY GENERATION (TW·h) [2.1]

	1980	1985	1990	1995	2000	2001	2002
Public service plants							
Hydropower	126.10	175.33	203.59	250.46	298.56	262.66	278.66
Fuel oil	1.56	1.15	0.85	1.34	6.19	6.07	3.68
Diesel oil	0.91	1.13	1.51	2.70	4.08	4.01	4.29
Natural gas	0.00	0.00	0.01	0.00	1.57	6.94	9.79
Nuclear	0.00	3.38	2.24	2.52	6.05	14.28	13.84
Coal	2.47	3.34	2.71	3.67	7.45	7.35	5.06
Biomass	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Total	131.04	184.36	210.91	260.68	323.90	301.32	315.31
Self-generators							
Hydropower	2.80	3.04	3.11	3.45	5.84	5.21	6.29
Fuel oil	2.52	1.30	2.00	2.10	1.81	1.97	1.74
Diesel oil	0.23	0.28	0.46	0.38	1.50	2.06	1.55
Natural gas	0.00	0.00	0.31	0.56	2.50	3.01	3.36
Coal	0.31	0.63	0.54	0.58	0.80	0.87	0.94
Biomass	1.81	2.97	3.58	5.42	7.42	8.35	9.55
Other primary	0.66	1.06	1.65	1.37	3.47	3.93	4.18
Other secondary	0.02	0.04	0.26	1.06	1.66	1.79	1.73
Total	8.34	9.33	11.91	14.92	25.01	27.19	29.34
Total generation							
Hydropower	128.91	178.38	206.71	253.91	304.40	267.88	284.94
Fuel oil	4.08	2.45	2.84	3.44	8.00	8.04	5.42
Diesel oil	1.14	1.42	1.97	3.08	5.59	6.07	5.83
Natural gas	0.00	0.00	0.33	0.56	4.07	9.96	13.14
Nuclear	0.00	3.38	2.24	2.52	6.05	14.28	13.84
Coal	2.78	3.96	3.25	4.25	8.25	8.22	6.00
Biomass	1.81	2.99	3.58	5.42	7.42	8.35	9.55
Other primary	0.66	1.06	1.65	1.37	3.47	3.93	4.18
Other secondary	0.02	0.04	0.26	1.06	1.66	1.79	1.73
Total	139.38	193.68	222.82	275.60	348.91	328.51	344.64
Share of total generation (%)							
Hydropower	92.5	92.1	92.8	92.1	87.2	81.5	82.7
Fuel oil	2.9	1.3	1.3	1.2	2.3	2.4	1.6
Diesel oil	0.8	0.7	0.9	1.1	1.6	1.8	1.7
Natural gas	0.0	0.0	0.1	0.2	1.2	3.0	3.8
Nuclear	0.0	1.7	1.0	0.9	1.7	4.3	4.0
Coal	2.0	2.0	1.5	1.5	2.4	2.5	1.7
Biomass	1.3	1.5	1.6	2.0	2.1	2.5	2.8
Other primary	0.5	0.5	0.7	0.5	1.0	1.2	1.2
Other secondary	0.0	0.0	0.1	0.4	0.5	0.5	0.5
Public (%)	94.0	95.2	94.7	94.6	92.8	91.7	91.5
Self-generators (%)	6.0	4.8	5.3	5.4	7.2	8.3	8.5

TABLE 2.6. ELECTRICITY USE BY SECTOR (TW·h) [2.1]

Sector	1980	1985	1990	1995	2000	2001	2002
Residential	23.3	32.6	48.6	63.6	83.5	73.7	72.7
Commercial	13.8	18.5	23.8	32.3	47.5	44.6	45.7
Public	10.4	14.4	18.1	23.1	29.2	27.1	28.3
Agriculture	2.0	4.5	6.7	9.2	12.8	12.4	13.1
Transport	0.8	1.1	1.2	1.2	1.2	1.2	1.3
Industrial	68.2	96.2	112.3	127.1	146.6	139.3	148.5
Energy	4.2	6.2	6.8	8.3	10.5	11.1	11.7
Total	122.6	173.5	217.6	264.7	331.4	309.5	321.3
			Share of total electricity use (%)				
Residential	19.0	18.8	22.4	24.0	25.2	23.8	22.6
Commercial	11.2	10.6	10.9	12.2	14.3	14.4	14.2
Public	8.5	8.3	8.3	8.7	8.8	8.8	8.8
Agriculture	1.7	2.6	3.1	3.5	3.9	4.0	4.1
Transport	0.7	0.7	0.5	0.5	0.4	0.4	0.4
Industrial	55.6	55.4	51.6	48.0	44.2	45.0	46.2
Energy	3.4	3.6	3.1	3.1	3.2	3.6	3.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

2.1.3.2. *Infrastructure*

Brazil's electric power generation infrastructure consists of three different electric systems, which cover the country's five macrogeographic regions (South, Southeast, Northeast, North and Midwest). The regional electricity balance is shown in Figure 2.2. In this figure, the Southeast and Midwest regions are grouped together to reflect the contribution of the Itaipu hydropower plant to these two regions. The largest interconnected power transmission system, which includes the Southeast, South and Midwest regions, accounts for more than 70% of Brazil's total installed capacity. It includes Itaipu and the two nuclear power plants. The second grid system connects the North and Northeast regions, accounting for almost 25% of the total installed capacity. Finally, the third system includes small, independent grids that are isolated in terms of electric power, largely in the North region. These isolated systems account for less than 5% of the total and are based mainly on thermal power plants [2.13].[8]

As discussed above, the gas pipeline from the Urucu field in Amazonia will allow the operation of a natural gas fired thermal generation plant, mostly for serving Manaus and Porto Velho. Since these two major cities in the North region account for more than 70% of the total power load supplied by isolated systems, and as they are expected to be connected to the North–Northeast system by 2011 [2.18], isolated systems in Brazil will account for less than 3% of the total power demand in the near future.

The interconnected hydropower systems have been fairly well complemented by thermal power plants and by self-generators. The self-generators' share in total electricity generation increased considerably with the restructuring of Brazil's electricity sector and as a result of the 2001 drought, which caused a dramatic fall in hydropower generation.

Through this national interconnected system, it has been possible to transfer energy among regions and optimize the use of hydropower, established according to different but complementary rainy seasons. It is estimated that, without this integration, Brazil's installed electric power capacity would have to be 22.1% higher [2.19] and some of the existing available hydropower

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[8] Electricity is supplied to isolated cities and villages in Amazonia by diesel generators for the most part, but also by automotive batteries and dry cells [2.17].

TABLE 2.7. INSTALLED ELECTRICITY CAPACITY (GW) [2.1, 2.13]

Fuel	1980	1985	1990	1995	2000	2001	2002
Hydropower	27.65	36.12	44.82	51.26	60.82	62.19	65.19
Fuel oil	2.67	2.39	2.29	2.24	2.43	1.23	1.21
Diesel oil	0.94	1.10	1.21	1.36	2.17	3.19	3.12
Natural gas	0.00	0.01	0.24	0.19	1.06	2.70	3.60
Nuclear	0.00	0.66	0.66	0.66	0.66	2.01	2.01
Coal	0.80	0.78	1.08	1.12	1.46	1.51	1.51
Wind	0.00	0.00	0.00	0.00	0.02	0.02	0.02
Solar	0.00	0.01	0.02	0.03	0.04	0.05	0.06
Fuelwood	0.07	0.18	0.15	0.13	0.13	0.09	0.10
Bagasse	0.42	0.49	0.57	0.73	1.09	1.30	1.43
Other primary	0.36	0.50	0.57	0.61	0.94	0.91	1.02
Other secondary	0.01	0.02	0.08	0.27	0.35	0.34	0.34
Total	32.92	42.25	51.66	58.56	71.12	75.48	79.54
Share of total installed electricity capacity (%)							
Hydropower	83.99	85.49	86.76	87.54	85.52	82.40	81.96
Fuel oil	8.11	5.65	4.44	3.82	3.42	1.63	1.52
Diesel oil	2.86	2.61	2.35	2.32	3.04	4.23	3.92
Natural gas	0.00	0.01	0.46	0.32	1.49	3.57	4.53
Nuclear	0.00	1.55	1.27	1.12	0.92	2.66	2.52
Coal	2.43	1.84	2.09	1.91	2.06	2.00	1.90
Wind	0.00	0.00	0.00	0.00	0.03	0.03	0.03
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuelwood	0.20	0.43	0.28	0.22	0.18	0.12	0.13
Bagasse	1.28	1.17	1.10	1.24	1.53	1.72	1.80
Other primary	1.10	1.19	1.10	1.05	1.32	1.20	1.28
Other secondary	0.02	0.04	0.15	0.46	0.50	0.45	0.42
Public (%)	92.9	94.4	94.8	94.6	93.3	93.4	93.1
Self-generators (%)	7.1	5.6	5.2	5.4	6.7	6.6	6.9

resources would be unavailable because of the lack of transmission capacity.

System optimization is based on large reservoirs planned for multi-year storage (normally five years) and standby turbines for generating surplus power during rainy periods. In this way, Brazil's large hydropower plants are able to supply the load curve not only on a continuous basis, but also during peak and intermediate hours. In this system, thermal power plants operate primarily to supplement hydropower during peak load or during the dry season. They are only dispatched during dry hydrological periods, when the value of the stored water in the reservoirs of hydropower units is greater than the operating variable cost of thermal power plants, or when the optimal hydraulic dispatch cannot meet demand during the heavy load periods. Thermal power plants thus function as virtual reservoirs, allowing more efficient country-wide operation [2.20].

2.1.4. Investments

The rapid increase in electricity generation and oil production in Brazil reflects the large investments made in the energy sector in past decades. Public owned energy companies invested heavily, even when the country faced a period of economic recession (for instance, in the early 1980s). In the power industry, large scale projects were

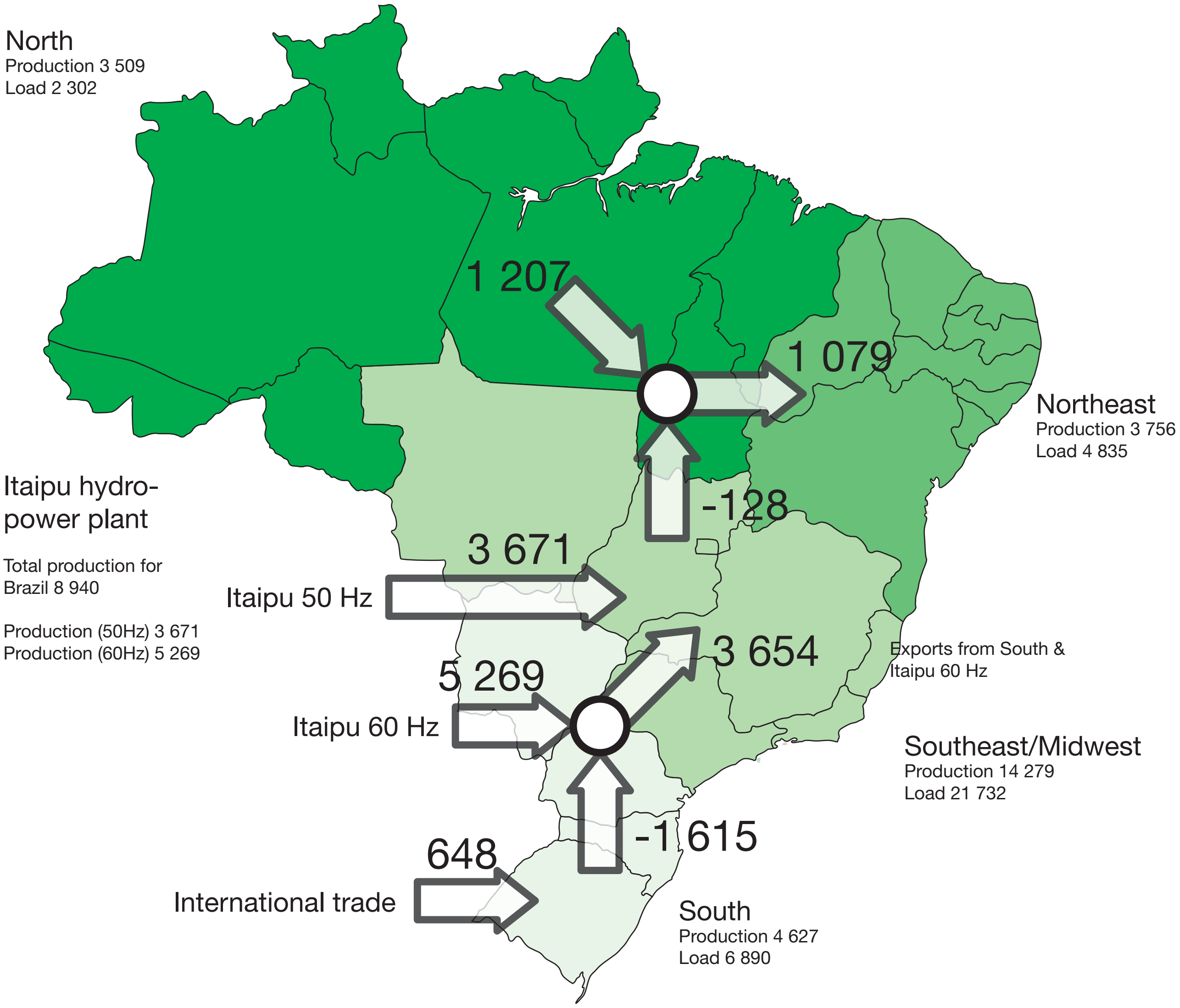

FIG. 2.2. Regional electricity balance: Interconnected systems as of January 2002 (average MW) [2.16].

undertaken in the 1970s — such as the 12 600 MW Itaipu and 4200 MW Tucuruí hydropower plants, and the 657 MW Angra I nuclear power plant — to a certain extent allowing the industrial sector to switch from oil products to electricity. Petrobras also made considerable investments in oil research, exploration and production.

Nevertheless, the investment capacity of public companies deteriorated during the 1980s. In this so-called ‘lost decade’,[9] the economy slowed down and the Government controlled public service tariffs in order to curb inflation. In turn, during the 1990s, structural changes introduced in the electricity sector failed to attract new private investments to expand the power supply. As a result, the average annual investment in the electricity sector decreased from US $12.6 billion in the 1980s to US $6.6 billion between 1990 and 1997 [2.21], and rose to only US $8.5 billion between 1998 and 2002 [2.22]. The most deleterious effect of this investment constraint was the electricity crisis of 2001, when there was insufficient investment in alternative generation technologies to make up for

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[9] The 1980s are considered the ‘lost decade’ because of the poor performance of the Brazilian economy during this period. This performance was due to debt crises that led the Brazilian Government to promote structural adjustments in order to generate currency to pay for the national debt. Thus, the country transferred a large amount of money abroad, reversing the trend of capital inflow seen in the 1970s.

the massive loss of hydropower during a normal drought period.

In the oil sector, Petrobras retains an excellent financial rating and so is attractive to private partners interested in the company's expertise in ultra-deepwater exploration and development. Moreover, through its affiliates[10] or Specific Purpose Enterprises (SPEs),[11] Petrobras investments have not been constrained by the public deficit fixed targets; thus they grew from US $2.6 billion per year in 1990 to US $4.8 billion per year in 2001. Structured as an SPE, most of the investments made by Petrobras could be kept separate from the account balance during the financing period, with the assets being transferred to Petrobras at the end of this period. Moreover, the September 2002 Stand-By Agreement between the Brazilian Government and the International Monetary Fund stressed the fact that "investments made by public companies whose administrations strictly follow commercial and technical criteria create financial value…and do not compromise the public finance sustainability in the long term…" [2.23]. This was considered to be the case for the investments of Petrobras. Nevertheless, given the expected change of the Brazilian oil products market profile (mostly an increased share of petroleum coke to the detriment of residual fuel oil) and the expected offshore heavy oil production increase in the medium term, investments aimed at converting the existing Brazilian refineries will be crucial.

Of even greater interest is the huge investment Brazil has made in developing its ethanol industry for import substitution. This has involved not only the development of a dedicated agricultural programme and specific distilleries, but also an automobile industry geared to the use of ethanol fuel. This enormous accomplishment has required major investments but has also resulted in huge savings and even in export revenues (for details, see Chapter 4).

2.2. ENERGY SYSTEM STATUS: ECONOMIC, SOCIAL AND ENVIRONMENTAL DIMENSIONS[12]

This section examines some of the most important factors that have shaped Brazil's energy system and policies according to the economic, social and environmental dimensions of sustainable energy development, using as a framework the Energy Indicators for Sustainable Development (EISD) devised for such purposes by the International Atomic Energy Agency (see Table 1.1 in Chapter 1).

2.2.1. Economic dimension

Within the economic dimension, major driving forces have shaped the evolution and current status of Brazil's energy system. Key indicators for this overview include overall energy use and productivity (energy use per capita (ECO1)[13] and per unit of GDP (ECO2)); end use productivity (disaggregated energy intensities (ECO6–ECO10)); efficiency (efficiency of energy conversion and distribution (ECO3)); resources (resource to production ratios (ECO4 and ECO5)); and security and diversity (import dependence (ECO15) and fuel mix (ECO11–ECO13)). A more detailed description of the linkages between energy and economic development in Brazil is presented in Chapter 5.

2.2.1.1. GDP growth

The Brazilian economy grew 7.4% per year on average between 1950 and 1980 [2.25], showing remarkable growth in productive capacity for capital goods, basic materials, energy, transport and communication. This rapid industrialization laid a solid basis for future economic development. This growth slowed in the 1980s to some 1.6% per year, and per capita income growth became negative

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[10] It is important to note that Petrobras is a global company and its investments abroad do not affect the public deficit.

[11] An SPE is created to obtain the financing to develop large projects, particularly in the area of power and infrastructure. The debt payment is secured by the enterprise's cash flow, avoiding real guarantee requirements. The lenders receive the future revenues and the property of the assets to be built. One of the most important project finance arrangements in Brazil is the Marlim project, structured to complete the development of the Marlim oilfield, the largest oilfield in Brazil.

[12] This section is based on the study on indicators for sustainable energy development by Schaeffer et al. [2.24].

[13] The terms given in parentheses are the identification codes of the corresponding indicators in the EISD list (see Table 1.1 in Chapter 1).

(–0.4% per year). There were a number of reasons for this slowdown. First, population growth outstripped economic growth. Second, the decade saw a dramatic increase in world oil prices (the second 'oil shock' of 1979) and a major increase in national debt throughout Latin America. Brazil was forced to reduce oil imports. The Government introduced incentives for consumers in the industrial and transport sectors to replace oil with ethanol automotive fuel.[14] A strong innovative streak revealed itself in the building of Brazil's import substitution industries. The Government encouraged the replacement of primary fuels with hydropower to take advantage of a major domestic and low cost energy source, and it constructed two nuclear generating stations. These provisions permitted energy supply to keep pace with demand throughout this period.

The decade of the 1990s brought some measure of uneven economic recovery, so that GDP grew at an average rate of 2.7% per year (and at 1.2% per year on a per capita basis). Moderate prosperity permitted some significant institutional reforms. Brazil re-opened its economy to goods and capital flows, and the Government progressively reduced its control and ownership within the economy, including some areas of the energy sector. The economy achieved unprecedented price stabilization in 1994 with the economic Plano Real (Real Plan). However, the severe drought and consequent shortage of electricity in 2001 and 2002 dampened economic activity, so that current growth rates are now around 1.5% per year.

Brazil's economic growth thus has experienced ups and downs during recent decades as a result of external and internal factors and response actions.[15] In general, economic plans adopted during these decades almost necessarily focused on short term problem solving, seeking to curb inflation and stabilize the economy. Energy use and production were closely linked to these changes, and the consequences of both energy and economic policies were closely intertwined (see Chapter 5 for details).

2.2.1.2. Energy use per capita

Table 2.8 shows per capita energy and electricity use expressed in a number of different ways for 1980 and 2000, and the corresponding annual growth rates. The per capita use of electricity grew faster than did the use of primary and final energy, especially at the residential level, reflecting faster growing demand for services powered by electricity. The figures indicate growth over the 20-year period for all categories except for residential energy. The per capita residential sector final energy use decreased at an annual rate of 1.7% during the period under analysis, mostly owing to the replacement of inefficient fuelwood with modern sources of energy (e.g. LPG). The higher use of modern energy services should, in theory, indicate general improvements in the quality of life. These average figures, however, mask a disparity in energy use that reflects a disparity in income.[16] The energy use per capita has other social implications — for example, whether or not the per capita energy and electricity use has reached a level that satisfies minimum living requirements. It is also important to analyse the difference in the growth rates of total use (direct and indirect use) versus residential use (direct use) of energy and electricity. The higher growth rates of total per capita energy use indicate that indirect energy use (industries, transport, products for export) has been growing at a faster rate than direct use (residential sector use). Conversely, the higher rates of electricity use in the

TABLE 2.8. PER CAPITA ENERGY AND ELECTRICITY USE [2.1]

	1980	2000	Annual growth rate (%)
TPES (GJ/capita)	39.7	46.7	0.8
Final energy use (GJ/capita)	34.4	39.1	0.6
Electricity (kW·h/capita)	1008.5	1947.5	3.3
Residential energy (GJ/capita)	7.2	5.1	–1.7
Residential electricity (kW·h/capita)	191.2	491.0	4.8

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[14] For details on ethanol and ethanol fuelled automobile technologies, see Chapter 4.

[15] Note that the GDP figures here are slightly underestimated owing to the share of underground activities in the Brazilian economy. An 'error' of up to 10% can be assumed for the GDP figures [2.26].

[16] The social implications resulting from the status of energy use are described in detail in Chapter 7.

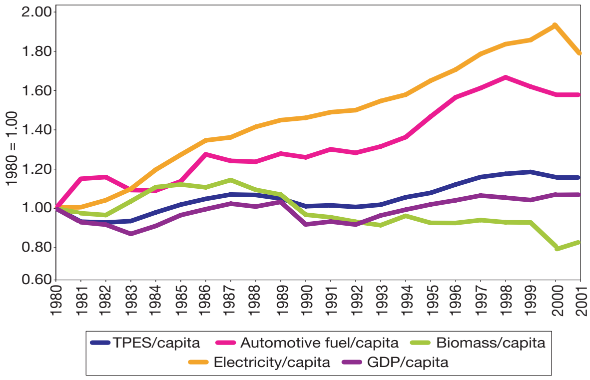

FIG. 2.3. Indices of energy use and GDP per capita [2.1, 2.11, 2. 27].
Note: *In 1980, GDP was US $737 billion at PPP-2000.*

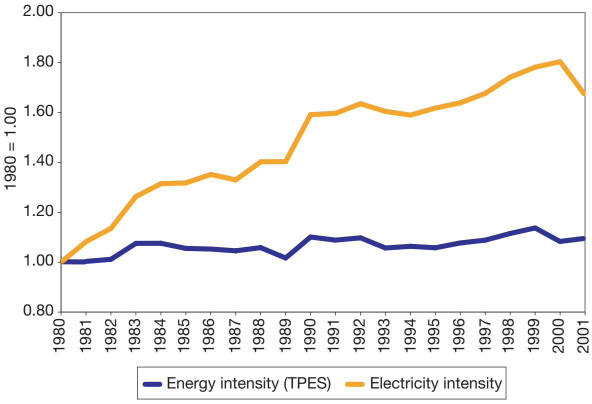

FIG. 2.4. Indices of energy and electricity intensities [2.1, 2.11, 2.27].

residential sector indicate that residential electricity use is growing faster than use in other sectors of the economy.

Figure 2.3 shows the evolution of per capita energy supply and use (in terms of TPES, automotive fuel, biomass and electricity) and per capita GDP growth from 1980 to 2001. Electricity and automotive fuel use per capita grew at much higher annual rates than did per capita GDP. The strong increase in per capita electricity use results from the continuously increasing use of household appliances in the residential sector and from the industrial shift to electricity intensive industries.[17] The relatively high per capita use of automotive fuel is mainly due to the increasing share of private vehicles in the transport sector.[18] The per capita biomass consumption increased during the 1980s, reflecting the fact that the industrial use of modern biomass largely compensated for the decrease in fuelwood use in the household sector caused by urbanization.[19]

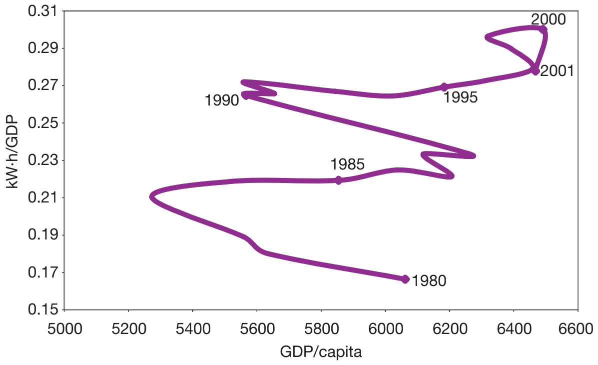

FIG. 2.5. Electricity intensity (kW·h/GDP) and GDP per capita (US $ PPP-2000) [2.1, 2.11, 2.27].

2.2.1.3. *Energy use per unit of GDP*

Overall energy use per unit of GDP increased only slightly over the past two decades (see Fig. 2.4), with significant interfuel substitution (mostly that of electricity for oil, and oil products for fuelwood) and technical progress offsetting shifts to energy intensive industries and the increase in private use of automobiles. Electricity intensity grew more rapidly and significantly, reflecting the substitution of electricity for primary fuels in industry and in households, the continued growth of electricity intensive industries, the modernization of the agricultural sector and economic policies that encouraged electricity use, such as electricity tariffs fixed at very low levels. These low tariffs did not cover costs and thus affected investment, ultimately exacerbating the consequences of the 2001 electricity crisis (see Box 2.1).

Figure 2.5 shows electricity intensity in relation to per capita GDP. This figure further illustrates the growth in electricity intensity even during periods of economic contraction. The electricity intensity continued to grow during the 1980–1983, 1989–1992 and 1997–1999 periods, during which Brazil's GDP per capita contracted.

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[17] This also reflects the increasing use of electrical control and automation in the industrial sector.

[18] The increase in automotive fuel use was particularly noticeable after 1993, when fiscal incentives were given for new 1 litre engine vehicles, whose market niche is in the medium to low income groups [2.28].

[19] Between 1970 and 1995, the share of households consuming fuelwood for cooking decreased from 52.6% to 17.5%, while the corresponding figure for LPG increased from 44.5% to 93.6% [2.29].

Box 2.1. Electricity tariff evolution in Brazil, 1971–2000

From 1971 until the reforms of the 1990s, the Federal Government set tariffs to allow for a 10% minimum real return on investment (cost-plus method). This practice reduced the risk of investing in power generation expansion, but effectively divided electricity utilities into new ones with above average production costs and old ones with below average production costs. This disparity was the basis for creating the ‘Reserva Global de Garantia’ fund to equalize electricity tariffs. Tariffs among regions were also equalized so that all regions of the country could benefit from amortized hydropower plants concentrated in the South and Southeast regions. Such equalization attempts ignored real disparities in costs and ultimately led to serious market distortions.

Within the same time frame, the Government also established a two part consumer tariff structure based on the marginal cost. However, because of the equalizing tariff principle, the final consumer tariffs did not in fact reflect the utilities’ true marginal costs of distribution.

After the oil shock of 1979, power tariffs were revised to subsidize the replacement of fossil fuels with hydropower, incorporating special rates for large consumers and promoting industrial electric heat generators. These measures were also designed to foster the use of excess installed power generating capacity that resulted from large investments made in the 1970s to accommodate the anticipated demand, which evaporated during the economic depression of the 1980s. This economic crisis also compromised the further financing of Brazil’s electricity system, which was based on three major components: external loans, State financial resources and internal financing through sales revenues. First, the financial costs of the external loans made by Brazilian utilities rose dramatically in the 1980s, exceeding the internal rate of return adopted by the Government. Given the scarcity of internal capital and the capital flight during the first half of the 1980s, servicing external loans became the most important financing problem of the Brazilian power sector. Second, these same factors created constraints on the balance of payments that severely reduced the State’s financial resources. Finally, during the 1980s, Brazil’s electric power sector was severely affected by the Government’s decision to use electricity tariffs as a vehicle for fighting inflation. Tight controls imposed on tariff levels resulted in insufficient income at the same time that subsidies were being granted to promote electricity use for fossil fuel substitution in the industrial sector. As a result, the industrial demand for electricity grew at 7.1% per year from 1980 to 1985, under high long term marginal costs but low electricity rates.

In 1986 the Government launched a programme designed to “recover the real price of the electricity supply in Brazil”, but, in the face of continued inflation, did not lift tariff controls. Consequently, between 1986 and 1992 generating capacity expanded only by about 10 GW [2.30]. In 1992, to cover the cost of providing electricity, the tariff would have had to have been 170% higher than the existing average tariff.

In 1993, a Governmental act finally eliminated the regional homogenization of electricity rates. At the same time, the State absorbed the utilities’ debts (almost US $20 billion). At the end of 1995, the Government finally stopped using electricity tariffs to try to control inflation. Between 1995 and 2000, with privatization of power distribution (but not generation), consumer tariffs began to remunerate distributors more than power generators. The generators’ share of the tariff shrank from 67% in 1991 to 40% in 1995 [2.31]. There has been a steep increase in electricity rates for the residential sector since 1995. Between 1995 and 2004, the average electricity rate for the residential sector grew at an annual rate of 15.1% for both the country and the macro-geographic regions [2.32].

The only time a considerable reduction in electricity intensity was observed was between 2000 and 2001, when the Government implemented nationwide power rationing in response to the severe electricity generation crisis. The constant increase in electricity intensity is the result of the continued replacement of primary fuels with electricity, a sign of modernization of the energy and economic sectors. An additional explanation is that the total electricity use includes that of households with low income elasticity. Hence, households continue to use electricity at normal levels even during times of recession, when there is a reduction in GDP or value added resulting from fewer goods and services being produced. Finally, in periods of economic contraction, commercial electricity losses have tended to increase in Brazil [2.33]. These losses are driven by the increased number of clandestine hook-ups made by households in slums and by business ventures in the informal economy.[20] This informal economy increases the electricity consumption and is not accounted for in the GDP.

2.2.1.4. Energy intensity: Selected industries

The industrialization of Brazil progressed steadily throughout the 20th century. By 2001, agriculture accounted for only 8% of GDP [2.34], while the industrial and services sectors accounted for some 37% and 55%, respectively.

The evolution of industrial activity was intertwined with energy development and reflects the static competitive advantages of Brazil either in terms of its cheap hydropower (e.g. aluminium production) or its labour costs (e.g. textiles). Figure 2.6 shows energy intensities (in terms of final energy use per value added) for selected energy intensive industries, all of which show a net increase in their energy intensities between 1980 and 2000.

Because of the continued electrification of industry, including a rise in self-generation, and the move towards electricity intensive industries, the industrial sector currently accounts for 50% of total electricity use [2.13]. Aluminium, iron, cement, petrochemical, chlorine, and pulp and paper manufacturers represented 27% of Brazil's total electricity use as of 2000 [2.1], while their contribution to the GDP value added was less than 8%,[21] reflecting in part their role as exporters of commodities and semi-finished goods. These major industrial consumers were also used to amortizing major Government investment in regional energy projects, benefiting in return from long term contracts for low cost energy (see Box 2.1).[22]

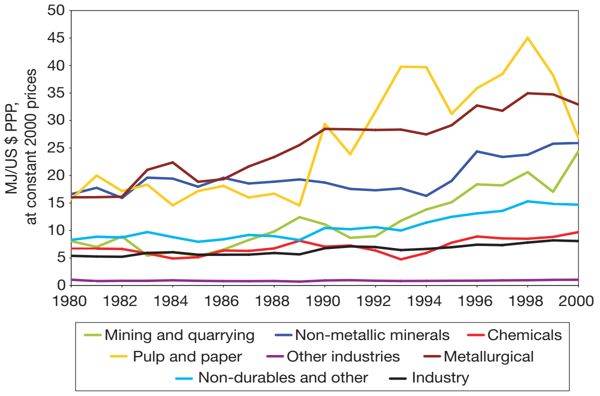

FIG. 2.6. Energy intensities: Final energy use per value added in selected industries [2.1, 2.11].

However, the growing energy intensities of the industries shown in Fig. 2.6 should not be taken as a sign of growing technological inefficiency. Owing to changes in industrial processes and specific technological improvements, between 1982 and 2000 the total specific energy consumption (energy per unit of physical output) decreased by 6.4% for the iron and steel industry, by 15% for the cement industry and by 27% for the pulp and paper industry [2.24].

Among the factors explaining the increase in energy intensities in these industries are the economic policies designed to guarantee the international competitiveness of semi-finished goods for export and the lack of adequate institutional supports for promoting dynamic competitiveness. Export focused industrial sectors (e.g. iron and steel, pulp and paper) have shown a shift to lower value added goods in the mix of their industrial output (see Fig. 2.7); this was particularly true during the 1990s. This represents an intrasectoral product mix change that is usually mistaken for reduced energy efficiency resulting from technology. The increased production of lower value added goods characterizes Brazil's industrial sector. Therefore, instead of progressively shifting to less energy intensive sectors by dematerializing the

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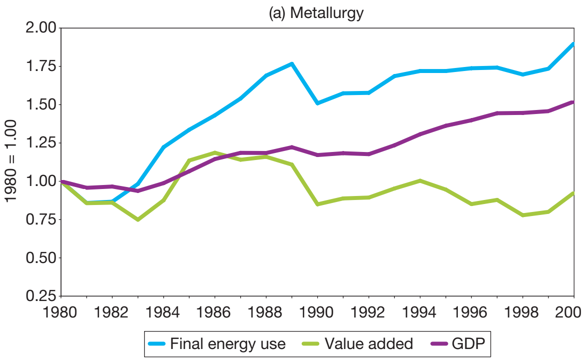
[20] The informal economy includes underground activities that have legal ends but employ illicit means. These activities do not intrinsically have a criminal content, but must be carried out illicitly, even though they are licit and desirable activities for the country. In general, the informal economy includes street vendors, labour for less qualified services and small scale manufacturers. For instance, the street vendor is a merchant with licit goals but illicit means, because of non-compliance with legal regulations and labour laws, and non-payment of taxes.

[21] Since 1980, the electricity intensive industrial sectors have accounted for more than 45% of industrial electricity consumption. By 2001, these sectors accounted for 99.8% of the industrial electricity consumption in the North region, compared with 39.9% in the Southeast region and 45.8% in Brazil as a whole [2.35].

[22] In 2002, the average electricity rate for the industrial sector in northern Brazil (weighted average) was 57% of the average rate for Brazil's industrial sector as a whole [2.14]. Some electricity intensive segments, such as primary aluminium smelters, are clustered in the North and Northeast regions.



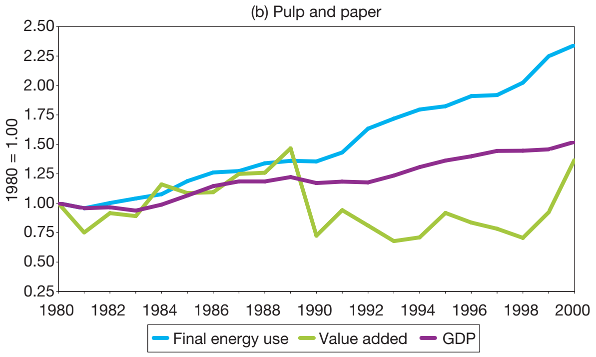


FIG. 2.7. Final energy use, value added and GDP indices for (a) metallurgy and (b) pulp and paper (1980 = 1.00) [2.1, 2.34].

economy and promoting relevant research and development (R&D) for important industries, Government policies focused on promoting electricity intensive products and industries.

2.2.1.5. Transport modes: Structural changes

The evolution of transport (passenger and freight) has also had a structural effect on the evolution of energy use in Brazil. Road transport of passengers (km/capita) grew 2.2% per year between 1980 and 2000, and now accounts for 98% of all passenger transport in Brazil. Similarly, road transport for freight grew 2.1% per year between 1980 and 2000, overtaking rail freight and accounting for 61% of freight activity by 2000 [2.36]. Moreover, urbanization, increasing mobility over long distances and improved standards of living have resulted in more private automobiles [2.37], while the Government's financial means to invest in public transport have diminished. The deterioration in the public transport system creates further pressure for investments in more road capacity [2.38]. These structural changes have resulted in an increase in the use of motor gasoline, ethyl alcohol and diesel oil. The combined use of motor gasoline and ethyl alcohol in road transport increased at an annual rate of 2.6% during the 1980–2002 period. The use of diesel oil in the overall transport sector increased at an annual rate of 3.2%, even though diesel oil use in railroads decreased during the same period.

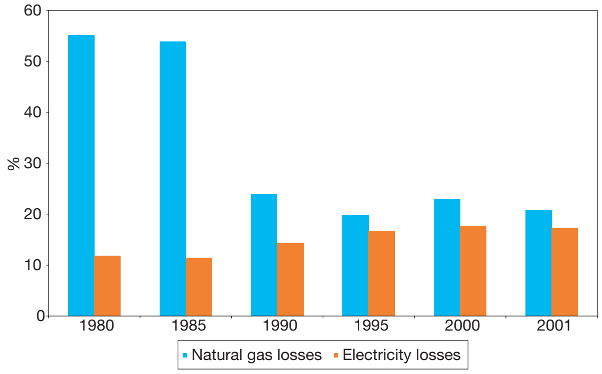


FIG. 2.8. Share of natural gas losses due to flaring and of total electricity losses (transmission, distribution and non-commercial) [2.1].

2.2.1.6. Energy efficiency: Supply side

As mentioned before, the TPES grew at a slightly higher pace (2.5% per year) than did final energy use (2.3% per year), reflecting increasing transformation losses. From 1980 to 2000, the electric power losses grew from 11.8% to 15.0% (see Fig. 2.8). This is due in part to the relatively remote locations of the large scale hydropower plants that came onstream during the 1980s, resulting in higher power transmission losses. It also reflects commercial losses by the power distribution utilities due to clandestine hook-ups. For instance, according to Abbud [2.33], in 1997 underground activities and clandestine hook-ups consumed 3% of the electricity supplied by power utilities.

In the case of natural gas, a 'Zero Burn-Off Plan' was introduced in 1998 to reduce flaring on offshore rigs and thus boost natural gas supplies. Nevertheless, around 20% of Brazil's gross natural gas supplies were still burned off in 2000 owing to the lack of natural gas transport infrastructure and to the fact that a large share of Brazil's natural gas production was associated gas [2.7]. The share of gas burned off will likely be reduced in the future, not only because of non-flaring programmes, but also because of the recent discovery of non-associated gas in the Santos Basin (in São Paulo State) amounting to 419 billion m^3 [2.39]. Increasing production of non-associated gas implies a reduction in the share of gas flaring in gross supplies in the future.[23] Figure 2.8 shows losses of natural gas due to flaring and of electricity due to transmission and distribution.

With respect to Brazil's refineries, it is important to note that domestic crude oils are mainly heavy and have a high acid content. Although the average oil refining efficiency has improved, increasing from 66% in 1980 to 73% in 2000, the production profile of Brazil's refinery park stock still includes almost 20% low value added products, especially residual fuel oils. Brazil's Long Term Energy Plan for 2000–2022 envisages new refineries producing only up to 9% (v/v) of heavy oil products and optimizing medium and low distillates [2.40]. Furthermore, the projected investment in existing Brazilian refineries for the next ten years, which is mostly focused on bottom of the barrel units (especially delayed coke and residual fluid catalytic cracking (RFCC)) and treatment units, is expected to reduce the average yield from heavy products from 23% in 2001 to 12% by 2011, while increasing the proportion of heavy acid Brazilian oils in the average refinery raw material input [2.41].

2.2.1.7. *End use efficiencies*

TABLE 2.9. FIRST AND SECOND LAW EFFICIENCIES OF BRAZIL'S ENERGY SYSTEM (%) [2.42–2.44]

Sector	Energy balance		Exergy balance	
	1987	1997	1987	1997
Residential and commercial	44.1	46.8	11.5	13.0
Transport	10.0	10.0	10.0	10.0
Industrial	71.1	71.2	42.7	43.0
Overall economy*	41.9	38.7	22.8	23.5

* The results for the overall economy in this table are slightly different from those presented by the sources listed owing to the fact that all references converted hydropower using a reference thermal plant efficiency of 27.5%.

The ratio of useful energy to primary energy, expressed by the energy balance (first law efficiency), has been steady at around 40% for the past ten years (see Table 2.9).[24] The second law efficiency, given by the exergy balance, was almost half the first law efficiency for the same period, implying that Brazil's energy system wastes a large amount of energy of high thermodynamic availability. This energy is being used for low quality (normally low temperature heat) applications that could be satisfied with low quality energy.

The differences between the first and second law efficiencies in the residential and commercial sectors are due to the wasting of a large fraction of heat in cooking and water heating end uses, and so cannot be redressed through capture or recycling. In the industrial sector, the difference between the two efficiencies arises mostly from the wasting of a large fraction of high quality heat in low to medium temperature applications, which can in fact often be captured and recycled. The differences in end use efficiencies show the theoretical potential for the use of cogeneration, heat pumps, heat exchanger networks and other such technical demand-side options [2.45].

2.2.1.8. *Resources and security of supplies*

Technological innovation and policies encouraging domestic exploration and production of oil and gas have led to a sharp decrease in oil imports and a rapid increase in oil and gas reserves over the past two decades, with significant impacts on the country's energy dependence and security. Figure 2.9 shows the ratio of imports to total energy supply. The reduction in oil imports resulted from technological innovations not only in oil exploration but also in ethanol production. Figure 2.10 shows the increase in oil and gas reserves and the corresponding ratios of reserves to production, which have remained at about the same level since 1980. The ratios correspond to reserves of about 20 years of current production. Technological innovation and policies have also helped to improve, to a

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[23] A recent study projected that by 2015 flaring will represent less than 10% of gross natural gas supplies, while the non-associated gas share in these supplies will rise to 37% [2.18].

[24] The first law efficiency assesses the quantitative match between energy supply and demand. It does not distinguish among the different qualities of the energy fuels. In turn, the second law efficiency, also considered in this analysis, expresses the problem of matching energy supply and demand with both minimum depletion of low entropy energy resources and minimum production of entropy. It assesses the match between exergy fuels in the input (supply) and the output (demand) of the energy system. Exergy is defined, in a simple manner, as the fraction of the energy that can be converted into useful work as a system proceeds to its final state in equilibrium with the environment.

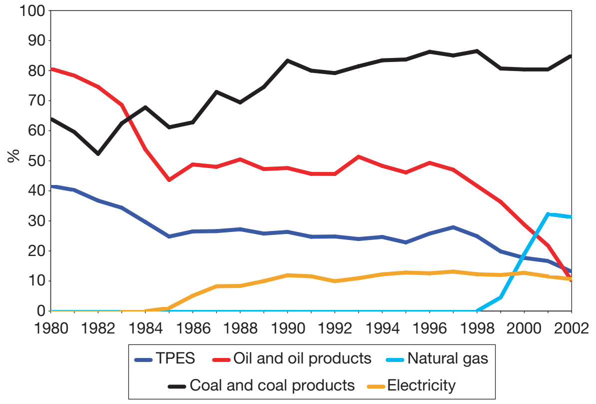

FIG. 2.9. Net energy imports as a share of total primary energy and total corresponding fuel supply [2.1].

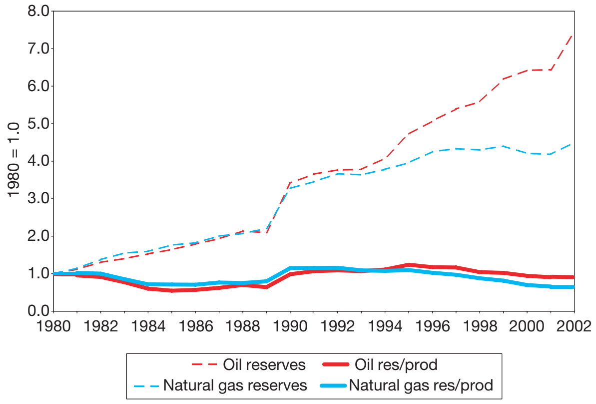

FIG. 2.10. Indices of oil and natural gas reserves and reserves to production ratio [2.1].

certain extent, the diversity of fuels in energy use. However, the electricity system in Brazil is still highly dependent on hydropower (see Table 2.5). For instance, some studies show that there are opportunities to improve the optimization of Brazil's hydraulic resource use by complementing it with the use of renewable energy sources, such as biomass or wind [2.46, 2.47].

2.2.2. Social dimension

Energy accessibility, affordability and disparity are issues of importance in the analysis of the social dimension of Brazil's energy development. Key indicators for this overview include the share of households without electricity or commercial energy (SOC1), the share of household income spent on energy (SOC2) and energy use for each income group (SOC3). A more detailed description of the linkages between energy and social development in Brazil is presented in Chapter 7.

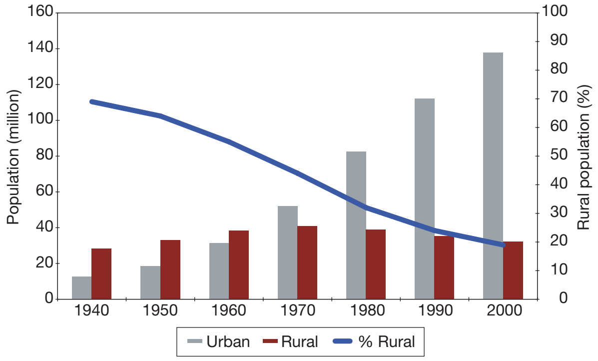

FIG. 2.11. Demographic evolution, 1940–2000 [2.11, 2.25].
Note: *Brazil's population reached 172.4 million in 2001.*

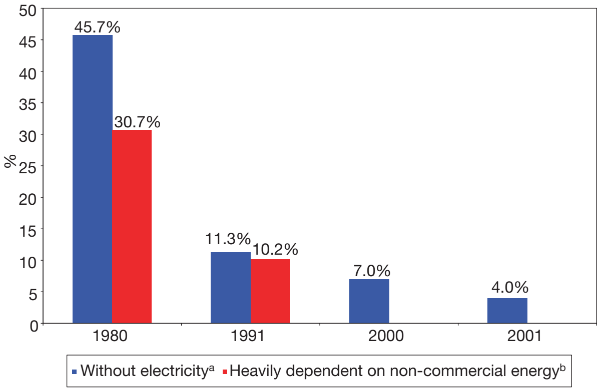

FIG. 2.12. Energy accessibility indicators [2.11].
[a] *Households without electricity meter.*
[b] *Households with a fuelwood oven; no data available after 1991.*

Population growth and urbanization have been major driving forces in the evolution of the country's energy system. Urbanization of the population grew from almost 30% in 1940 to more than 80% in 2000 (see Fig. 2.11) [2.25]. By 2000, around 28% of the population was concentrated in cities with more than 500 000 inhabitants [2.14].

Per capita final energy use grew at an average annual rate of 0.6% between 1980 and 2000, reflecting a growth in energy demand (2.3%) that was higher than the corresponding growth in population for the period (1.7%). The rapid increase in urban population allowed more and faster access to energy services for a larger share of the population, since rural areas in the poorest regions of the country are isolated and thus are difficult to connect to the electricity grid and to serve with commercial fuels.

Figure 2.12 shows the share of Brazilian households without electricity or heavily dependent on non-commercial energy. Although data on non-commercial energy dependence are not available after 1991, a recent study [2.48] estimates that the share of households dependent on fuelwood for dedicated or non-dedicated consumption (dual fuel stoves for LPG and fuelwood) was still 10% in 2000. These households are mostly located in rural areas, and their fuelwood consumption is explained not only by a lack of access to modern fuels, but also by affordability issues (which is the reason for the dual fuel stoves).[25]

Although per capita electricity consumption varies considerably by income level across the population, access to electricity among the lower income levels is almost universal in urban areas. In these areas, per capita electricity consumption is mainly limited by affordability factors, not a lack of physical access to the power grid. Access to the power grid has become a problem more specific to remote rural areas owing to the geographic dispersal of potential consumers. In urban areas, electricity consumption is also limited owing to the stocks of domestic appliances that people in these income groups can afford to buy.

Moreover, data on overall energy accessibility and affordability do not clearly reflect the heterogeneity of Brazil's various regions. Table 2.10 shows regional differences in household electricity consumption for the 1970–2001 period. Although about 4% of all households in Brazil (or about 6.5% of the total population[26]) have no access to electricity, this share is about 25% in rural areas and even higher in the North and Northeast regions [2.49]. Lack of access to the electric power grid is mainly a regional problem that is indirectly linked to the low population concentration in rural areas and to income distribution patterns among the various regions of the country — around 90% of the households lacking electricity in Brazil have an annual income of less than US $550 at 2000 purchasing power parity (PPP-2000) [2.49].

Income inequalities and regional disparities in Brazil are important factors affecting the Government's ability to satisfy social needs in the context of sustainable energy development. In 2000, the average Gini index for Brazil was 0.566, reflecting a high degree of income inequality compared with many countries in the world (see Chapter 7).[27] Furthermore, the Gini index varies among the different Brazilian States; for example, the Gini index for Paraíba State was 0.644, around 30% higher than that for Santa Catarina State (0.495) [2.50].

Estimates for household energy expenditures in 2000 (see Table 2.11) indicate the disparity among income classes in Brazil. Households in the lowest income group, on average, consume about a quarter of the electricity consumed by those in the highest income group. Conversely, the highest

TABLE 2.10. AVERAGE MONTHLY HOUSEHOLD ELECTRICITY CONSUMPTION (kW·h) [2.13]

Region	1970	1975	1980	1985	1990	1995	2000	2001	Annual growth rate (%)	
									1980–1990	1990–2000
North	83	101	127	135	154	150	165	152	1.97	0.67
Northeast	74	80	85	85	96	102	111	93	1.19	1.44
Southeast	116	131	156	152	176	189	201	164	1.24	1.30
South	78	90	106	125	146	160	176	167	3.29	1.87
Midwest	101	118	133	141	161	174	183	151	1.94	1.32
Total	103	116	133	135	152	162	173	146	1.34	1.30

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[25] Although the share of households consuming fuelwood for cooking is smaller than that consuming LPG for cooking, the overall household consumption of fuelwood is higher owing to the higher efficiencies of LPG stoves (7–10 times higher than those of fuelwood stoves) [2.29, 2.41].

[26] The population to household ratio decreased from 6.9 in 1980 to 3.4 in 2001, while total population rose from 122 to 172 million within this period [2.11].

[27] The Gini index measures the extent to which the distribution of income (or consumption) among individuals or households within a country deviates from a perfectly equal distribution. A value of 0.0 represents perfect equality; a value of 1.0, perfect inequality.

income group spent less than 3% of their average income on energy versus about 14% for the lowest income group (see Chapter 7, Fig. 7.4). Also, the richest segments of the population not only consume more energy but also use higher shares of the most convenient commercial fuels compared with the lower income segments of the population.

Finally, the disparities in income and regional development will continue to complicate energy and economic policy making, especially when it comes to balancing a desire to ensure affordability of energy for the poor with the need for efficient pricing and sufficient investment. In addition, increases in energy use among the lower income classes, especially in rural areas, are a challenge for diversifying the energy mix, mainly by promoting the use of renewable resources and by improving energy efficiency.

2.2.3. Environmental dimension

Brazil has a relatively 'clean' energy system, relying significantly on renewable energy sources such as biomass, hydropower and nuclear power. Nevertheless, it is necessary to examine the environmental impacts resulting from important trends in Brazil's development, such as increasing urbanization, rapid growth of the road transport sector and the country's energy intensive manufacturing sector. Key indicators for this overview include local atmospheric pollutants (ENV3), greenhouse gases (ENV1) and deforestation (ENV6). A more detailed description of the linkages between energy and the environment is presented in Chapter 6.

2.2.3.1. Local atmospheric pollutants

Local atmospheric pollutants from energy systems in Brazil include sulphur oxides (SO_x), nitrogen oxides (NO_x) and carbon monoxide (CO). Most of Brazil's sulphur dioxide (SO_2) emissions derive from the use of high sulphur residual fuel oil in the industrial sector, coal use in steel making and use of diesel fuel in transport. SO_2 emissions underwent a major reduction in 1997 as a result of the implementation of the diesel oil upgrade programme and a major shift to light vehicles running on neat ethanol [2.53]. Because of the predominance of hydropower and to a lesser extent nuclear in Brazil's electricity generation sector, the power sector does not emit large amounts of SO_x. However, there are different impacts from SO_2 emissions, depending on the sources and the geographical coverage, including long range acid rain, sulphates aggregated to fine particulates from diesel vehicles in urban areas and direct exposure to SO_x around industrial complexes. Therefore, SO_x emissions need to be assessed locally and not just at the national level.

Similarly, the industrial sector accounts for a significant portion of the NO_x emissions, mainly from high temperature boilers and furnaces. NO_x emissions are expected to increase in the electricity

TABLE 2.11. HOUSEHOLD ENERGY EXPENDITURES, ESTIMATES FOR 2000
(based on Refs [2.27, 2.51, 2.52])

	Income group				
Monthly household expenditures (US $ PPP-2000)[a]	<362	362–543	543–906	906–1811	> 1811
Number of minimum monthly wages[b]	< 2	2–3	3–5	5–10	>10
Electricity expenditure (US $ PPP-2000)	13.22	25.51	29.31	50.35	82.86
LPG expenditure (US $ PPP-2000)	10.92	14.96	16.9	18.58	21.10
Households by income class (%)	22.3	14.6	18.1	16.5	12.6
Electricity tariff (US $ PPP-2000/kW·h)	0.09	0.15	0.15	0.22	0.25
Estimated electricity consumption (kW·h/month)[c]	89	114	131	225	333
Average national electricity consumption (kW·h/month)[d]			173		

[a] Disposable income based on IBGE [2.51] (1997 and later editions). The latest edition (August 2003) covered only 11 Brazilian state capitals, or 26% of the Brazilian population in 1996.

[b] In 2000, the minimum monthly wage was equal to US $181.12 (PPP-2000).

[c] Estimates based on assumptions about the identification of different tariffs with different income groups.

[d] The estimated average consumption is equal to the actual value for 2000.

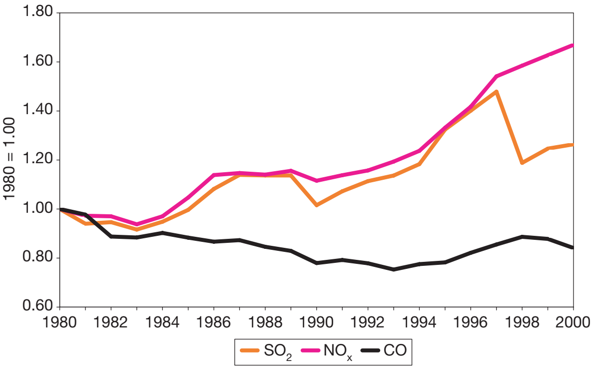

FIG. 2.13. Indices of estimates of national pollutant emissions (based on Refs [2.24, 2.53]).
***Note:** In 1980, SO_2 emissions were 2133 kt, NO_x emissions were 1423 kt and CO emissions were 19 403 kt.*

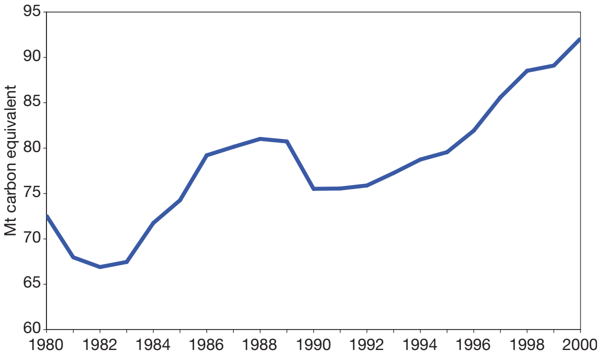

FIG. 2.14. Estimated GHG emissions from energy use (fossil fuels and non-renewable biomass) (based on Refs [2.24, 2.53]).

sector with the broader introduction of thermal power and cogeneration plants fuelled by natural gas.

CO emissions in Brazil are mainly from biomass use in the residential sector (specifically fuelwood for cooking purposes) and in the industrial sector (from fuelwood used in furnaces). Since fuelwood use has decreased sharply in the past two decades, CO emissions have dropped considerably, despite the fact that charcoal has kept its importance in the steel industry (see Fig. 2.13). CO emissions continue to be important occupational pollutants from fuelwood burning in poor communities.

2.2.3.2. Global pollutants

Greenhouse gas (GHG) emissions were more than 20% higher in 2000 than in 1990 (see Fig. 2.14), and they might increase even more as renewable charcoal is replaced by metallurgical coking coal and gas fired generating capacity is expanded. However, it is possible that the introduction of flex-fuel vehicles (able to run on a flexible mixture of gasohol) and the expansion of biomass fired cogeneration and other new renewable energy options, such as wind farms and small scale hydropower, might counterbalance or even reverse this trend.

It is important to note that while GHG emissions have been rising in absolute terms, per capita GHG emissions have dropped. This is partly because the rise in per capita energy use has been largely met through the use of hydropower and ethanol. This places Brazil in a favourable position in terms of global climate change concerns. For instance, in 1998, Brazil's per capita carbon dioxide (CO_2) emissions from energy use reached 1.94 t (CO_2 only). This is below the corresponding value for the world (3.89 t) and for the Organisation for Economic Co-operation and Development (OECD) countries (10.93 t).

The large share of renewable energy in the country's energy balance also explains the relatively low intensity of GHG emissions (CO_2 emissions per unit of GDP) in the overall economy. In 2000, this intensity was 21.1% lower than in 1980. It is also lower in Brazil than in the industrialized countries: 0.36 kg CO_2 per US dollar in 1998 in Brazil versus 0.66 kg CO_2 per US dollar worldwide and 0.62 kg CO_2 per US dollar in the OECD countries.

Finally, it must be emphasized that the largest share of Brazil's GHG emissions is derived from non-energy sources such as agriculture and livestock, land use change and forestry, and waste treatment. Between 1990 and 1994, land use changes, energy use and transformation, and soils and liming, in that order, were the most important sources of CO_2 emissions in the country [2.54]. Land use changes per se represent two thirds of Brazil's per capita CO_2 emissions. In turn, new forest plantings, mainly eucalyptus and pine, provide the single most important CO_2 removals in this sector.

2.2.3.3. Impact of large dams

The most important social cost of constructing hydropower dams is the resettlement of communities. A major environmental externality is the impact on affected ecosystems. Resettlement tends to be a major socioeconomic issue. The construction of dams in Brazil for hydropower generation has accounted for the flooding of over 36 000 km^2 [2.55], which is equivalent to 0.4% of Brazil's total land area. Nevertheless, power densities (in MW/km^2) vary greatly, implying that hydropower plants in Brazil have different productivities. For instance, at the end of the 1990s the average power density of the Paraná River basin, which includes 45 hydropower plants, was 2.84 MW/km^2, and individual power plant densities varied between 0.81 and 10.67 MW/km^2.

2.2.3.4. Land use for ethanol fuel production

It is estimated that some 65% of the 1989 sugar cane harvest was channelled to ethanol production, accounting for 4.8% of the land set aside for planting primary crops in Brazil [2.56]. This is far less than the area used to grow maize (24.0%), soybeans (19.2%) or rice (10.8%). That same year, Brazil's sugar cane plantations (for both sugar and alcohol) accounted for 7.3% of Brazil's primary croplands and 0.48% of the country's territory. In 2000, the sugar cane harvest channelled to ethanol production was again grown on 4.8% of the land set aside for planting primary crops [2.57]. For the entire historical series under consideration here, regardless of whether the sugar cane was grown to produce sugar or ethanol, it is clear that only a small fraction of Brazil's arable land was used for this crop. However, as discussed in Chapter 6, the highly intensive production systems for ethanol in Brazil have caused environmental imbalances owing to the use of fertilizers and pesticides. Moreover, sugar cane is a major source of air pollution owing to burning practices prior to manual harvesting. Estimates are that 20% of all Brazilian sugar cane is now harvested mechanically, without the need for such burning practices, and therefore is not subjected to environmental penalties.

2.2.3.5. Deforestation due to energy use

The use of fuelwood as an energy source is not a driving force behind deforestation in Brazil. The supply of fuelwood for energy biomass relates to small scale decentralized demands from the residential sector, of which, on average, one half of the fuelwood is gathered in the form of secondary growth such as scrub, twigs and branches [2.53], and consequently does not impose deforestation pressures (non-commercial woody biomass circuit).[28] Another use for fuelwood is charcoal production. However, the share of non-renewable fuelwood consumed for charcoal production decreased from 86% in 1980 to 28% in 2000 [2.4].

2.3. INSTITUTIONAL DIMENSION

In the 1990s, major structural and policy reforms were implemented aimed at simultaneously achieving six major objectives: to promote competition and to attract private investors for expanding the energy supply; to diversify Brazil's energy system, mostly by increasing natural gas consumption; to broaden access to modern energy services; to guarantee minimum quality standards in energy services; and to improve the performance of energy suppliers. Brazil's institutional dimension is currently in a transition phase, which poses uncertainties, opportunities and risks for the country's sustainable energy development.

2.3.1. Electricity sector

2.3.1.1. Brief historical overview

From a historical perspective, the institutional dimension of the electricity sector evolved in five separate phases. During the initial fiscal phase (1955–1964), the institutional foundations for provision of electricity were improved by establishing the Federally owned holding company Eletrobras (1961) and other important institutions, such as the Brazilian Nuclear Energy Commission (1956). During the subsequent business phase (1964–1974), tariffs previously calculated according to the historical costs of power generation, transmission and distribution services were updated and calculated according to service costs (cost-plus regulation). In the debt phase (1974–1979), under the shadow of Brazil's foreign debt, the country built huge hydropower complexes as part of its industrialization programme. In the subsequent crisis phase (covering the 1980s and the beginning of the 1990s), further capacity expansion was undermined by the scarcity of financial resources. Finally during the current phase (which started

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[28] The exception to this rule is the urban sprawl around large towns and cities in northern Brazil, where there is an established market for fuelwood and charcoal, in addition to easily available wood from the Amazon rainforest [2.3].

around 1993), there has been a series of reforms designed mainly to boost the competitive dynamics of the electricity sector, while also attracting private funding to underwrite the expansion of Brazil's installed capacity and reduce the risk of electricity shortfalls.

2.3.1.2. Institutional reforms: The current institutional status of the electricity sector

The cornerstone of the current electricity sector reform was laid in 1993, with the suppression of the tariff equalization system between regions and the implementation of the National Electric Transmission System (SINTREL), which gave independent power producers open access to the transmission grids. In 1995, the Federal Government launched an intensive privatization process that focused mainly on distribution utilities, allowing the State and Federal Governments to use cash proceeds from the asset sales to pay down debt [2.58].[29]

In 1996, the Federal Government regulated the status of two new players in the power generation segment: independent power producers and self-generating firms. As a result, the new model created three business segments in a semi-competitive framework: (a) generation companies operating in an open marketplace, making both spot and contract sales to eligible customers (initially, distributors and heavy users); (b) transmission companies guaranteeing open access and operating under a set tariff framework, allowing a regulated return on assets; and (c) distribution companies having both eligible customers (large energy intensive users that have permission to purchase electricity from their choice of power provider at a market price) and non-eligible customers (users that purchase from the distributor under regulated tariffs).

In addition, three regulatory agents were created to oversee the operation of the power sector:

- The National Electricity Regulatory Agency (ANEEL) oversees concessions, bids and inspection of utilities services, and competition for electricity system expansion; solves conflicts between agents; and establishes power accessibility targets for each distribution utility.
- The Wholesale Energy Market (WEM), created in 1998, consists of four distinct regions with system independent marginal costs and real time spot prices, aimed at free negotiation between players and the Independent System Operator (ISO). The WEM is a non-profit private civil organization with compulsory members (power generators higher than 50 MW) and non-compulsory members (self-generators, cogenerators not connected to the transmission grid). It coordinates spot market operations according to the rules defined by ANEEL.
- The ISO is the dispatch authority that prioritizes dispatch on a low marginal cost basis and is in charge of coordination and control of the operation of interconnected systems. The ISO is a non-profit private organization including transmission utilities, international electricity traders, eligible consumers and the Ministry of Mines and Energy (MME).

In this new model, the ISO controls the physical dispatch of the power system, according to the declared availability of each generator and with the objective of optimizing the use of hydropower resources in space (avoiding deleterious competition between hydropower plants) and time (considering the opportunity cost of using or stocking water). Two different transactions coexist between power generators and consumers (distribution utilities and final consumers):

- Transactions inside the spot market, involving mainly surplus power and non-regular energy trades among power generators, traders and eligible consumers;
- Transactions through bilateral contracts, which avoid the price volatility of the spot market.

In spite of these innovations, not all the barriers to attracting private sector investments in installed capacity expansion have been removed. These barriers include uncertainties regarding the

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[29] For the electricity sector, the privatization process started in July 1995 and resulted in the privatization of 23 publicly owned utilities by 2000 (2 distribution utilities from the Federal Government, 18 distribution utilities from State Governments and 3 generation utilities). By 2000, this process had resulted in US $22 billion [2.59].

market structure, the operation of the WEM and gas prices (quoted in US dollars).[30] In addition, since 1995 the utilities' debts have increased, to a great extent as a result of external loans, as utilities were used as guaranties for new acquisitions in the Brazilian power sector [2.22]. The devaluation of the Brazilian real in 1999 worsened the financial situation of these indebted companies, reducing their ability to invest.

The lack of new investments (public and private) and the consequent delay in power plant construction and transmission capacity expansion forced the MME to announce, in February 2000, the Thermoelectric Priority Programme (PPT), which planned for 49 natural gas power plants to be built by 2005. The PPT offered incentives for private investments through relatively long term contracts for the sale of electricity and for buying gas at fixed exchange rate prices. From the Government's point of view, the PPT would improve the reliability of the electricity supply, which is excessively dependent on hydropower. However, difficulties in gas pricing and contracting, and the context of crisis and uncertainty, frustrated the plan [2.60]. This aggravated the lack of alternative generation during 2001, which resulted in a major nationwide power rationing programme in response to the electricity supply crisis.

Within this uncertain context, a better division of the different roles of the ministries and the regulatory agencies is needed. The initial concept of power sector reform distinguished the former as planning and policy making agents, and the latter as regulatory and operational agents, implementing policies and guaranteeing the optimum operation of the system. Yet between 1998 and 2002, the new institutional model was the subject of debates concerning the limits of the agencies' and ministries' tasks in practical terms.[31] The electricity shortages of 2001 and how they were managed illustrate the importance of energy planning for energy security (see Chapter 8).

Finally, since the beginning of 2003, the Government has been discussing a new model for the Brazilian power sector that will be driven by three main principles [2.40]: first, electricity should be made available to all Brazilians; second, the MME should ultimately be responsible for energy planning; and third, assets from private investors or private–public partnerships will be managed by a new agent that, once created, will sign long term contracts with power generators and final consumers. The Government expects that investors who win long term contracts will benefit from a captive market and thus will have the incentive to accept this arrangement. There seems to be a gradual shift from the model built in the 1990s, based on an open market with third party access, to a variation of the 'single buyer' model, in which a new single State agent is responsible for operating a single power pool, acting as a kind of trader between power producers and consumers. Regarding the sustainable development of energy, however, while this new model includes the promotion of renewable energy sources through fixed quotes, it still does not strongly promote energy efficiency, for instance, by bidding for final energy savings measures (for more details on policy proposals, see Chapter 9).

2.3.2. Oil and gas sector

2.3.2.1. Brief historical overview

The first Brazilian oil law dates from 1938, when the National Petroleum Council (CNP) was created and oil and gas resources were declared the property of the Federal Government. The CNP regulated oil exploration and production, as well as imports, exports, transport and distribution of oil and oil products. In 1953, Brazil's national oil company, Petrobras, was created as a monopoly for research, exploration, refining and transport of oil and oil products. In 1975, foreign investment in oil exploration and production was allowed, but it did not materialize to any great extent, mainly owing to

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[30] Indeed, there is some wariness about the volatility of electricity spot prices, prompted by the overwhelming weight of hydropower in Brazil's generation profile, as spot market prices are determined largely by the availability of energy at hydropower plants. Price spikes are likely to occur in dry periods, and price depressions in wet periods, with the short run marginal cost being close to zero when surplus power from hydraulic resources is available. In other words, the financial risks of new thermal units are directly related to the stochastic nature of water inflows.

[31] During the first half of 2003, this issue was still dividing technicians into those defending the direct participation of the MME in defining electricity tariffs and those critical of the degree of governmental intervention in activities primarily assumed by regulatory agencies.

the country's adverse geology, the low quality of Brazilian crude and economic uncertainties. In 1988, the Brazilian Constitution eliminated risk contracts.[32] Finally, in 1995, the Government began liberalizing the oil and gas industry. A constitutional amendment authorized the Government to deal with public or private companies to promote activities in oil and gas research and exploration; oil refining; and transport, imports and exports of oil, oil products and natural gas. The National Petroleum Agency (ANP) was then created, whose functions included regulation, supervision and control of the oil and gas industry, as well as the biofuel market. Its activities include improvement of market competition and protecting consumer interests as to price, supply and quality of fuels.

In 1997, a new oil law was signed, breaking the monopoly of Petrobras. The Federal Government kept the majority of Petrobras voting shares (51%) and ownership of oilfields and gas fields, yielding concessions for eligible private and public companies to explore these resources. Oil product prices were liberalized in January 2002.

2.3.2.2. *Institutional reforms: The current institutional status of the oil and gas sector*

Under the new regime, in addition to Petrobras, 42 other companies have started operations in the Brazilian upstream market, through concessions for oil and gas exploration. The number of players in downstream operations (oil product distribution) has also increased, especially since the liberalization of oil product prices in January 2002.

Additionally, Petrobras Transporte S.A. (Transpetro) was created in 1998 to transport oil, oil products and natural gas. However, no agreement has been signed between Transpetro and Petrobras and, as yet, Transpetro has no assets and only operates those of Petrobras (ships and pipelines). Thus, the intended unbundling of the two companies (and of the activities of production, transport and commercialization) has not happened.

By 2003, a new arrangement, the Projeto Malhas, had been agreed to, creating three new companies: the first for the transport of natural gas between Brazil's Northeast coastal region and the Southeast region (TNS), the second for gas transport within the Northeast region (NTN), and the third for transport of gas within the Southeast region (NTS). TNS now owns the existing Petrobras assets for gas transport (the existing grids), and the new assets created by the Projeto Malhas will belong to NTN and NTS. Moreover, natural gas contracts should now be signed between Petrobras and these three companies.

In summary, developing natural gas transport has been complicated by the need to finance pipeline expansion while maintaining competitiveness. Clearly, monopolies can muster and amortize large scale investment the most rapidly. The current institutional framework for the natural gas sector includes different agents and information asymmetries, but through its price control mechanisms it could provide needed incentives to investors. The ANP regulates gas transport prices, and the MME, allied with the Ministry of Economy, determines the upper limits for internal producer prices for natural gas. In turn, the responsibility of natural gas distribution and its regulation has been given to the State Governments. Therefore, the ANP is responsible for controlling natural gas production, imports and transport up to the city gates, whereas State regulatory agencies regulate gas distribution to final consumers. This arrangement results in a lack of coordination throughout the industrial chain.

Although the Brazilian Government aims at improving competitiveness in the natural gas market, this may be premature until sufficient investments in infrastructure are realized and new investors are persuaded to enter the market. Moreover, the electricity sector, a major consumer of natural gas, is still in a transition phase, undermining to some extent natural gas sector reform as it was originally planned.

2.4. SUMMARY OF MAIN ISSUES

Brazil is a country with a reasonably large and diverse supply of indigenous energy resources, including renewables, oil, natural gas, uranium and

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[32] A risk contract is a type of hybrid contract applied in the Brazilian oil sector. The 1953 Brazilian oil law (Law 2004/1953), valid up to 1997, established that the Federal Government would hold the monopoly rights in the oil industry and trade. After the first oil shock, the Brazilian Government aimed at increasing oil exploration and production, and thus a different legal instrument was proposed in order to attract private investments (national and international), through Petrobras, without exceeding the boundaries of Law 2004/1953.

coal. The country currently satisfies its energy demand mostly with oil, biomass and hydropower, which is by far the predominant technology for electricity generation. Industry and transport are the largest users of energy. The country is a world leader in the development and use of technology for the production of ethanol automotive fuel and biofuel from bagasse for electricity generation.

Brazil has implemented very successful measures to reduce its dependence on energy imports through the use of innovative technologies for both oil exploration and ethanol production from sugar cane. Other advantages resulting from technological innovation and effective policies include the increase of oil and natural gas reserves, the increased use of domestic commercial fuels to diversify primary and final energy, and the reduction in oil dependence in the transport sector. Accessibility to commercial energy, including electricity, has increased dramatically, especially in urban areas. This has translated into a strong reduction in the use of fuelwood. From the environmental point of view, Brazil's energy system is relatively clean owing to the large share of hydropower and other renewables in its energy mix.

Nevertheless, there are major issues that need to be addressed to improve the development and sustainability of Brazil's energy system.

In the economic dimension, one of the major areas for improvement in Brazil is energy intensity, which is directly related to inefficient pricing of fuel and energy services, especially in the industrial sector. Brazil has abundant hydropower at low short term marginal costs that has helped to fuel its industrialization. However, subsidized fuel prices in some sectors have encouraged wasteful energy use, and distortions caused by price subsidies have been deleterious to improvements in energy and exergy efficiencies. They have also encouraged the highly energy intensive industries that characterize Brazil's manufacturing sector. There is unrealized potential for reduction in fuel use through heat integration in the industrial sector and for increased efficiencies in energy supply in refineries, in the electricity grid and in natural gas and ethanol networks. Also, energy pricing does not consider environmental externalities.

Brazil's high dependence on hydropower justified the investment in a highly coordinated power transmission system with long distance transmission lines, which is managed by the ISO. This whole complex system has been based on investments in multi-year reservoirs to avoid seasonal problems and in transmission lines to allow power to flow between regions. This, however, poses risks of power outages and affects the stability of the electricity system. As a result, such reliance on hydropower represents a security issue.

The main issues concerning the status of Brazil's energy system within the social dimension are the disparity and affordability of energy use, not only for the poor living in rural areas but also for those living in the slums of urban centres. Even where modern energy services are available, the poor in many areas cannot pay for commercial services and so either cannot satisfy their minimum energy needs or have to return to the use of traditional fuels, a practice that is inefficient and potentially health damaging. The disparity is evident in the types of fuel consumed by different economic sectors, with the poor making (inefficient) use of less efficient and more polluting fuels, while the rich (more efficiently) use cleaner and more efficient fuels. There is also some question about what level of energy use is sufficient to satisfy minimum energy needs. Extraordinary progress has been achieved in electrification in the past two decades, but there are still a number of villages in rural areas that have no access to modern energy services, and to electricity in particular.

Most environmental impacts from energy production and use are local impacts resulting from the discharge of pollutants such as NO_x, SO_x and particulates. The situation is of particular concern in dense urban areas. Other issues such as GHGs, deforestation and land use for energy purposes do not present major problems. The environmental impact of some large dams built in the past is still an important issue under investigation.

With regard to the institutional dimension, under the aegis of the country's energy sector reforms, a continuous regulatory effort has been deployed aimed at opening power and oil markets and cutting subsidies. This is an ongoing process that might promote the implementation of efficiency measures throughout the economy and the internalization of pollution impacts, and slow resource depletion from energy use. The results of these reforms are still uncertain, and the regulatory tasks are not trivial. Questions remain regarding how to simultaneously achieve competing goals such as fostering the use of renewable energy and energy efficiency, promoting a balance between increasing technical efficiency and reducing energy prices, and attracting sufficient investment. It is crucial to build institutional capacity to accommodate these needs in order to enhance the State's ability to promote sustainable energy development simultaneously within the economic, social and environmental dimensions. Some key provisions include regulatory systems for the natural gas and power sectors, efficient pricing schemes and enforcement systems for electricity payment, and improvements in the coordination and implementation of an integrated energy planning programme.

With respect to infrastructure, at least three major issues require attention: the electricity grid that interconnects all regions should be able to wheel bulk power among regions without constraints; the gas transport network should be completed to provide this fuel to major demand centres; and the refinery system should be reformulated to allow the consumption of increasingly heavy and acid oils, optimizing the production of light and middle cuts, and also of feedstocks, especially high grade lube oils and petrochemicals.

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Chapter 3
DOMESTIC ENERGY RESOURCES

F. ROSILLO, J.R. MOREIRA

3.1. NATURAL ENERGY RESOURCES IN BRAZIL

Brazil is endowed with reasonably large and varied amounts of energy resources. Table 3.1 gives the country's energy resource picture in 2003. The conventional fossil fuel resources amount to about 10.4 billion toe, of which 21% is oil and gas. Additionally, there are about 10.8 billion toe of unconventional fossil fuels (shale oil and shale gas). Of the total fossil fuel resource base of 21 billion toe, 4.8 billion toe are proven reserves (measured/indicated/inventoried). On a per capita basis, the availability of proven fossil fuel reserves in Brazil is

TABLE 3.1. ENERGY RESERVES AND RESOURCES IN 2003, EXCLUDING RENEWABLE RESOURCES EXCEPT LARGE HYDROPOWER [3.1]

Resource	Unit	Reserves and resources[a]		
		Measured/ indicated/inventoried	Inferred/estimated	Total
Coal (in situ)	Mt	10 108	22 240	32 348
	Mtoe	2 554	5 620	8 174
Oil	m^3 (10^3)	1 685 518	459 783	2 145 301
	Mtoe	1 471	397	1 868
Natural gas	m^3 (10^6)	245 340	106 275	351 615
	Mtoe	244	106	349
Conventional fossil fuels	Mtoe	4 269	6 123	10 392
Shale oil[b]	m^3 (10^3)	445 100	9 402 000	9 847 100
	Mtoe	383	8 086	8 469
Shale gas[b]	m^3 (10^6)	111 000	2 353 000	2 464 000
	Mtoe	104	2 212	2 316
Total fossil fuels	Mtoe	4 756	16 421	21 177
Hydropower[c]	GW·year	93	51	144
	Mtoe/year	70	38	108
Uranium	t U_3O_8	177 500	131 870	309 370
	Mtoe	1 017	756	1 773
Peat	kt	129 330	357 960	487 290
	Mtoe	40	111	151
Total	Mtoe	5 883	17 326	23 209

[a] Reserves refer to those occurrences that are identified and measured as economically and technically recoverable with current technologies and prices. Resources are those occurrences with less certain geological and/or economic characteristics, but that are considered potentially recoverable with foreseeable technological and economic development. Data published in the National Energy Balance [3.1] do not distinguish between reserves and resources. The difference between measured/indicated/inventoried and inferred/estimated is based on geological and physical certainty, while the economic aspect is not taken into account.

[b] Data for 2001 from Ref. [3.2].

[c] Evaluated from measured and estimated power generation assuming annual production from hydropower at 55% plant factor.

TABLE 3.2. PROVEN OIL RESERVES, 1980–2004 [3.1, 3.2, 3.4]

Year	10^3 m^3	10^3 toe*	Year	10^3 m^3	10^3 toe*
1980	209 540	181 043	1993	792 100	684 374
1981	234 640	202 729	1994	854 468	738 260
1982	273 210	236 053	1995	989 385	854 829
1983	294 100	254 102	1996	1 062 143	918 910
1984	320 520	276 929	1997	1 129 755	976 108
1985	344 694	297 816	1998	1 169 710	1 010 630
1986	374 958	323 963	1999	1 296 273	1 119 980
1987	405 538	350 385	2000	1 345 746	1 162 725
1988	447 730	386 839	2001	1 348 998	1 165 534
1989	438 779	379 105	2002	1 560 258	1 347 977
1990	717 516	619 986	2003	1 685 518	1 471 457
1991	766 055	661 872	2004	1 787 493	1 560 481
1992	789 490	682 119			

Note: Proven oil reserves are as defined in footnote a of Table 3.1.
* 1 m^3 oil = 0.864 toe, based on table 6.2 in Ref. [3.2].

only 27 toe per inhabitant, compared with the world average of about 185 toe per inhabitant. According to estimates from the United States Geological Survey, Brazil has some 12 billion toe of undiscovered resources of oil and gas; however, they are not included in this chapter owing to their high uncertainty [3.3].

In terms of hydropower resources, Brazil is better off. The total technical potential is estimated to be 260 GW, which on the basis of a per capita hydropower production potential of 6.7 MW·h per year per inhabitant compares quite favourably with the world average of 2.4 MW·h per year per inhabitant. About one fourth of this total potential has already been built. Brazil currently is the world's second largest hydropower producer after Canada.

The country has some 309 000 t of uranium resources, of which about 57% are proven reserves. The total uranium resources are sufficient for a lifetime fuelling of 36 nuclear power plants of 1000 MW each, based on light water reactor technology without spent fuel reprocessing.

There are some peat resources as well, but they are not being used. If the potential for annual production from hydropower is also included, Brazil has about 23 billion toe of total energy resources (excluding the potential of all other renewables). The following sections give a detailed account of the energy resource situation in Brazil.

3.1.1. Oil

Brazil has invested heavily in oil exploration for decades, particularly since the late 1970s, and is currently the world's 15th largest oil producer, with proven reserves of almost 1.8 billion m^3 in 2004. Table 3.2 shows the status of proven reserves of oil from 1980 to 2004. Oil reserves have increased more than eightfold from 181 million toe in 1980 to over 1.56 billion toe in 2004. Petrobras anticipated that production of oil and natural gas could reach 1.9 million boe/d in 2005, compared with 1.55 million boe/d in 2002, with further investment in exploration and development of some US $32 billion (US $26 billion for oil and US $6 billion for natural gas), most of which would be raised domestically.

The main oilfields are offshore in the Campos Basin, in Rio de Janeiro State. This area is Brazil's largest oil and natural gas producer and has about 87% of the country's total and proven reserves. About 80% of the oil and gas comes from offshore, increasingly from deep waters.[1] Oil has also been found in the States of Amazonas, Maranhão and Santa Catarina. Petrobras estimates production

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[1] There are discrepancies about offshore oil and gas wells, but generally water depths between 500 and 1500 m are classified as deep water and those greater than 1500 m, as ultra-deep water.

costs to be on average around US $3.00/bbl,[2] which makes Brazilian oil quite competitive in international markets.

Exploration for oil and gas continues apace, and thus major new discoveries are possible, particularly in the Amazon region (Amazonia) and offshore. However, some experts argue that significant new discoveries are unlikely, as the most promising geological sites have already been explored. It is important to bear in mind that oil exploration technology has advanced rapidly, with major improvements in oil drilling. New oil discoveries in Brazil have been small compared with those of major world producers; however, in relative terms, oil reserves have increased faster in Brazil than in many other oil producing countries (see Fig. 3.1).

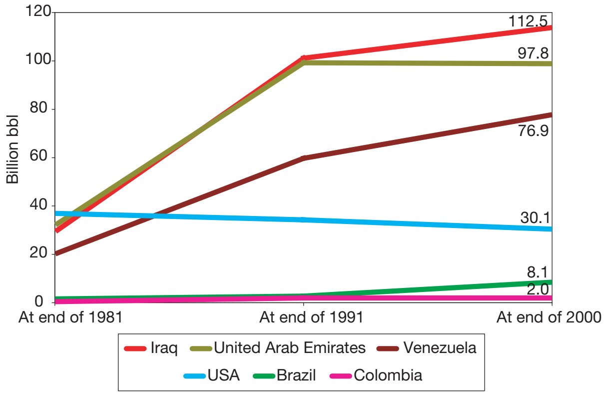

FIG. 3.1. Countries with the largest relative increases in proven oil reserves since 1981 [3.5].

Brazil also has vast shale resources (see Table 3.1). However, since shale oil and gas are highly unlikely to be used on a large scale before 2025, these resources are not considered in any detail in this chapter. It is recognized that the combination of technological advances and increases in oil prices could make this option an important economic alternative in the future.

3.1.2. Natural gas

Natural gas reserves at the end of 2004 were 326 billion m^3 (2.1 billion boe, or 11.8 EJ). Table 3.3 summarizes the development of proven natural gas reserves in Brazil from 1980 to 2004. There was a significant increase of 33% in 2004 compared with 2003. As with oil, Rio de Janeiro State has the largest known gas reserves with about 37% (121 billion m^3), followed by São Paulo with about 24% (79 billion m^3), Amazonas with about 15%

TABLE 3.3. PROVEN NATURAL GAS RESERVES AND ANNUAL INCREASE, 1980–2004 [3.1, 3.2, 3.6, 3.7]

Year	Volume (10^9 m^3)	Annual increase (%)	Year	Volume (10^9 m^3)	Annual increase (%)
1980	52.5	16.6	1993	137.4	0.5
1981	60.3	14.7	1994	146.5	6.6
1982	72.3	20	1995	154.3	5.3
1983	81.6	12.8	1996	157.7	2.2
1984	83.9	2.8	1997	227.7	44.4
1985	92.7	10.5	1998	225.9	0.8
1986	95.8	3.3	1999	231.2	2.4
1987	105.3	9.9	2000	221	–4.4
1988	108.9	3.4	2001	219.8	–0.5
1989	116	6.5	2002	235.6	7.2
1990	114.6	–1.2	2003	245.3	4.1
1991	123.8	8	2004	326.1	32.9
1992	136.7	10.4			

Note: Data for 1980–1999 are from Refs [3.2, 3.6]; data for 1999–2002 are from Ref. [3.7]; data for 2002–2004 are from Ref. [3.1].

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[2] This figure is often quoted in oral statements from Petrobras officers. No official evaluation has been published. A major difficulty is the way Petrobras presents its costs; usually, exploration and exploitation costs are combined.

(49 billion m^3), Bahia with 8% (26 billion m^3), and Espírito Santo and Rio Grande do Norte, each with 7% (22 billion m^3) [3.8].[3] There is too little information from Petrobras to be able to evaluate gas production costs satisfactorily. Up to 2002, natural gas was exploited as a by-product of oil. Only in Amazonia is natural gas being exploited as a main energy source. Nevertheless, the natural gas production volume is not negligible and has been around 16–20% of that of oil.

About two thirds of the gas reserves are located offshore, usually as associated gas (occurring with oil). The offshore proportion in production is also about the same. For technical and economic reasons, about 40% of the gas production in 2002 was re-injected or flared.

3.1.3. Coal

Brazilian coal reserves are modest by world standards and of relatively poor quality. Coal resources in Brazil covering the 1980–2003 period are shown in Table 3.4. These resources have increased steadily from 22.8 Gt in 1980 to over 32.3 Gt in 2003. Coal deposits of various qualities and quantities have been found in many areas in Brazil (e.g. Amazonia, Acre, Bahia, Minas, Pará), but the largest and lowest cost reserves are found in the south of the country (Rio Grande do Sul, 3.7 Gt; and Santa Catarina, 0.5 Gt) [3.9]. The largest reserves are located in the Candiota mine, in Rio Grande do Sul State, with about 23% of the country’s proven economic reserves.

The production costs of domestic coal make it more expensive than imported coal. Coal from only one mine-mouth generating station in Brazil, the Candiota, is able to compete in price with imported coal. High domestic production costs in the face of stable or declining world coal prices further limit the future exploitability of these reserves. For example, from 1990 to 2000, current prices for metallurgical coal fell from US $50–70/t to US $30–40/t, and prices of coal for energy use fell from US $35–50/t to US $20–30/t.

3.1.4. Hydropower

Hydropower has played a key role in the socioeconomic development of Brazil and is a major and mature industry; it was responsible for more than 90%

TABLE 3.4. COAL RESOURCES, 1980–2003 (Mt) [3.1, 3.2]

Year	Steam coal[a]	Metallurgical coal[b]	Total	Year	Steam coal[a]	Metallurgical coal[b]	Total
1980	21 331	1 483	22 814	1992	27 251	5 150	32 401
1981	21 331	1 483	22 814	1993	27 251	5 150	32 401
1982	21 346	1 483	22 829	1994	27 247	5 149	32 396
1983	21 403	1 483	22 886	1995	27 242	5 149	32 391
1984	21 470	1 483	22 953	1996	27 237	5 149	32 386
1985	25 600	5 393	30 993	1997	27 231	5 149	32 380
1986	26 555	5 892	32 447	1998	27 226	5 149	32 375
1987	26 555	5 873	32 428	1999	27 221	5 149	32 370
1988	26 555	5 866	32 421	2000	27 215	5 149	32 364
1989	26 543	5 850	32 393	2001	27 209	5 149	32 358
1990	27 265	5 150	32 415	2002	27 204	5 149	32 353
1991	27 260	5 150	32 410	2003	27 199	5 149	32 348

Note: Excludes peat resources, estimated at 487 Mt.

[a] Steam coal is produced in various forms, depending on its physical and chemical characteristics, with ash content varying from 20% to 54%, plus various concentrations of sulphur, volatile organic compounds, fixed carbon, etc.

[b] For domestic metallurgical coal, a calorific value of 6800 kcal/kg is used; 7300 kcal/kg is used for imported coal.

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[3] In 2003, Petrobras announced the discovery of a large offshore natural gas field on the coast of São Paulo State (see Table 3.3). This had major implications for the regional distribution of natural gas stated here, since until 2003, for example, Rio de Janeiro led the ranking with a 49% share [3.8].

of the electricity generated in the country during the 1990s. Brazil is the world's second largest producer of hydropower, after Canada. Favourable physical characteristics (i.e. the large extension of land, large rivers with huge hydropower potential and relatively low costs), combined with relatively modest reserves of oil, gas and coal, have made hydropower the overwhelming source of electricity in Brazil.

The technical hydropower potential in Brazil has been estimated at about 260 GW [3.10], of which about 25% (65 GW, including only 6 GW from the Itaipu hydropower plant) was being utilized in 2002 [3.11, 3.12]. The Amazon hydrological basin has the largest share of the total potential (40%), followed by the Paraná with 23%, Tocantins with about 11% and São Francisco with 10% of the total potential. Table 3.5 shows the distribution of hydropower plants according to capacity. Table 3.6 shows the hydropower potential in Brazil according to the main hydrological basins. Much of this technical potential remains untapped, and despite uncertainties (e.g. possible climatic changes, increasing doubts about the potential economic contribution from the Amazon basin and the already overwhelming dependence on hydropower), hydropower will continue to be a major source of electricity generation in Brazil for decades to come.[4] It is important to consider that, even in western European countries where no conventional hydropower plants have been constructed in the past 20 years, the installed capacity represents around 60–70% of total technical potential. This indicates that economic potential (influenced by environmental and social costs) sets an upper limit

TABLE 3.5. DISTRIBUTION OF HYDROPOWER PLANTS ACCORDING TO CAPACITY, JANUARY 2002 [3.11]

Capacity range (MW)	Number of plants	Installed capacity (MW)	Percentage of total
Up to 30	337	1 509	2.4
31–100	29	1 776	2.7
101–500	36	9 219	14.9
501–1000	8	5 365	8.7
Over 1000	23	44 260	71.4
Total	433	62 129	100

Note: Total capacity changes constantly as new plants become operational, old plants are withdrawn or capacity is reduced, and hence estimates often vary.

TABLE 3.6. HYDROPOWER TECHNICAL POTENTIAL ACCORDING TO MAIN HYDROLOGICAL BASINS, 2000 [3.11]

Hydrological basin	Inventoried		Remaining uninventoried[a]		Total	
	MW[b]	%	MW[b]	%	MW[b]	%
Amazon	31 809	19.4	73 510	77	105 319	40.5
Tocantins	24 831	15.1	2 709	2.8	27 540	10.6
Atlantic–North–Northeast	2 047	1.2	1 355	1.4	3 402	1.3
São Francisco	23 847	14.5	2 472	2.6	26 319	10.1
Atlantic East	12 037	7.3	2 055	2.2	14 092	5.4
Paraná	51 706	31.4	8 670	9.1	60 376	23.2
Uruguay	10 903	6.6	2 434	2.5	13 337	5.1
Atlantic–Southeast	7 327	4.5	2 290	2.4	9 617	3.7
Total	164 507	100	95 495	100	260 002	100

[a] Of national total.

[b] Correlation between installed capacity, quoted here in MW, and the amount of electricity generated, quoted in GW·year in Table 3.1, is obtained assuming a utilization factor of 55% of the time for the installed capacity.

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[4] For example, in 2001 there were electricity shortages in some regions of Brazil as a result of water shortages that precluded full operation of hydropower plants (see Chapter 8 for a detailed discussion).

for installed capacity. If this value were applied to Brazil, it would imply an economic potential of around 160 GW, of which around 80 GW have already been developed or are under construction.

Plans exist to expand hydropower considerably. Some 20 hydropower plants are under construction, with an installed capacity of 6284 MW. Expansion of existing large hydropower plants as well as construction of new plants being considered may add a total of 15.4 GW of hydropower capacity in the next few years. Of the planned new capacity, the largest percentage (36%) corresponds to the Tocantins hydrological basin, followed by the Uruguay basin (24%). To put the cost of this construction into perspective, from 1970 to 1997 Brazil invested a total of US $220 billion (in 2002 dollars) in the electricity sector [3.13]. Of this, some 59%, or US $130 billion, is estimated to have been for generation, more than 90% of which was in hydropower. Roughly dividing this total investment by the total incremental installed capacity of 50.5 GW, the unit cost for new hydropower capacity was about US $2570 (in 2002 dollars) per kilowatt.

Another possibility is to modernize existing hydropower plants, for example, installing more efficient adjustable speed generation turbines or expanding existing capacities. It is estimated that hydropower plants over 20 years old could generate some 1–8 GW of additional energy at costs far below (i.e. between US $100/kW and US $300/kW) the costs of building new hydropower plants (see Chapter 2).

One problem with hydropower is its concentration in the north of the country, far from the main consumption areas (e.g. 114 GW, approximately 44%, is located in the Amazon hydrological basin, and 26 GW, or 10%, is located in the Northeast region). Amazonia is generally flat, which means large areas need to be flooded for each hydropower plant. The best sites can provide reasonable power density, for example, the 4245 MW Tucuruí Dam (which is being expanded to 8370 MW) with 1.48 W/m^2 (2.91 W/m^2 in the future) [3.14]. However, there are examples of extreme inefficiency; for instance, for the 250 MW Balbina Dam, near Manaus, 2346 km^2 were flooded, giving a power density of 0.10 W/m^2. [5]

In addition, long distances involve high transmission costs as well as high losses. Since most of the economically feasible hydropower resources closer to the main consumption areas have already been exploited, any major new scheme could have significant environmental implications and additional costs for transmission infrastructure expansion.

3.1.5. Uranium

Uranium reserves are concentrated mostly in Minas Gerais, Bahia and Ceará States. Other uranium deposits have been found in Pitinga (Amazonas) and Cajaras (Pará) (see Table 3.7). Approximately 25% of Brazil's territory has been thoroughly explored for uranium; therefore, it is highly likely that new uranium deposits will be found in the future [3.15].

The largest uranium deposits are located in Itataia (Ceará), with over 142 000 t, although to be economically viable they must be produced simultaneously with phosphoric acid, used in the production of fertilizers. In any case, existing reserves are large enough to supply the domestic market and allow for exports.

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[5] Hydropower supporters hold that, given the fact that modest power density is acceptable in many parts of the world, the same principle should apply to Amazonia, despite its large area and low population density.

TABLE 3.7. PROVEN AND ESTIMATED URANIUM (U_3O_8) RESERVES (kt), 2001 [3.15]

Deposit/mine	Reserves at US $40/kg uranium	Reserves at <US $80/kg uranium	Sub-total	Inferred reserves at <US $80/kg uranium	Total
Caldas (Minas Gerais)	—	500	500	4 000	4 500
Lagoa Real/Caetite (Bahia)	24 200	69 800	94 000	6 770	100 770
Itataia (Ceará)	42 000	41 000	83 000	59 500	142 500
Other	—	—	—	61 600	61 600
Total	66 200	111 300	177 500	131 870	309 370

The development of nuclear energy will depend on many factors, including world energy developments, cost reductions, the existence of alternatives, environmental and policy considerations. New technological developments are likely to make nuclear energy a more reliable alternative in the future, both environmentally and economically. Uranium resources are not expected to pose any restriction on nuclear power development in Brazil over the next 20–30 years.

3.2. NON-CONVENTIONAL ENERGY RESOURCES

Brazil has a wide variety of non-conventional fuels available and has reasonably well developed technologies for their use, primarily for electricity generation. While these resources are described in greater detail below, it is worth noting here their economic potential compared with more conventional resources (see Table 3.8).

3.2.1. Biomass energy in Brazil

A distinguishing characteristic of Brazil is the large industrial scale development and application of biomass energy technologies (see Ref. [3.17]). Good examples are the production of ethanol from sugar cane and of charcoal from eucalyptus plantations, the cogeneration of electricity from bagasse, and the use of biomass from the pulp and paper industries (sawdust, black liquor, etc.). Brazil's use of biomass is the result of a combination of factors, including the availability of cheap biomass resources and cheap labour, rapid industrialization and urbanization, and historical experience with large scale industrial applications of biomass energy.

TABLE 3.8. COST COMPARISON OF NEW ELECTRIC GENERATING PROJECTS FROM VARIOUS ENERGY SOURCES [3.16]

Source	Potential (GW)	Generation costs (US $/MW·h)
Biomass	27.7	38–78
Wind	28.9	39–84
Coal	17.5	50–65
Natural gas	—	38
Imported coal	—	49
Imported natural gas	—	47

Brazil is in a position to increase its use of biomass energy, offering considerable potential for energy diversification. A large extension of land is available for expansion of planted forests and cultivation of energy crops, with a limited impact on food production. The Cerrados alone,[6] with vegetation similar to that of savannahs, add more than 100 million ha to the land available for biomass production. This area has just started to be exploited, mainly for soybeans, which are grown on less than 10% of the Cerrados. According to the National Electricity Regulatory Agency (ANEEL) [3.11], in January 2002 there were 159 biomass based thermoelectric plants with an installed capacity of 992 MW, or 8% of the country's thermal power.[7] The majority of these plants — accounting for approximately 952 MW and located mostly in São Paulo State — use sugar cane bagasse. There are four plants with a combined installed capacity of 25.5 MW that use residues from the timber industry, and three other plants (14.4 MW) that burn rice residues.[8] In total, there are some 19 new biomass based projects that will add a further 105 MW to the total biomass based power sector [3.11].

A recent survey of biomass residue costs carried out by the Brazilian Reference Centre on Biomass (CENBIO) of the University of São Paulo provided costs of some biomass energy resources, as shown in Table 3.9.

3.2.2. Fuelwood

Brazil has the world's largest reserves of natural forests, with about 670 million ha out of a total land area of 851 million ha, including 300 million ha of broadleaves. This represents an enormous fuelwood potential. It is estimated that a

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[6] Cerrado is formed by vegetal formations of variable aspects and physiognomy, mainly of small and twisted trees that become covered by creeping plants. Cerrados originally covered around one fourth of Brazil's territory and are among the richest ecosystems on Earth.

[7] The real figure is even higher, since there are more than 300 sugar mills in operation. Data from ANEEL are based on officially registered power plants, and some sugar mills were not yet officially registered as power producers.

[8] This survey included only half the sugar mills in the country — that is, about 165 of Brazil's 330 mills.

TABLE 3.9. ESTIMATED COSTS OF MAJOR RESIDUES, 2003 [3.18]

Type of residue	Cost		Remarks
	Brazilian reals/t	US $/t	
Sugar cane	20	7.07	Estimated general costs
Rice husks	38	13.44	Condensed residues
Residues from forest plantations	22	7.78	Residues from sawnwood from forest plantations
Residues from native forests	27	9.55	Residues from sawnwood from native Amazonian forest
Residues from timber mills	27	9.55	

Note: 1 Brazilian real = US $0.3537.

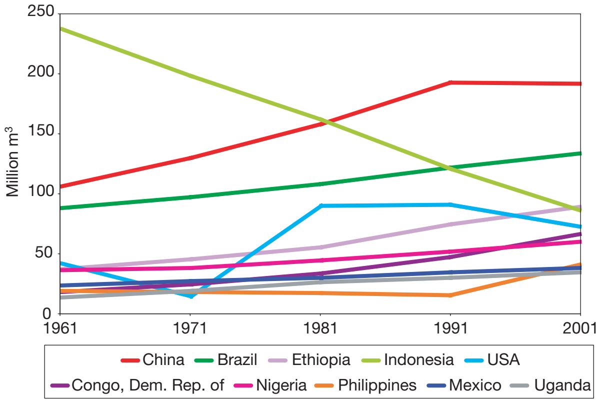

FIG. 3.2. Fuelwood production in major fuelwood producing countries, 1961–2001 [3.19].

minimum of 400 Mt/year or 8 EJ/year (all sources)[9] of fuelwood could be available nationwide on a sustainable basis. Production in Brazil is well below this estimate and is modest compared with that of other countries (see Fig. 3.2). In practice, however, this potential may remain largely untapped for the following reasons:

- Demand for traditional fuelwood is declining rapidly in Brazil, as better and cheaper alternatives become more available.
- Large scale use of fuelwood would only be possible in advanced combustion or gasification plants. However, these plants are more likely to use fuelwood from plantations rather than from natural forests.
- In most cases, large scale use of fuelwood from natural forests probably will not be economically feasible because of the long distances to the main demand centres, unless the fuelwood is used to supply small centres or industries.
- Environmental and ecological limitations exist, such as the limited availability of suitable good land.
- There are high financial and capital costs.

Fuelwood and timber production and other related activities employed about two million people in Brazil in 2001, including half a million on plantations. The forestry industry represents 4.5% of Brazil’s gross domestic product, equivalent to about US $28 billion [3.20]. Table 3.10 shows total wood production and consumption in the main sectors for energy purposes only. Fuelwood is widely used in many cottage industries — for example, by approximately 7000 ceramic producers — although at low efficiencies.

3.2.3. Charcoal

Brazil is a highly efficient producer of large scale industrial charcoal, with biomass to charcoal conversion efficiencies ranging from 30% to 35%, particularly from plantations (see Table 3.11). Traditional charcoal production was primarily from forestry residues resulting from the expansion of agriculture and pastureland, and from waste from wood processing, sawmills and the thinning of forests. In recent years, however, charcoal production has increasingly become a professional activity, with most charcoal being produced from dedicated plantations. For example, in 2000 about 72% of charcoal was produced from eucalyptus plantations, compared with 34% in 1990 [3.21]. Approximately 25.4 million m^3 (6.35 Mt) of

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[9] This figure assumes 1 t of fuelwood per hectare per year, collected on a sustainable basis, and 20 GJ/t.

TABLE 3.10. TOTAL PRODUCTION OF WOOD AND CONSUMPTION FOR ENERGY PURPOSES ONLY, 1985–2002 (kt) [3.1, 3.6]

Year	1985	1990	1995	1999	2000	2001	2002
				Production			
Total	106 252	92 091	75 066	69 478	70 222	70 768	76 274
				Energy use			
Households	34 735	25 687	19 710	20 893	21 415	22 263	24 767
Agriculture	8 500	7 000	6 081	5 562	5 394	5 718	5 790
Industry	20 511	17 386	16 016	17 186	17 536	17 098	15 932
Total	64 289	50 459	42 098	43 912	44 610	45 345	46 699

Note: Energy use totals include wood that could not be clearly attributed to any one sector.

charcoal were used in 2001 in steel making, metallurgy, cement production, etc.

3.2.4. Utilization of residues from agriculture, forestry, livestock and municipal solid waste

Table 3.12 summarizes the recoverable residues from the main commercial crops and forestry. Except for bagasse, only a very small proportion of these residues is used for energy purposes. This is due to a combination of factors, including the availability of cheaper alternatives, the lack of commercially available technologies for residue collection, the high cost of baling and transport, and a lack of tradition. However, this situation could change with better technologies, greater institutional support, increased environmental pressures, etc.

Brazil generates a considerable amount of forest residues (timber, furniture, clearings, pulp and paper, etc.). However, there is no nationwide inventory, and thus only partial estimates are possible. For example, Paim [3.20] estimates that the forestry sector uses about 166 million m^3 (around 44.5 Mt) of wood annually, 60% of which comes from plantations.

With over 1.5 million ha of plantations (see Table 3.13), the pulp and paper industry generates the equivalent of almost 5 million toe of residues, which are currently largely wasted. For example,

TABLE 3.11. CHARCOAL PRODUCTION IN BRAZIL, 1990–2000 (10^6 m^3) [3.21]

Year	Charcoal from natural forests*	Percentage of total production	Charcoal from plantations	Percentage of total production	Total
1990	24.35	66.1	12.54	34	36.9
1991	17.86	57.7	13.1	42.3	30.97
1992	17.82	61.1	11.35	38.9	29.2
1993	17.92	56.5	13.77	43.5	31.7
1994	15.18	46	17.82	54	33
1995	14.92	48	16.16	52	31.08
1996	7.8	30	18.2	70	26
1997	5.8	25	17.8	75	23.6
1998	8.6	32.6	17.8	67.4	26.4
1999	8.07	30	18.83	70	26.9
2000	7.2	28.3	18.2	71.7	25.4

* Still significant, as charcoal continues to be produced illegally from native forests.

TABLE 3.12. MAIN COMMERCIAL CROPS AND COMMERCIAL RESIDUE PRODUCTION

Crop	Planted area (10^6 ha)	Average productivity (t/ha/year)	Annual production	Type of residue	Quantity of residues (t/ha/year)	Total amount of residues (Mt/year)
Sugar cane[a]	4.5–5	60–80[b]	270–300 Mt	Bagasse	20	90–100
				Barbojo	20	90–100
Eucalyptus[a]	3.0[c]	30 m^3	90×10^6 m^3	Bark	14.7 (every 7 years)	6.8
Pinus species[a]	1.7	24 m^3	41×10^6 m^3	Bark	18.4 (every 14 years)	2.2
Rice[d]	3.1	3.2 t	9 Mt	Husks	2.00	6.3[e,f]
Maize[d]	12.3	3.3 t	41.4 Mt	Trash, cobs	2.24	29[e,f]
Soybeans[d]	13.9	2.7 t	37.7 Mt	Straw, etc.	1.89	26.4[e,f]
Wheat	1.7	1.9 t	3.2 Mt	Husks	1.33	2.4[e,f]

Note: The values given in this table are indicative only.

[a] Data from Ref. [3.22].

[b] The average productivity in São Paulo State is 79 t/ha/year.

[c] Excludes eucalyptus for the production of charcoal.

[d] Data for 2001 from Ref. [3.23].

[e] Based on a recoverable residue ratio of 0.7 t per tonne of grain harvested.

[f] CENBIO estimates are 1.8 Mt per year for rice, 55 Mt per year for maize, 48 Mt per year for soybeans and 2.6 Mt per year for wheat.

Eletrobras [3.25] has estimated the technical cogeneration potential at 1.7 GW in 2003, compared with 600 MW of installed capacity.[10]

Given its large size, there is considerable potential for using residues from the livestock industry in Brazil, at least in theory. However, little use of this potential is being made owing to the nature of the livestock produced (i.e. cattle ranching) and the existence of other, possibly cheaper alternatives. The most promising is the poultry sector, which is a major industry. Although there are no overall detailed nationwide studies, this potential could be well over 100 MW.

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[10] Technical potential is the part of the thermodynamic potential that can be used. According to Eletrobras [3.25], the total amount of electric generating capacity is 1189 MW.

TABLE 3.13. AREA OF PLANTATIONS FOR THE PULP AND PAPER AND CELLULOSE INDUSTRY, END OF 2000 (ha) [3.24]

State	Eucalyptus	Pinus	Araucaria	Acacia	Other	Total
Amapá	61 771	33 823	—	2 650	878	99 122
Bahia	303 754	5 711	—	—	—	309 465
Espírito Santo	115 940	31	—	—	—	115 971
Maranhão	5 465	—	—	—	—	5 465
Mato Grosso do Sul	56 478	—	—	—	—	56 478
Minas Gerais	150 975	2 890	446	—	1 923	156 234
Pará	40 355	2 429	—	—	—	42 784
Paraná	44 812	201 958	7 652	—	110	254 533
Rio Grande do Sul	43 895	8 801	603	7	51	53 357
Sta. Catarina	7 803	100 906	875	—	33	109 617
São Paulo	312 939	35 913	79	—	314	349 245
Brazil	1 144 187	392 462	9 655	2 657	3 309	1 552 270

Brazil has been struggling unsuccessfully for years to enact a law on municipal solid waste (MSW) to provide incentives to recycle waste through the Programa Brasileiro de Reciclagem (PBR). The country has one of the highest indices of waste recycling in the world (approximately 80%), largely linked to poverty. For example, it is estimated that about one million people make their living by collecting urban residues. Data from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatistica — IBGE) show that, in 2000, about 125 000 t of residues were collected in Brazil each day. Collection varied between 0.45 and 0.70 kg per person per day in towns with up to 200 000 inhabitants, and between 0.8 and 1.2 kg per person per day in cities with over 200 000 inhabitants. Approximately 70% of the collected MSW received some kind of treatment, and the rest was left untreated in landfills, although estimates vary.

Production of biogas seems to be one of the most promising alternatives for disposing of MSW in Brazil because of the large component of organic matter (over 50%). Biogas plants are becoming an increasingly popular option for waste management where several types of raw material (e.g. animal manure, crop residues, industrial wastes, sewage) can be combined in a single digestion plant. However, the main driving force is not energy but the necessity of addressing environmental and sanitary problems posed by excess manure, water pollution, urban waste, etc.

Currently there are very few MSW projects in Brazil; the main interest is within universities and research centres linked to agricultural sectors concerned with the disposal of residues or the production of biofertilizers. In the metropolitan area of São Paulo there are two MSW based projects to recover biogas to generate electricity, with capacities of 40 and 60 MW, and the Companhia de Saneamento Basico do Estado de São Paulo (SABESP) has a project to produce 2.0–2.6 MW of electricity from biogas. CENBIO has estimated the potential of electricity generation from biogas from MSW at between 300 and 500 MW [3.26]. With the introduction of small scale units together with new incentives provided by the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC),[11] this potential could increase significantly.

3.3. DEDICATED ENERGY FORESTRY/CROP PLANTATIONS

There are two main views with regard to energy forestry/crop plantations. There are those who believe such plantations will be established largely in industrial countries where there is surplus land (excess and underutilized) not needed for food production, capital, skills, greater environmental pressure, etc. Then there are those who believe that tropical developing countries are the prime candidates for plantations owing to the higher productivities and lower costs, particularly in cleared and degraded lands, forestland occupied by low value commercial species, the possible use of carbon credits, etc.

There is remarkably little experience with large scale energy plantations. Exceptions are eucalyptus grown for charcoal production and ethanol made from sugar cane in Brazil, and willows used for heat and power generation in Sweden. Ethanol from maize in the United States of America and rapeseed oil in the European Union can hardly be classified as coming from plantations, since energy production is not the primary objective.

In Brazil, the early plantations also followed traditional practices. However, more recently forestry management practices have been targeted specifically at charcoal production. In the 1970s, a concept emerged in charcoal oriented plantations called ‘energy forest’, which uses closer spacing between tree rows and young cutting — for example, spacing might be about 1.0 m × 1.5 m (approximately 5000 trees/ha), with cutting every four years.

The current trends are to use wider spacing to facilitate mechanical harvesting (e.g. Mannesmann uses 3 m × 3 m),[12] and cutting cycles of seven years if the plantations are intended for charcoal production. Another difference is the type of species planted. Species with high wood densities that adapt well to the poorer and drier soils of the areas where most eucalyptus plantations are found are preferred, for example, *Eucalyptus camaldulensis, E. urophyla, E. closesiana* and *E. citriodora* [3.17].

Overall, it seems that projections concerning large scale energy plantations are unlikely to be achieved; a more likely global scenario would be between 300 and 500 million ha [3.27]. There are various reasons for this:

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[11] For more information, see www.unfccc.int

[12] See www.shortrotationcrops.com/

- Reduced attractiveness of degraded land owing to higher costs and lower productivity;
- Capital and financial constraints, particularly in developing countries;
- Cultural practices, mismanagement, perceived and potential conflict with food production and population growth;
- Productivity that will have to increase far beyond what may realistically be possible, although large increases are possible;
- Increasing desertification problems and potential impacts of climate change in agriculture, which are currently too unpredictable;
- Emerging energy alternatives;
- Water constraints.

The combination of all these factors will severely limit large scale development of dedicated energy plantations. Even so, and depending on biomass yields, a significant amount of energy can be obtained from 300–500 million ha [3.28]. Also, if the production of liquid biofuels from cellulose containing material becomes economically feasible, interest in planted forests could change significantly. It would make more sense to concentrate efforts on high productivity crops such as sugar cane. Brazil is in a favourable position because the country has good quality land available, its climate conditions are suitable and it has experience; for example, there are over 6 million ha of plantations for pulp and paper and charcoal production in Brazil. There is, undoubtedly, considerable potential for further expansion of energy plantations, and this merits careful consideration. Table 3.14 shows costs of delivered feedstock and average productivity of dedicated energy plantations in several countries, including Brazil.

3.4. OTHER RENEWABLE SOURCES OF ENERGY

As most of the technologies treated in this section are still emerging, it is difficult to foresee whether they will succeed. The Federal Government has initiated a programme in support of renewable energy projects known as PROINFA.[13] The overall aim is to build 3.3 GW of capacity based on biomass, small hydropower and wind in the first phase, which should be in full operation by the end of 2006. Eletrobras will purchase this energy through a special 20-year agreement at a price higher than that of conventional energy.

3.4.1. Solar

Because of its geographical location, Brazil receives a large amount of solar radiation year-round (on average about 230 W/m^2), with much higher radiation in the Northeast region (e.g. 260 W/m^2 in the Rio São Francisco Valley). In recent years, there have been concerted efforts to take advantage of this energy potential by both the Government and the private sector, particularly through the Energy Programme for Small Communities (PRODEEM).[14] For example, photovoltaics (PV) were being used by about 3000 communities by the end of 2000 and by about 6000 schools by the end of 2002. The target for 2003 was

TABLE 3.14. COSTS AND AVERAGE PRODUCTIVITY OF DEDICATED ENERGY PLANTATIONS IN SELECTED COUNTRIES [3.29]

Country	Costs of delivered feedstock (US $/GJ)	Average productivity (dry t/ha/year)
USA (mainland)	1.90–2.80	10.0–15.5
USA (Hawaii)	2.06–3.20	18.6–22.4
Portugal	0.00–2.30	15.0
Sweden	0.00–4.00	6.5–12.0
Brazil (Northeast)	0.97–4.60	3.0–21.0
China (Southeast)	0.00–0.60	8.0
Philippines	0.42–1.18	15.4

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[13] PROINFA was introduced in 2002 under Law No. 10438.

[14] PRODEEM was set up in December 1994 and modified under Decree No. 3746 of 6 February 2001 as the Programa Energia das Pequenas Comunidades.

set at 9000 communities, but the actual achievement has not yet been confirmed. Altogether, there are about 6000 projects and nearly 3000 kWp installed as a result of this programme.[15]

In mid-2003, the installed capacity of PV systems was estimated at 20 MWp. Fraidenraich [3.30] estimates that an additional 115 MWp could be installed during the next 10–15 years at a cost of about US $1.2 billion, a unit cost of some US $10 000/kWp installed. He further estimates the current cost of solar energy to be between US $0.12 and US $0.20/kW·h, falling by half in the near future [3.30]. This is very expensive compared with other energy sources. Nonetheless, people living in rural areas currently without access to electricity would receive the benefits of such an investment. There are a large number of small projects with a variety of applications that can be grouped into the following categories:

- Water pumping for domestic use, small irrigation projects and fish ponds;
- Lighting in small communities and individual households;
- Public lighting in schools, health centres, community centres, etc.;
- Telecommunications.

3.4.2. Wind power

Wind resources can best be exploited where wind power density is at least 400 W/m^2 at 30 m above ground or 500 W/m^2 at 50 m above ground (7.0 and 7.5 m/s, respectively). Wind speed in Brazil varies considerably, with the Northeast region and the coastline of Rio Grande do Sul being the most promising; less favourable regions are the North region and some parts of the interior. For the Northeast region, wind speed varies from 3–6 m/s in sheltered terrain to 4.5–7.5 m/s in open plain to 8.55 m/s along the coast to 7–11.5 m/s in hill ridges.[16] With new wind technology developments such as variable speed, improved aerodynamics, lighter materials and increased turbine power, it will be possible to exploit wind power at much lower densities in the near future. Global wind energy potential has been studied in some detail; it ranges from 19 000 to 500 000 TW·h/year [3.31]. Wind power has been one of the fastest growing energy technologies around the world in recent years. Wind generation costs have declined steadily over the past decade, and this trend is expected to continue.

The wind potential in Brazil has been estimated at between 20 and 145 GW; the most widely accepted figure is 60 GW. The largest potential is in the Northeast region, which is one of the poorest regions in terms of energy resource endowment, as shown in Table 3.15.

It seems that wind power may finally take hold in Brazil as a result of investment already committed, mostly triggered by PROINFA, which received proposals above the target set for the wind share of the programme (1100 MW). Through PROINFA, around 70% of the investment will be financed by the Brazilian National Development Bank (BNDES). ANEEL has authorized more than 6 GW from wind power,[17] but most of this potential will not be installed owing to a shortage of capital and economic infeasibility. Also, it should be noted that, compared with hydropower or thermal power, wind power generation can be expanded more quickly and less expensively, should the need arise. One of the problems facing wind power in Brazil is

TABLE 3.15. ESTIMATED WIND POWER POTENTIAL BY REGION [3.32]

Region	Capacity (GW)	Potential power generation (TW·h)	Utilization factor (%)
North	12.84	36.45	32.4
Northeast	75.05	144.29	21.9
Midwest	3.08	5.42	20.1
Southeast	29.74	54.93	21.1
South	22.76	41.11	20.6
Total	143.47	282.20	21.7

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[15] ANEEL is currently updating the solar potential; for more information, see www.aneel.gov.br/

[16] For more information, see www.cresesb.cepel.br/

[17] For more information, see www.mct.gov.br; see also Ref. [3.33].

that investors are unlikely to undertake a new installation until the Government guarantees some kind of initial subsidies. Through the most promising programme, PROINFA, the Government is proposing to purchase electricity from wind farms at US $43/MW·h.

There are just 23 MW of wind power installed capacity in Brazil, corresponding to a very small share of the total power capacity. The capacity connected to the grid is estimated at 20.3 MW, all through wind mills of medium to high capacity. This technology is available in Brazil, but it relies on international manufacturers. It has been estimated that about 28 900 MW of wind potential can be exploited at a cost in the range of US $39–84/MW·h [3.16].

3.4.3. Small hydropower

In the past, the Federal Government favoured large hydropower schemes, for the most part ignoring small hydropower (less than 30 MW installed capacity according to Brazilian legislation). But as most of the economically feasible large dams have already been built, the attention is now shifting to small scale hydropower, particularly in rural areas.

Recent institutional changes introduced in the energy market favour the construction of small hydropower plants. For example, small hydropower plants of less than 5 MW stand to benefit directly through PROINFA. The law foresees a reduction of 50% of the transmission and distribution tariffs; in addition, it allows the direct sale of electricity to consumers if production is 500 kW or less. Other benefits include exemption from State and municipal taxes and the possibility of building such plants without going through complicated open tenders.

Existing small hydropower plants account for almost 1.3 GW of installed capacity. In the short term, an additional 4.0 GW received initial permission for implementation in the 1988–2005 period and 0.6 GW are under construction [3.34]. Based on such figures and considering the lack of information about all possible sites, it is reasonable to accept the total small hydropower potential to be around 9.5 GW.

It is estimated that the typical unit cost of small hydropower plants in Brazil ranges from US $1100/kW to US $1500/kW, including environmental studies [3.35].

3.4.4. Geothermal

There are indications of some geothermal energy resources in Brazil. During oil exploration in the 1980s, many sites with geothermal potential were identified in São Paulo State, but the potential has not been estimated. This energy source is not expected to play any significant role in meeting future energy requirements in Brazil.

3.5. MAIN ISSUES AND FUTURE PROSPECTS FOR BRAZIL

As has been shown in this chapter, Brazil has extensive natural energy resources, both renewable and non-renewable, although oil and natural gas are relatively limited given the current and expected future demand for these resources.

Brazil is unique in the sense that renewable energy already makes a major contribution to the primary energy portfolio (around 40% in 2001), and its contribution could be increased significantly by 2025. Within this context, one of the most promising alternatives is biomass energy, particularly from residues (bagasse and forestry) and plantations, which already make a significant contribution. The possibility of cofiring of biomass, particularly with coal and natural gas, should be considered. This technology is advancing rapidly at the global level, although not in Brazil. It is one of the most promising alternatives to large scale utilization of biomass. This technology has not yet caught the attention of utilities operating in Brazil

Hydropower, which today is responsible for more than 80% of Brazil's electricity generation, still has room to grow. New hydropower plants are planned or are already under construction, including very large units. The prospects for further expansion remain good, although less so for the large units. Environmental, social and economic barriers will probably limit future hydropower installations to medium sized and small units.

Due to its favourable geographical situation, Brazil has a very large solar energy potential, but the country is technologically behind the leading countries; at the same time, the installed capacity remains quite low. It seems that the development of such potential will be largely dependent on technological advances in the international market.

The potential for wind power is also large, but there is still considerable disagreement regarding its actual potential contribution to the energy matrix owing to the lack of reliable data. However, favourable Government policies combined with rapidly falling costs of wind power around the world make this option an attractive one. With support from international capital, wind energy can play a significant role in Brazil within a decade, particularly in the Northeast.

A clear policy in support of renewable energy and energy sustainability is needed. Efforts like PROINFA are extremely useful, but they cannot yet guarantee successful and continuous expansion of renewables. More studies are necessary to motivate decision makers to become aware of the large potential of new and renewable sources of energy.

Nuclear energy is the subject of continual political discussion, but progress has been slow and there is no reason to expect different behaviour in the next two decades. Fundamental changes in policy and social attitudes will be required if nuclear is to play a larger role in Brazil's sustainable energy matrix.

In summary, resource availability is not the real limitation to a sustainable energy future; rather, it is the increasing societal demand for environmentally sustainable fuels at affordable costs, whether or not the energy sources are renewable. Current socioeconomic development, demanding ever increasing amounts of finite energy resources, is not sustainable, and thus maintaining the present energy intensity and energy portfolio is not the answer. It is clear that considerably more products can be manufactured using far less energy, and that there are other sustainable energy alternatives that are socially and environmentally more acceptable. Such alternatives need to be pursued more vigorously if a more sustainable path is to be achieved.

Brazil is very fortunate because its resource base is large enough to allow considerable energy flexibility and thus is less vulnerable to international fluctuations, although in an increasingly global market there will always be a strong international interdependence. This interdependence is not limited simply to energy, but also encompasses trade, politics, technology, economics and finances.

During the preparation of this report, it became clear that there are limitations with respect to energy planning activities that need to be addressed, in particular the quantity and quality of energy related data. The availability of long term, consistent, reliable data is a fundamental prerequisite for sound decision making. There are various areas in Brazil where availability of information is particularly limited, including the following:

- *Biomass energy*: Brazil is a major consumer and has one of the world's greatest biomass potentials. With the exception of sugar cane, there is a considerable lack of consistent, reliable and up to date data on a nationwide scale about biomass's potential as an energy source. This is particularly the case with regard to residues, which Brazil produces in large quantities. Despite the difficulties, it is hoped that The Brazilian Atlas of Biomass Energy[18] will eventually become a truly effective source of information about biomass energy resources in Brazil.
- *Solar thermal/PV*: More and better data on the potential uses of these sources and better coordination among players are still required.
- *Wind*: The Atlas of Wind Power [3.32] is in the process of being updated, which hopefully will facilitate the assessment of the potential growth of wind energy in Brazil; so far there are large discrepancies with regard to estimates of the real potential of this energy source.

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Chapter 4

INDIGENOUS AND ADAPTED ENERGY TECHNOLOGIES AND ENERGY EFFICIENCY

S.T. COELHO, A. WALTER

Brazil has significant experience in the development and use of innovative technologies. This chapter presents and discusses general aspects of indigenous and adapted energy technologies in Brazil and analyses of energy efficiencies of selected technologies.

The most important technologies include sugar cane production and conversion to ethanol, hydropower, electricity transmission and offshore oil production.

4.1. SUPPLY TECHNOLOGIES

4.1.1. Sugar cane conversion

Brazil has long been one of the largest sugar cane producers in the world, but large scale ethanol production began only in 1975, when the Brazilian Alcohol Programme, PROALCOOL, was created with the goal of partially replacing gasoline in light transport. At that time, the country was heavily dependent on imported oil, and gasoline was the main oil derivative consumed.

For years, PROALCOOL has been the largest commercial biomass to energy system in the world. Despite some difficulties, the programme has succeeded regarding its primary goals, namely, the reduction of oil imports, the stabilization of the sugar market, the enhancement of Brazil's competitiveness in the sugar market and the creation of almost one million jobs as of 2002.[1]

Among its results, those related to the environment and sustainability — such as reduced deterioration of air quality in large cities and a substantial reduction of greenhouse gas (GHG) emissions — are important and should be highlighted.[2] These results were possible because of the technological developments achieved in both sugar cane and ethanol production. As a result of these developments, Brazil now sets the benchmark for ethanol production from sugar cane, and Brazilian industry is now highly competitive regarding equipment and services. The sections that follow present the main developments in the agricultural and industrial sectors.

4.1.1.1. Technology development in sugar cane production

Regarding ethanol production, 60–70% of the final cost of the product is the cost of the raw material itself — that is, the sugar cane. Thus, as far as economic competitiveness with gasoline is concerned, most of the cost reduction results have been achieved in the agricultural phase [4.1].

Agricultural yield and the amount of sucrose in the plant have a strong impact on the cost of sugar cane products. Agricultural yield is a function of soil quality, weather conditions and agricultural practices, and is also strongly influenced by agricultural management (e.g. the timing of planting and harvesting, and the choice of sugar cane varieties). By 1998, the average productivity in Brazil was around 65 t/ha [4.2], but it ran as high as 100–110 t/ha in São Paulo State [4.3]. Since the beginning of PROALCOOL, yields have grown about 33% in São Paulo State with the development of new species and the improvement of agricultural practices.

The development of sugar cane varieties aimed at increasing the sugar content in the sugar cane (expressed by the total reducing sugars (TRS) index[3]), developing disease resistant species, adapting to different soils and extending the crushing season [4.4]. As a result of this research and development (R&D) effort, the TRS index of sugar cane in Brazil has almost doubled since PROALCOOL began [4.2, 4.5].

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[1] This issue is discussed further in Chapters 7 and 9.

[2] See Chapter 6 for a discussion of the environmental and health aspects of Brazil's energy system.

[3] The TRS impacts sugar and alcohol production and thus is considered in the sugar cane cost.

Many of the results achieved in sugar cane agriculture are due to the introduction of machinery for soil preparation and conservation. Many operations have been mechanized over the past 20–25 years, but advances in harvesting are more recent. In the past five years in the Midwest, Southeast and South regions, about 35% of the area planted with sugar cane has been harvested mechanically, and about 20% has been harvested without previously burning the field.[4] Because of the lower costs associated with mechanized harvesting, in some regions up to 90% of the sugar cane is harvested mechanically. It is estimated that mechanized harvesting would allow a significant cost reduction per tonne of sugar cane [4.3].

Green cane harvesting requires the development of appropriate machines, taking into consideration the local topography and the way the sugar cane is planted. This development is necessary to ensure high performance in sugar cane recovery, lower costs, reductions in the amount of soil left on the sugar cane that is transported and low levels of sugar losses [4.4]. A number of appropriate harvesting machines have been developed in Brazil. One of the main projects in this area has been undertaken by COPERSUCAR with the support of the Global Environment Fund (GEF), aimed at identifying the best techniques for green cane harvesting and potential uses of the recovered biomass.

Gains in productivity and cost reductions have also been achieved with the introduction of operations research techniques in agricultural management and the use of satellite images for identifying varieties in planting areas. Similar tools have been used in decision making regarding harvesting, planting and application rates for herbicides and fertilizers.

4.1.1.2. Technology development in ethanol production

Throughout the evolution of PROALCOOL, different priorities have been defined regarding technological improvements in the industrial process of ethanol production [4.6]. Initially, the focus was on increasing equipment productivity. As a consequence, the size of Brazilian mills also increased, and some mills now have a crushing capacity of 6 Mt of sugar cane per year. The focus was then shifted to improvements in conversion efficiencies, an effort that continues today.[5] During the past 15 years, the primary focus has been on better management of the processing units. Altogether, since the mid-1980s the conversion efficiency of the industry has increased from 73 to 85 L, or from 1.6 to 1.9 GJ,[6] of ethanol per tonne of sugar cane processed.

A summary of the main technological improvements in the industrial process is presented in Table 4.1.

Environmental issues should be the focus of further improvements in the industrial process. For instance, water consumption is still quite high — on average 5 m^3 of water per tonne of sugar cane processed, with most values in the range of 0.7–20 m^3/t [4.7]. Finally, it is worth mentioning that reducing steam consumption to 350 kg per tonne of sugar cane processed, or even less, is necessary to allow for better use of the power cogeneration potential. Steam consumption in Brazilian mills is typically in the range of 450–550 kg per tonne of crushed sugar cane.

As a result of the technological developments achieved in both agriculture and industry, average production yields have grown from 3900 L/ha/year (87 GJ/ha/year) in the early 1980s to 5600 L/ha/year (125 GJ/ha/year) in the late 1990s. In the most efficient units, this parameter can be as high as 8000 L/ha/year (180 GJ/ha/year) [4.8]. Table 4.2 shows the production of alcohol distilleries grouped by State and region for the 2001–2002 season.

The consequence of such technological developments is that production costs have fallen remarkably since PROALCOOL began, as discussed below.

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[4] Sugar cane is usually burned in the field to allow higher throughput in both manual and mechanized harvesting. The burning process is fast and almost entirely eliminates the leaves and tops of the plant to allow manual harvesting.

[5] On average, the conversion efficiency (e.g. litres of ethanol per tonne of sugar cane) rose about 1% per year between 1985 and 1996.

[6] This value is based on the lower heating value (LHV) of anhydrous ethanol. Considering hydrated ethanol production, the range would be the same if the conversion efficiency were expressed as litres per tonne of sugar cane, but 5% lower on an energy basis; the LHV of anhydrous ethanol is 22.3 MJ/L and the LHV of hydrated ethanol is 21.3 MJ/L.

TABLE 4.1. MAIN TECHNOLOGICAL IMPROVEMENTS IN THE INDUSTRIAL PROCESS OF ETHANOL PRODUCTION [4.2, 4.6]

Process step	Actions	Average and best practice results
Juice extraction	● Increase in crushing capacity ● Reduction of energy requirements ● Increase in yield of juice extraction	● Extraction yield up to 97.5% (average yield around 96%)
Fermentation	● Microbiological control ● Yeast selection based on genetics and better yeast selection ● Large scale continuous fermentation, better engineering and better control of process	● Fermentation yield up from 83% to 91.2% (best practice 93%) ● Production time down from 14.5 to 8.5 hours (best practice 5.0 hours) ● Wine content up from 7.5% to 9.0% (best practice 11.0%) ● Reduction of about 8% on ethanol costs owing to continuous fermentation and microbiological control
Ethanol distillation	● Improvements in process control	● Average yield up from 96% in the early 1990s to up to 99.5% (result also influenced by higher ethanol wine content)
Sugar cane washing	● General improvements	● Reduction in water consumption ● Reduction in sugar losses (2% down to just 0.2% in some cases)
Industry in general	● Instrumentation and automation	● Impact on juice extraction, evaporation and fermentation, crystallization and steam generation

4.1.1.3. Cost reductions

Since PROALCOOL began, ethanol production costs have fallen 3.2% per year in the Midwest, Southeast and South regions and about 1.9% per year in the North and Northeast regions [4.10]. It was estimated that in 2001 production costs in a mill with good performance were around 0.45 Brazilian reals per litre [4.11], or about US $0.18/L.[7] However, by the end of 2003 production costs were estimated at just US $0.16/L, or US $7.2/GJ. The large scale use of existing technologies would allow an average reduction of production costs of about 13% over the next 5–6 years, resulting in costs of about US $0.14/L. At the beginning of 2002, it was estimated that the production of hydrated ethanol in the most efficient Brazilian mills would be competitive with gasoline for oil prices of about US $25/bbl — or about one fourth of the cost during the initial stages of PROALCOOL [4.7].

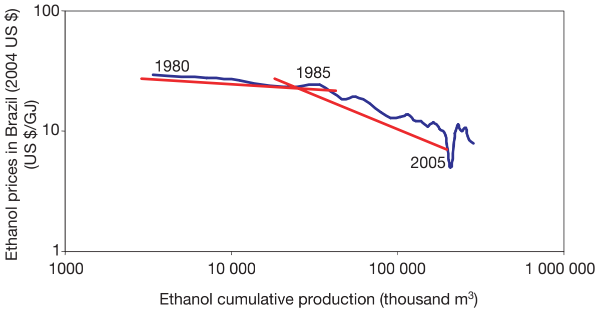

FIG. 4.1. Learning curve for ethanol production [4.1].

Figure 4.1 shows the ethanol learning curve from 1980 to 2005 [4.1]. The curve is based on prices paid to producers, which are a good indication of the production cost trend. The progress ratio[8] in the 1980–1985 period was 0.93, but it fell to 0.71 in the 1985–2005 period. The increase in the scale of production and pressures for cost reductions as a result of low oil prices and market deregulation explain the trend in the second period.

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[7] At that time, the exchange rate was 2.5 reals per US dollar.

[8] The progress ratio is defined as the ratio of unit costs after a doubling of cumulative production to the unit costs before the doubling.

TABLE 4.2. PRODUCTION OF ALCOHOL DISTILLERIES IN BRAZIL, 2001–2002 SEASON (m^3) [4.9]

State	Anhydrous ethanol	Hydrated ethanol	Total
Amazonas	963	1 703	2 666
Pará	14 048	10 945	24 993
Maranhão	65 714	9383	75 097
Piauí	5 507	13 169	18 676
Ceará	—	1 186	1 186
Rio Grande do Norte	46 592	33 273	79 865
Paraíba	87 832	138 774	226 606
Pernambuco	120 417	141 516	261 933
Alagoas	317 573	244 713	562 286
Sergipe	27 728	24 296	52 024
Bahia	32 898	21 514	54 412
Total: North and Northeast regions	719 272	640 472	1 359 744
Minas Gerais	331 438	193 003	524 441
Espírito Santo	76 299	54 721	131 020
Rio de Janeiro	23 960	40 832	64 792
São Paulo	4 239 200	2 879 691	7 118 891
Paraná	362 207	598 063	960 270
Santa Catarina	—	—	0
Rio Grande do Sul	—	5 306	5 306
Mato Grosso	276 007	304 120	580 127
Mato Grosso do Sul	225 201	171 320	396 521
Goiás	195 876	183 408	379 284
Total: Midwest, Southeast and South regions	5 730 188	4 430 464	10 160 652
Total: Brazil	6 449 460	5 070 936	11 520 396

Note: According to the Ministry of Agriculture, there are 387 sugar mills in Brazil, most of which are located in the Midwest, South and Southeast regions, mainly in São Paulo State.

As a consequence of the observed cost reductions, subsidies were fully eliminated by 1997 and are no longer applied for anhydrous or hydrated ethanol. Hydrated ethanol is sold to consumers in the range of 70–85% (by volume) of its break-even price vis-à-vis gasohol.

4.1.1.4. Technology development regarding ethanol use

In Brazil, ethanol is used as an oxygenate and octane enhancer for gasoline and in neat ethanol engines. In the first case, anhydrous ethanol (99.6 Gay-Lussac) is blended with gasoline in the proportion of 20–26% volume of ethanol.[9] All gasoline sold in Brazil is in fact gasohol. In the case of neat ethanol engines, hydrated ethanol (95.5 Gay-Lussac) is used. About five million automobiles with neat ethanol engines (and thus able to run on pure hydrated ethanol) have been produced in Brazil since 1979. The current share of these vehicles in the automobile fleet is estimated at about 18%. Moreover, since 2003, automobile manufacturers have been introducing so-called flex-fuel vehicles to the Brazilian market, with great success. These vehicles run on both hydrated

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[9] This is the range defined by national legislation. A specific regulation set by the National Petroleum Agency (ANP) defines a value in this range that then remains valid for a certain period. This tool for handling alcohol stocks has been used in the past when production was not able to meet demand. During 2003 and 2004, the blend level was set at 26 ± 1%.

ethanol and gasohol, in any blend. In 2005 there were 600 000 flex-fuel vehicles in Brazil, and the number of flex-fuel models available in the country is rising.

Ethanol is an excellent motor fuel. It has a higher octane number than does gasoline, and its vapour pressure is lower than that of gasoline, resulting in fewer evaporative emissions. Its flammability in air is also much lower than that of gasoline, reducing the risk of vehicle fires. Additionally, ethanol has no tendency to form gum, and antioxidants and detergent additives are not required. On the other hand, its metal corrosivity is higher than that of gasoline [4.12].

In general, the performance of neat ethanol vehicles is better than that of gasoline vehicles regarding power, torque and maximum speed, but worse regarding fuel consumption on a volume basis (about 25% higher[10]). Because of ethanol's higher efficiency, the fuel consumption of neat ethanol vehicles on an energy basis is lower than that of gasoline vehicles.[11] The multinational automotive industry based in Brazil has introduced all the necessary engine and vehicle modifications for ethanol use. For neat ethanol vehicles or for those using a blend with more than 25% ethanol, modifications include materials substitution (e.g. of the fuel tank, fuel pump and electronic fuel injection system) and new calibration of devices (e.g. of ignition and electronic fuel injection systems).

The new flex-fuel vehicles, with engines able to operate using different fuels or fuel blends, make use of a technology originally created in the 1980s to minimize the problems associated with the lack of distribution and supply infrastructure for methanol and ethanol in Europe and the United States of America. This technology has recently been developed for conditions in Brazil, resulting in a superior concept,[12] with the new flex-fuel vehicles proving to be better in terms of performance and fuel savings (owing to their higher compression ratios) and able to use up to 100% ethanol.

There is considerable optimism, as recent consumer resistance to buying neat ethanol vehicles has been mainly due to the fluctuations in the relative prices of ethanol and gasoline. For the vehicle manufacturers there is an opportunity for savings, as it is possible to avoid developing duplicate projects. In fact, some manufacturers have decided that, for some models, only flex-fuel engines will be available. For alcohol producers, flex-fuel vehicles mean greater flexibility in supplying fuel, allowing adjustments for seasonal harvest variations and opportunities in the sugar market. In 2003, flex-fuel vehicles cost around US $300 more to produce than similar ethanol or gasoline fuelled vehicles; however, the price for the buyer was the same for all three types of vehicle. The excess cost was absorbed by manufacturers, who expect future savings from handling only flex-fuel engines instead of both ethanol and gasoline engines.

Brazilian vehicle manufacturers are also developing tri-fuel engines, and some prototypes are already available. These engines are able to run on gasoline, ethanol or natural gas. The use of natural gas in light duty vehicles has been growing slowly but steadily owing to the considerable price advantage of natural gas compared with gasoline (US $0.35/Nm^3 [13] versus US $0.70/L for gasoline). This fleet is basically composed of converted vehicles, since original natural gas fuelled models are not yet available on the market. Converting the engines is a very simple process of installing a conversion kit. The main problem with such conversions is the use of unauthorized mechanics and kits whose quality has not been certified, which results in increases in atmospheric emissions compared with gasoline fuelled vehicles.

In the years to come, ethanol could be the fuel of choice for fuel cell power systems. Also, there is an effort in Brazil to develop ethanol reformer systems to allow ethanol's use in fuel cells [4.13].

4.1.1.5. Sugar cane bagasse and barbojo[14] utilization

Bagasse is the by-product of sugar cane crushing. The amount of bagasse produced is

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[10] Fuel consumption expressed in litres per 100 km.

[11] Owing to ethanol's higher octane number, neat ethanol engines have a higher compression ratio than do gasoline engines and, consequently, are more efficient.

[12] The technology is based on checking (directly or indirectly) the ethanol content in the gasoline blend. The ignition delay and the air–fuel mixture are adjusted according to the blend used in order to optimize engine operation.

[13] A normal cubic metre (Nm^3) is the volume of dry gas that occupies a volume of 1 m^3 at a temperature of 273 K and an absolute pressure of 101.3 kPa.

[14] Barbojo is the sugar cane trash, that is, the tops and leaves abandoned in the fields after harvest.

generally equivalent to about 25–30% (by weight) of the sugar cane.[15] It is used as fuel for cogeneration systems, ensuring energy supply self-sufficiency (thermal, mechanical and electric) in almost all existing sugar cane mills. In 2003, fewer than 10% of the existing mills were able to generate and sell surplus electricity to the grid — and those only during the sugar cane season.[16] This was equivalent to about 20% of the sector's installed capacity (close to 2000 MW for self-consumption).

For many reasons, the interest in producing surplus electricity from sugar cane bagasse was limited until the end of the 1990s.[17] However, investments have since risen steadily. Nonetheless, commercialization of power is still limited considering the existing potential, which is estimated at 4000 MW for year-round production from commercially available technologies and modest use of sugar cane residues alone.

Efficient technologies (high pressure boilers) for conventional steam systems are available in Brazil and are being implemented by the mills (replacing the old systems) to generate surplus electricity to be sold to utilities.

The role of electricity generation from biomass, and from sugar cane residues in particular, will be more important once the PROINFA law[18] — approved in 2002 to deploy electricity production from biomass, wind and small hydropower plants — is enforced. PROINFA ensures better prices for the electricity produced from these sources and a 20-year contract. It was expected that 3300 MW, divided equally among the three energy sources, would be installed in the first phase of the programme (up to the end of 2006). The long term aim of the programme is for 10% of the power generation in Brazil to be provided by renewable sources (excluding large hydropower plants). However, the biomass projects have achieved only 655 MW, owing to the low tariffs offered by the Government. In 2004, the remaining 455 MW were shared between small hydropower plants and wind energy.

Large scale electricity generation from sugar cane bagasse and residues would help to increase the diversity and further reduce the production costs of the traditional products of Brazil's sugar cane industry — sugar and ethanol. To give an example, one of the largest mills in the country earned 7% of its income from selling surplus electricity to the grid in the harvest season in 2001–2002. Moreover, the tariff paid for surplus electricity was relatively small, so the power sold was equivalent to just 20% of its electricity potential.

4.1.2. Other biomass conversion technologies

4.1.2.1. Charcoal[19]

During the second oil crisis, Brazil began an effort aimed at replacing imported coal with charcoal in the steel industry. Charcoal for steel and pig iron production requires a higher fixed carbon content and density than that used by households. Throughout the 1980s and early 1990s, many of these industries carried out their own R&D programmes aimed at developing new kilns for improving charcoal production. At that time, the main goal was to increase the yields of traditional discontinuous kilns with internal heating. Most of these development efforts were phased out by the mid- to late 1990s, because of the gradual reduction in coal prices.

MAFLA, the forest division of the Brazilian steel company Mannesmann, has developed a high capacity rectangular kiln. This kiln has a condenser that allows the recovery and further distillation of tar for producing high value by-products. Gases can also be recycled and used as fuel for the carbonization process. Compared with traditional kilns, this technology increases productivity and yields, improves charcoal quality and includes partial mechanization of the operation. Most of the rectangular kilns developed in Brazil are large enough to allow trucks to enter them, reducing the time required for loading and unloading.

A conceptually similar kiln was developed by the steel company Belgo-Mineira between 1991 and 1998. Results of their R&D programme show that,

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[15] Mass basis after crushing, with 50% moisture. The amount of bagasse depends on the sugar cane fibre content. Its LHV is in the range of 7.5–8.0 MJ/kg.

[16] Harvesting season is from May to November in the Midwest, Southeast and South regions, and from November to May in the North and Northeast regions.

[17] The most relevant reason for this lack of interest was institutional barriers, since before 1997 there was no obligation for utilities to buy electricity from independent power suppliers.

[18] PROINFA is Brazil's Alternative Energy Sources Incentive Programme.

[19] In this context 'charcoal' means 'sustainable charcoal' produced from wood from reforestation.

compared with traditional kilns, the new technology has lower initial capital costs and workforce requirements while producing charcoal of similar quality.

During the 1990s the steel company Acesita also developed a programme aimed at modernizing charcoal production and consumption. This programme included the development of a continuous carbonization retort — that is, a kiln in which heating is promoted by circulating gas. During tests, the measured yield was 35% (by weight), while the maximum yield for charcoal production (depending on the composition of the wood used) was estimated at between 44% and 55% (by weight, dry basis) [4.14]. The same company has developed a rectangular kiln with charcoal production costs 15% below those of traditional kilns. As part of the same R&D programme, in the mid-1990s the company developed a continuous pyrolysis process for charcoal production and recovery of liquids. Theoretically, continuous kilns allow better control of the process and, consequently, produce better quality charcoal. In such equipment, gases produced by pyrolysis are recovered and burned, supplying energy for the process. Liquids are also recovered — tar among them — and can be used in chemical production. According to test results, the yield of charcoal production was estimated at 33% (by weight, dry basis). This R&D programme was conducted while Acesita was a State owned company, and the pyrolysis plant, for instance, was dismantled after the company's privatization [4.15].

Despite the phasing out of the most important R&D programmes on charcoal production, the charcoal process itself has been modernized, and today most charcoal production for the pig iron and steel industries occurs in the more efficient rectangular kilns [4.14].

4.1.2.2. Vegetable oils/biodiesel

Another opportunity for biomass use is electricity generation from in natura vegetable oils[20] in adapted or modified diesel engines. The Amazon region in Brazil (Amazonia) has an enormous diversity of native oil plants and favourable soil and weather conditions for the cultivation of highly productive oil plants with potential environmental and social benefits.

There is a potential, yet to be evaluated, for small communities to extract oil from locally available nuts or other vegetable sources. For power generation applications, palm oil is one of the most readily available sources. This is because palm is currently the only crop among those considered as fuel sources that is already being used for oil extraction on large commercial plantations, with reliable yields and standardized production. Pilot units for small scale generation (under 200 kW) are being tested in some municipalities in Amazonia, using in natura vegetable oil fired in modified diesel engines [4.16].

Brazil is also starting to consider the development of biodiesel and biodiesel–diesel fuel blends. The feasibility of this option is being analysed by the Government and the country's automotive industry, together with research institutes and fuel and lubricant developers. Biodiesel is an esther resulting from transesterification, a chemical reaction between a vegetable oil and an alcohol (methanol or ethanol). Because of the large ethanol capacity already installed, ethyl ester (from a vegetable oil and ethanol) is the most interesting option.

Biodiesel can be used in conventional engines; its primary disadvantage is its higher production cost compared with vegetable oils and diesel. According to some feasibility studies, production costs of biodiesel are expected to be much higher than those of diesel [4.17].

Biodiesel, which is produced through an industrial process, cannot be made in remote villages, where there is no capacity for such production. Therefore, if commercially available, it can only be used in the transport sector, as a replacement for diesel oil.

4.1.2.3. Agricultural/wood residues

In Brazil, the use of agricultural and wood residues for energy purposes is not yet well developed. With respect to electricity generation, there is some experience in the pulp and rice industries, as well as in some sawmills. All pulp industries in Brazil use wood residues and black liquor[21] as fuel, but despite the significant existing potential (1700 MW of surplus electricity, according

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[20] In natura vegetable oils are extracted and purified without chemical treatment, which differentiates them from products made through transesterification.

[21] A by-product of pulp production using sulfate chemicals.

to Eletrobras [4.18]), just one plant (CENIBRA — Celulose Nipo-Brasileira S.A.) generates surplus electricity that is provided to the grid. Recently, some rice industries in the South region have started to use rice husks for cogeneration. A few sawmills use their residues for electricity generation, generally with low efficiency technologies [4.19].

As in sugar cane mills, conventional steam cycles are commercially available and in use in Brazil. In the Aracruz and Klabin do Paraná pulp industries, a more efficient (fluidized bed) boiler was introduced. The efficiency is lower for small scale systems (under 3 MW) than for larger systems because some technologies are not feasible in smaller systems (e.g. high pressure boilers and more efficient turbines). Recently, some local manufacturers have started to produce steam cycles under 200 kW, but the specific cost (US $/kW) is still too high.

According to a study by the Brazilian Reference Centre on Biomass (CENBIO) [4.20], considering only the technology that is commercially available in Brazil, the investment cost for electricity generation from biomass residues would vary from US $600/kW to US $1200/kW, and generation costs would range between US $10/MW·h and US $30/MW·h, with the lower values being for rice husks and the higher values being for wood residues. According to the same study, the cost of electricity produced from sugar cane residues is about US $54/MW·h.

4.1.3. Hydropower

As discussed in Chapter 2, hydropower has an important role in the Brazilian energy system. The bulk of the installed capacity of electricity generation is based on large hydropower plants — some 80%, or about 62.5 GW (2001 data), of installed hydropower capacity, mostly in the South and Southeast regions of the country. The total hydropower potential is estimated at 260 GW (see Chapter 3), but most of the remaining potential is located in the North region, far from the most industrialized areas and with strong environmental impacts likely to be associated with its development and use (see Chapter 6). Brazil's high hydropower potential has led it to develop its own expertise and technologies concerning both the manufacture of mechanical and electrical equipment and the construction of hydropower plants themselves.

4.1.3.1. The hydropower industry and dam construction in Brazil

In Brazil, the very first hydropower plants were installed in the 19th century. Until the 1950s, only small hydropower plants were installed, operating in isolated systems. Later, various State owned electric companies were created and interconnected systems based on large scale hydropower plants were established.

Brazil's industrial sector is able to supply all the electrical and hydromechanical equipment required by hydropower plants with a wide range of capacities, such as valves, turbines, generators, governors and other electric components. Regarding hydro turbines, Brazil's industrial sector is able to produce machines ranging from non-conventional small capacity units to traditional types, such as Pelton, Francis, propeller, Kaplan and cross-flow turbines.

Small industries, using their own technology, are able to produce turbines of up to 5 MW; the inability to produce bulb and tube hydro turbines with high specific speeds is a constraint for such industries. In contrast, large companies that use foreign technology have no constraint regarding capacity or type. There are no substantial differences between the technologies used in Brazil and those used in other countries.

Dams not only constitute an important means of retaining water but are also a strategic investment to provide for the multiple uses of water, thus bringing several benefits. Some of these are typical of huge construction projects; others are specific to these kinds of civil works, such as electricity generation.

The Brazilian Register of Large Dams (higher than 15 m) includes 823 dams, of which half were built in the semiarid Northeast region for streamflow regulation and 240 were built specifically for electric power generation.

Until the 1950s, 40% of the dams higher than 15 m were made of concrete. From the 1950s until the 1990s, there was a decrease in the construction of concrete dams because of the high cost of the concrete. At the same time, as a result of scientific developments in the mechanics of soil technology, there was an increase in the popularity of earth dams and rock-fill protection.

Efforts to increase the safety of concrete dams and the efficiency of earth dam construction, highlighting the use of new equipment in the construction of earth and rock massif dams, led to the development of the rolled compacted concrete (RCC) method. The RCC method for dam building was first used in Brazil in 1978, with the construction of the dam at the Itaipu plant. Afterwards, this technique was used in the gate at the Tucuruí plant and in the modifications of the drain at the Three Marias plant.

The construction of the Saco Dam in Nova Olinda using RCC had numerous repercussions, as the cost of the rolled concrete was around US $40/m^3 (compared with the cost of conventional concrete of about US $52/m^3). Regarding costs, the dams account for up to 30% of the total construction costs of hydropower plants.

Because of the limitations imposed by Brazil's environmental legislation, the construction of some large hydropower plants and a great number of small water head plants or deviation plants can be foreseen, with multiple uses of water, such as for irrigation or fluvial transport. In these cases, dams whose water levels can be regulated have a good chance of being developed.

4.1.3.2. Small hydropower plants

Small hydropower plants are characterized as small-load hydropower plants with an installed capacity of between 1 and 30 MW and a reservoir area equal to or less than 3 km^2. Small hydropower plants have smaller implementation risks than do large hydropower projects because they generally have small reservoirs and are works of low or medium complexity, often constructed to make use of natural drops in water courses. The current estimated cost of installation for a small hydropower plant, on average, is about US $1000/kW [4.21], which tends to be competitive in the Brazilian market over the short and medium terms.

In the case of isolated rural communities, the most significant prospects with respect to expanding access to electricity (and to reducing poverty) are small hydropower plants. By early 2004, small hydropower plants (less than 30 MW) accounted for almost 1.2 GW installed capacity in 242 plants. In the short term, an additional 3.5 GW could be built. According to Eletrobras, small hydropower plants represent a potential of 9.5 GW, a figure that might actually be even higher considering the lack of existing information. The potential of small hydropower plants is still being assessed.

Generally, this technology minimizes the adverse environmental impacts of large hydropower plants; it also improves the economy and quality of life of areas alongside rivers. In PROINFA, the small hydropower projects reached 1265 MW (38% of the programme's total energy sources). The tariff paid for the Government is about 162 Brazilian reals (US $2.70) per megawatt-hour.

4.1.4. Nuclear power and fuel cycle technologies[22]

Brazil's first nuclear power plant, a pressurized water reactor plant manufactured by Westinghouse, was installed in the 1970s in the city of Angra dos Reis in Rio de Janeiro State. This turnkey project, called Angra I, went into commercial operation in 1985. The second unit, Angra II, was connected to the grid in 2000, also in Angra dos Reis. Angra II was the first of the eight reactors to be installed in Brazil by 1990 according to the agreement between Brazil and the Federal Republic of Germany. Various steps of the nuclear fuel cycle — uranium mining, conversion, enrichment, fuel fabrication, etc. — were to be developed, albeit on a small scale.

At the beginning of the programme, enriched uranium was expected to be produced using the untested 'jet nozzle' process; however, this process of enrichment was not successful. In the future, fuel for Brazil's reactors is expected to be supplied by an enrichment plant under construction based on ultracentrifuges developed independently by the Brazilian Navy. This plant is expected to supply the needs of Angra I and II, and, eventually, Angra III.

According to Eletronuclear, the company responsible for the operation and maintenance of Brazil's nuclear power plants, Angra I has an installed capacity of 657 MW and was operating with a capacity factor of 86.3% in 2002; Angra II has 1350 MW installed capacity and had a capacity factor of 91.5% in 2002.

Angra III, considered the second reactor of the eight planned, is less than half finished, and there is strong debate in Brazil over whether or not it should be completed. The estimated additional cost is US $1.8 billion, and there are plans to finish it by 2010. Even if this happens, nuclear electricity will represent only approximately 2% of all electricity used in the country.

According to the Ministry of Energy, the generation costs of nuclear power plants in Brazil are expected to be US $80/MW·h.

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[22] This section was written by J. Goldemberg.

4.1.5. Transmission system

Regarding the manufacture of transmission lines, Brazilian enterprises are able to meet all equipment and service demands. The majority of manufacturers of cable, high tension towers, insulators, lightning rods and power transformers are domestic enterprises.

The transmission system is divided into transmission chains (to supply the large population centres) and sub-transmission chains (to supply the small municipal districts and industrial clients). The transmission lines are organized according to tension: in the transmission chains, tension is equal to or above 230 kV; in the sub-transmission chains, tension is between 69 and 138 kV.

The Brazilian electric power transmission system is highly dependent on the country's hydropower plants. Because the largest consuming centres are not located in the areas of great hydropower potential, and because of the great territorial extension of the country, the transmission lines are widespread. Today Brazil relies on an extraordinary transmission system divided into subsystems, including isolated systems and the interlinked North, Southeast, Northeast and South subsystems. Only the States of Amazonas, Roraima, Acre, Amapá, Rondônia and parts of Pará and Mato Grosso have not been linked to the national transmission system. In these States, small thermoelectric or hydropower plants situated near the capitals supply the needed electricity.

Table 4.3 shows the length of Brazil's transmission grid in kilometres for the different voltage levels of operation in 2000 and for the planned expansion until 2010. The total investment for the expansion of the transmission grid was assessed at US $8.5 billion for the 2001–2005 period (at the exchange rate of 2 Brazilian reals to 1 US dollar in February 2001).

The interconnection of electricity transmission systems in South America is part of a larger infrastructure integration policy that also includes the transport and telecommunications sectors. Table 4.4 shows the system interconnections currently in operation or under construction in which there is Brazilian participation. In 2000, there were bids for an additional 3600 km of the interlinked transmission grid, on three different lines, for the North, South and Southeast regions.

4.1.5.1. New technologies applied to transmission lines

In this subsection, three relatively new technologies currently being applied in the Brazilian transmission grid are discussed: high voltage direct current (HVDC) converter stations and transmission lines, flexible alternating current transmission systems (FACTS) devices and transmission line surge arresters.

High voltage direct current (HVDC) converter stations and transmission lines: HVDC converters and transmission lines are not really a new technology in the Brazilian transmission system, since their use dates back to the 1980s when two 600 kV direct current (DC) transmission lines, approximately 800 km long, were commissioned to connect the Itaipu hydropower plant to São Paulo State. These two DC transmission lines carry approximately half the total power (6300 MW of 12 600 MW) generated at Itaipu. The decision to use DC transmission lines was based on the need to convert the frequency from the 50 Hz generating units in Paraguay to the 60 Hz operating frequency of Brazil's electrical system. The DC lines were also competitive in financial terms, since for very long distances (~600 km), the cost of DC transmission is lower than the cost of alternating current (AC) transmission because of the simpler tower and line

TABLE 4.3. LENGTH OF THE TRANSMISSION GRID AT DIFFERENT VOLTAGE LEVELS (km) [4.22]

	Voltage level (kV)						
	750 AC	600 DC	500 AC	440 AC	345 AC	230 AC	138 AC
Configuration in 2000	2 386	1 600	15 732	4 841	8 271	31 152	50 692
Added 2001–2010	313	—	11 416	518	649	7 167	13 382
Configuration in 2010	2 699	1 600	27 148	5 359	8 920	38 319	64 074

Note: AC = alternating current; DC = direct current.

configuration, despite the cost of the converter stations.

Although no other DC transmission lines are currently planned before 2010, the interconnections with other South American countries that have 50 Hz as their operating frequency also require HVDC converter stations. In these cases, the converters are connected in a back-to-back configuration; that is, the rectifier and the inverter are directly connected without a DC transmission line between them.

For the very long transmission lines that may be built in Brazil — such as the interconnection between the planned Belo Monte power plant and the Southeast region currently under study — DC transmission lines may be more economically competitive than AC transmission lines.

Flexible alternating current transmission systems (FACTS) devices: Advances in transmission line technologies since 1990 have focused on the needs of the Brazilian transmission system. Since Brazil is a very large country, the task of interconnecting all its major load centres has been very demanding, both technically and financially. Until the late 1990s there was no interconnection between the North and Northeast and the Midwest, South and Southeast systems.

After several years of study, it was decided that a 1000 km AC transmission line operating at a voltage level of 500 kV would be built to allow a power flow of the order of 1000 MW in both directions. This alternative, however, would lead to a low frequency and low damped oscillation around 0.2 Hz. To eliminate the technical restrictions of this undamped inter-area oscillation without abandoning the AC transmission alternative, a thyristor controlled series capacitor (TCSC) was installed at each end of the transmission line. This was the first use of modern FACTS devices in Brazil. The TCSCs were commissioned in 1999; after about a year of testing, the control system was modified, and the results have since been very satisfactory [4.23].

This was just the first interconnection between the North and South subsystems in Brazil. Because vast hydropower potential exists in the Amazon region, very long lines to link weakly coupled systems will be commissioned, in the form of either DC transmission or AC transmission. In either case, the potential for electronic devices is enormous, either with HVDC converters or FACTS devices in order to improve the overall system stability.

Transmission line surge arresters: The installation of transmission line surge arresters in parallel with insulator strings has become a relatively common practice in Brazil. At least two of the largest Brazilian utilities — FURNAS, owned by the Federal Government, and CEMIG, owned by Minas Gerais State — have installed transmission line surge arresters after detailed studies showed the significant impact that these devices can have in reducing transmission line outages [4.24, 4.25]. The conventional alternative of adequate ground wire protection and careful dimensioning of the tower grounding may not be sufficient in sites with very high keraunic levels — that is, regions with a high density of lightning strikes — and high soil

TABLE 4.4. SYSTEM INTERCONNECTIONS BETWEEN BRAZIL AND OTHER SOUTH AMERICAN COUNTRIES IN OPERATION OR UNDER CONSTRUCTION [4.22]

Country	Terminals	Capacity (MW)	Voltage (kV)	Remarks
Argentina	Rincón (Argentina) – Garabi (Brazil)	2 000	500	1 000 MW in operation 1 000 MW under construction
	Paso de los Libres (Argentina) – Uruguaiana (Brazil)	50	132 / 230	In operation
Venezuela	Guri (Venezuela) – Boa Vista (Brazil)	200	230 / 400	In operation
Uruguay	Rivera (Uruguay) – S. Livramento (Brazil)	70	230 / 150	In operation
Bolivia	Puerto Suárez (thermal power plant)	88	—	In operation
Paraguay	Acaray (Paraguay) – F. Iguaçú (Brazil)	70	132	In operation
	Itaipu (hydropower plant)	14 000	—	12 600 MW in operation 1 400 MW under construction

resistivities. These conditions apply to the most populated States in Brazil, and the vast majority of unscheduled transmission line outages are due to lightning strikes, especially for transmission lines that operate below 230 kV.

The Brazilian market for transmission line surge arresters is still very large, both because the country itself is large and because the transmission lines are very long.

4.1.5.2. Upgrade of transmission line voltage levels

One of the fastest ways to increase the power capacity of transmission lines is to refurbish the lines. This process is much less costly than the alternative of building new transmission lines and may alleviate the power flow limitations of the system, at least in the short term. Such actions are particularly to be recommended when there is a high probability of electric power shortages, such as occurred in Brazil in 2001. Since electricity generation in Brazil is predominantly from hydropower plants, the possibility of future shortages cannot be ruled out. Transmission lines usually can be refurbished with small increases in cable soil height and insulator string length. Of course, it is necessary to upgrade the substations connecting such lines as well. Some utilities are studying this alternative, and COPEL, a utility owned by Paraná State, has undertaken a practical application [4.26].

4.1.6. Deepwater drilling and oil production

4.1.6.1. Importance of offshore production

The strong growth in global oil demand and the low rate of replacement of oil reserves have forced the search for new prospects.[23] Based on the actual level of proven reserves, oil producers cannot fully meet the future oil demand, even with a new favourable price scenario. Since the two oil shocks in the 1970s and 1980s, the oil industry has passed through an important learning and diversification process involving long range research into non-conventional oil resources and the focusing of investments in deepwater and ultra-deepwater reserves.

Deepwater[24] drilling and oil production represents an important opportunity for the global oil industry. It is estimated that potential reserves of 150 billion boe[25] are located in water depths of more than 500 m. Approximately 50 billion bbl have been discovered, and only 3 billion bbl have been produced [4.33].

Offshore production represented approximately 35% of world oil production in 2001. Considering only those oil producing countries that are not part of the Organization of Petroleum Exporting Countries (OPEC), the offshore share increased to approximately 58%, while in Brazil the proportion exceeded 80%.[26] Because of growing deepwater oil production, it is foreseen that Brazil might reach oil self-sufficiency by 2006.

Deepwater production is currently concentrated in three basins: the Gulf of Mexico, Brazil and West Africa. Reserves of approximately 21 billion boe are estimated to be distributed in these three main offshore areas. Estimated deepwater petroleum reserves for Brazil represent about 80% of total national reserves (see Chapter 3).

Deepwater production is an attractive investment opportunity for two important reasons: first, giant fields continue to be discovered, and second, there is the possibility of significant returns. Over 85% of the world's remaining offshore reserves are believed to lie in water depths greater than 1000 m [4.33]. At the same time, there have been important shifts in the political environment worldwide. Changes in tax systems and the regulatory framework have created opportunities for new investments in geographical areas with even deeper waters.

While the size of oil reserves in deep water is significant, so too are the geological, physical,

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[23] In the 1985–2000 period, the world population grew 18%, while oil demand grew 20%. Projections for 2001–2020 indicate a population growth of 22% [4.27] and a growth in oil demand of 51% [4.28]. At the same time, onshore and shallow water reserves are declining.

[24] Oil companies, Government institutions and associations use different definitions of deep and ultra-deep water. However, there is broad acceptance that water depths greater than 500 m are deep water and those over 1500 m are ultra-deep water. Petrobras, Brazil's State owned oil company, defines deepwater limits as 400 m for production and 600 m for exploration, and the ultra-deepwater limit as 2000 m [4.29–4.32] .

[25] Including oil and gas.

[26] In 2002, Petrobras domestic oil production was more than 1.6 million bbl/d distributed as follows: 17% onshore, 19% from shallow water and 64% from deep and ultra-deep water [4.34].

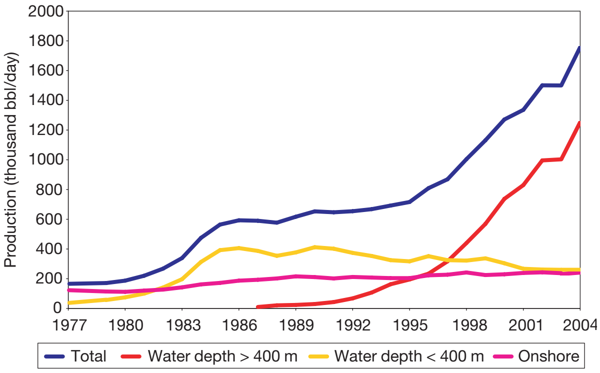

FIG. 4.2. *Oil production profile in Brazil [4.34].*

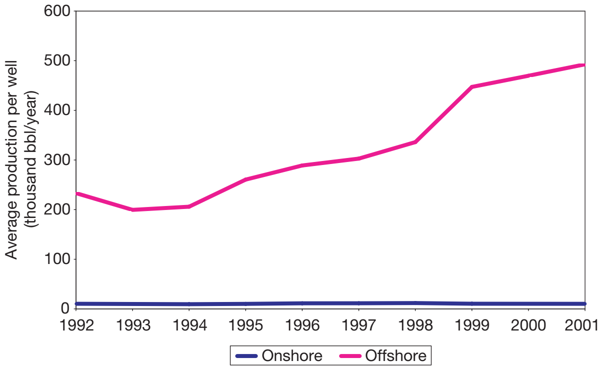

FIG. 4.3. *Average production per well in Brazil [4.34].*

environmental, economic and technological challenges. Substantial investments are required in all phases of the deepwater exploration and production cycle. While exploration drilling is expensive, it is relatively insignificant compared with the costs of developing a reservoir of 600 million bbl, which can easily exceed US $1 billion.

4.1.6.2. *Offshore industry in Brazil*

The experience and capabilities of Brazil's petroleum industry with respect to deepwater exploration and production are still relatively limited. Despite discoveries over the past two decades, relatively few fields in water depths greater than 2000 m have been developed.

As previously stated, most of Brazil's oil production comes from deep and ultra-deep waters, and this proportion is rising as exploration pushes into deeper water. Since the 1980s, Petrobras has made important discoveries in the Campos Basin and more recently in the Santos and Espírito Santo Basins.

Figure 4.2 shows the profile of oil production in Brazil since 1977. Taking into account the most recent discoveries and reserves, the tendency is towards increased shares of offshore production in total oil production. Oil production in Brazil is largely from deeper reservoirs and is mainly from heavy oil.

Among the new technologies required for commercial exploitation of these deepwater heavy oil reservoirs are new artificial lifting devices and long horizontal wells, complete with efficient sand control mechanisms [4.35]. It is expected that, as the costs of these new technologies decline, they will allow additional reservoirs to be exploited. Indeed, an increasing number of deepwater heavy oil reserves can be exploited due to the cost reducing effects of new technologies (the reduction of capital expenditures and operational costs), which more than offset the cost increasing effects of resource depletion [4.36].

4.1.6.3. *Importance of technology in offshore systems*

Offshore technology systems are constantly evolving, and several concepts have been developed in various regions of the world to meet the challenge of deeper offshore exploration and production. The technologies that received greater impetus once the barrier of 400 m depths was surpassed were the tension-leg platform (TLP) and the floating production system (FPS). TLP technology received strong support in the Gulf of the Mexico under the leadership of Shell, whereas FPS technology underwent a major expansion in the Campos Basin through the action of Petrobras.

The present stage of technological innovation is very complex, and several designs compete in those deepwater regions where there is no marked preference for or general trend towards one technological option over the others. The systems need to meet specific environmental, geological, operational and safety challenges.

Several other areas of technology have evolved with the increases in ultra-deepwater production. One technological advance in Brazil has led to increases in average well production, as shown in Fig. 4.3, in part accomplished by horizontal drilling. Well productivity is key to the future economic viability of deepwater oil production.

4.1.6.4. *Technology development conducted by Petrobras*

Since 1986, Petrobras has conducted a Technological Development Programme on Deepwater Production Systems, known as PROCAP. The main purpose of the first PROCAP was to improve Brazil's technological competence in oil and natural gas production in water as deep as 1000 m. This first PROCAP focused on the Albacora and Marlim oilfield developments [4.37].

In this first PROCAP, substantial emphasis was given to alternatives already used in shallow water but needing further adjustments or developments to be extended to deep water. These systems consisted of semi-submersible platforms and ships equipped with a process plant and subsea equipment. The main achievement of this six-year programme was the development of semi-submersible FPSs that enabled production in water depths of 1000 m. With its know-how, Petrobras was able to adopt the FPS owing to its high flexibility and the reduced time for construction and installation. According to Furtado et al. [4.38], an assessment of this first technological programme gave an average benefit–cost ratio of 12.2, showing the importance of R&D expenditure for economic growth. The first PROCAP was funded, managed and executed for the most part by Petrobras. Thus it is a good example of a huge technological programme in a developing country acquiring a place on the technology frontier more commonly taken by industrialized countries.

The role of suppliers serving as the commercial partners of Petrobras was decisive for the diffusion of technological processes. Furtado et al. [4.38] point out that this arrangement was not part of a linear innovation scheme, where the new deepwater technology was transferred formally by licence contracts to suppliers. Rather, in the context of the first PROCAP, the transfer was indirect, spilling over to suppliers and resulting in new inputs and lower prices for equipment.

At the end of 1992, as exploration moved into regions of deeper water, Petrobras embarked on a new programme called PROCAP 2000 aimed at designing systems capable of producing at water depths of 2000 m. The main goals of PROCAP 2000 were the development of innovative projects for reducing capital investment and operational costs related to deepwater production systems and incorporating new reserves located in water depths of up to 2000 m.

PROCAP 2000 ran from 1993 to 1999. Among its many achievements were the design and execution of an extended-reach well in deep water[27]; the development of a horizontal Christmas tree[28] for use in water depths of 2500 m; installation and operation of an electric submersible pump in a subsea well in deep water; a subsea separation system called the vertical annular separation and pumping system (VASPS); and a subsea multiphase pumping system for deep water.

The third version of the programme, PROCAP 3000, was expected to last five years, from 2000 to 2004, and its initial budget was estimated at US $130 million [4.30]. The overarching goal was to bring into production discovered deepwater fields as well as fields discovered in water depths of around 3000 m, using a set of new technologies to be extended and developed by the petroleum industry.

The main aims of PROCAP 3000 can be summarized as follows: to produce and support the next development phases of the Marlim Sul, Roncador, Marlim Leste and Albacora Leste oilfields, all of which are in water depths beyond 1000 m, with various fluid characteristics and reservoirs; to reduce the capital expenditures in production developments in water depths beyond 1000 m; and to reduce lifting costs in currently producing oilfields in water depths beyond 1000 m. The main systemic projects from PROCAP 3000 are presented in Table 4.5.

An increasing number of prospects are stimulating the creation of new technologies. Several questions remain in the technological forecasting scenario for deep water: How deep could production go? How long could it take to create the technology needed to produce at these depths? What would be the costs of creating these new technologies?

Based on the current situation, there is no limit to the physical oil and gas resources that can be reached with this technology. In Brazil, the potential is enormous, as there recently have been very large discoveries promising over 1 billion boe in deep waters. Ultra-deep waters have also yielded significant recent discoveries. However, several

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[27] The extended-reach well was used in 1214 m of water. Petrobras also drilled a 500 m horizontal offset to a 3258 m well in the Marlim Sul oilfield.

[28] A Christmas tree is an arrangement of pipework connections and valves installed on the wellhead prior to production. It is typically assembled from gate valves and connecting fittings.

TABLE 4.5. PROCAP 3000 SYSTEMIC PROJECTS
(adapted from Ref. [4.30])

Well technologies	● Extended-reach wells in ultra-deep water ● Design wells in ultra-deep water ● Drilling, well test evaluation and completion in ultra-deep water ● High production rate wells in ultra-deep water
Artificial lift and boosting technologies	● Gas lift optimization in ultra-deep water ● Subsea multiphase pumping system
Subsea equipment, risers and pipelines	● Subsea equipment for ultra-deep water ● Unconventional subsea production systems ● Subsea risers and pipelines (gathering, export and control) ● Subsea connection system for water depths of 3000 m
Flow assurance in ultra-deep water	● Low density foam pigs[a] ● Commercially available multi-size pigs[a]
Hull concepts, anchoring technologies, acquisition and treatment of geological, geophysical, geotechnical and oceanographic data	● Cost effectiveness analysis for different hull concepts considering dry and well completion ● Dry completion stationary production units ● Mooring systems[b] for ultra-deep water ● Acquisition and treatment of geological, geophysical, geotechnical and oceanographic data for ultra-deep water

[a] A pig is a cylindrical device that is inserted into a pipeline to clean the pipeline wall or to monitor the internal condition of the pipeline.

[b] Mooring systems maintain a ship in a relatively fixed position without the use of anchors or mechanical mooring systems.

constraints and technological challenges remain in this area.

Technology innovation will be very important for sustaining the development of these oil resources. Considering that there is great geological potential in these ultra-deepwater regions, there is a need to increase production and push industry to develop new technologies to allow production of heavy oil from ultra-deepwater reservoirs. New production facilities, horizontal and multilateral wells, and different production strategies are examples of technologies that will be essential for complying with this demand.

4.2. ENERGY EFFICIENCY

4.2.1. End use technologies in Brazil

With respect to energy use, Brazil uses many of the same technologies that are used worldwide — household refrigerators and other household appliances, lighting devices such as incandescent and fluorescent lamps, induction motors, air conditioning systems, automobiles and trucks, industrial furnaces and boilers, and industrial processes such as aluminium smelters or petrochemical refineries. These end use technologies are often produced in Brazil by Brazilian and/or multinational companies.

In some cases, end use technologies produced in Brazil are less energy efficient than those produced in industrialized countries. For example, automobiles produced in Brazil tend to be, on average, slightly less fuel efficient in terms of litres per 100 km than those produced in western Europe or Japan, as technical innovations introduced by the automotive industry in those countries tend to be transferred to Brazil with a delay of a couple of years. Likewise, window air conditioners produced in Brazil tend to be less efficient than those produced and sold in industrialized countries, owing to the use of older product designs and less efficient components, and a lack of efficiency standards and other policies stimulating innovation and higher energy efficiency. Also, there are pressures to reduce the first cost of products in Brazil, which tends to lead to lower energy efficiencies.

The discussions below review energy efficiency trends and the current status of energy efficiency for key energy end uses in Brazil. Special note is made of technologies where there has been innovation within Brazil with respect to energy efficiency.

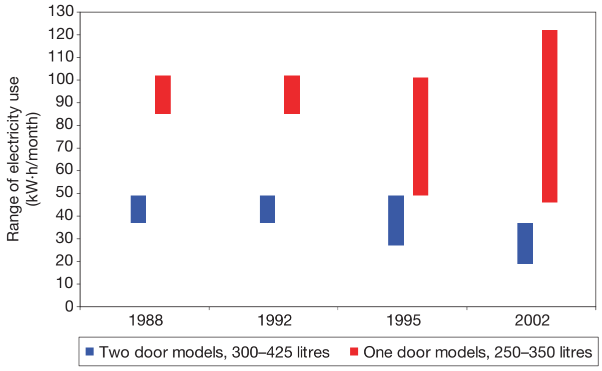

FIG. 4.4. Energy efficiency improvements in refrigerators.

Note: *The energy efficiency test procedure was changed in 1997, so the values for 2002 are not directly comparable with values for earlier years; all values based on 127-volt models.*

4.2.2. Household refrigerators

Refrigerators were used in approximately 83% of Brazilian households in 2000 [4.39] and account for about 32% of residential electricity use [4.40]. Most refrigerators used in Brazil are single door models, with a small freezer compartment inside and a total volume of 250–350 L. However, more efficient two door refrigerator–freezer models with a volume of 300–450 L are gaining popularity.

Brazil initiated an energy consumption testing and labelling programme for refrigerators in 1986. The Government and appliance manufacturers reached two agreements calling for voluntary efficiency improvements during the 1990s. Also, the National Electricity Conservation Programme (PROCEL) began presenting awards and using labels to identify top rated models in 1995. Furthermore, there was spillover from efforts to improve the energy efficiency of refrigerators in other countries (e.g. appliance efficiency standards in North America). All of these efforts contributed to improvements in the efficiency of new refrigerators and freezers produced in Brazil (see Fig. 4.4). On a technological level, the efficiency improvements were due to the use of better insulation, more efficient motors and compressors, and other design changes.

There is an interesting story related to the efficiency of Brazilian refrigerators and freezers. Embraco, based in southern Brazil and now a subsidiary of Whirlpool, is one of the largest motor compressor manufacturers in the world. Since most of Embraco's compressors are exported, with a large number shipped to the United States of America, starting in the mid-1980s the company had to significantly increase the efficiency of the compressors it was exporting because of US appliance efficiency standards. This had the spillover effect of improving the efficiency of the compressors used in Brazilian refrigerators at the same time [4.41].

4.2.3. Lighting

Since 1998, lighting has accounted for about 16% of electricity use in Brazil, or 48 TW·h/year. Commercial and public buildings account for about 46% of total lighting electricity use, followed by the residential sector at around 28% and street lighting at 20% [4.41].

A wide range of energy efficient lighting technologies is now available. Sales and use of some of these technologies have increased very rapidly in recent years, in large part because of the 2001 electricity crisis and mandatory reductions in electricity use during the crisis.

Table 4.6 shows the increase in sales of compact fluorescent lamps (CFLs) and the decrease in sales of incandescent lamps in Brazil in recent years. CFL sales exploded in 2001, but remained relatively high even after the electricity crisis ended. For comparison, about 8 million CFLs had been sold in Brazil up to 1998 [4.41]. The ratio of CFL to incandescent lamp sales — about 1:6 as of 2002 — is probably one of the highest ratios in the world. For comparison, the ratio of CFL to incandescent lamp sales was 1:50 in the United States of America as a whole, and 1:17 in California as of the end of 2001 [4.43].

For many years, the incandescent lamps produced in Brazil were less efficient than lamps produced in industrialized countries in terms of light output per unit of power consumption. After pressure from energy efficiency advocates and some members of Congress, in 1999 Brazil's lamp

TABLE 4.6. CFL VERSUS INCANDESCENT LAMP SALES IN BRAZIL, 2000–2003 [4.42]

Year	CFL lamps (10^6)	Incandescent lamps (10^6)
2000	14	450
2001	60	250
2002	50	300
2003 (estimated)	40	300

manufacturers agreed to change to a higher voltage and higher efficiency filaments. This cut electricity use and improved the efficiency of the incandescent lamps produced in Brazil.

Fluorescent lighting is often inefficient and of poor quality, with fixtures that are poorly designed, become dirty quickly, lack reflectors, etc. However, the adoption of energy efficient fluorescent lamps and fixtures is increasing, especially in new buildings. The market share of high efficiency fluorescent tubular lamps (specifically, T5 and T8 type lamps) was approximately 20% in 2002, up from a market share of about 5% in 1996. Likewise, the market share of higher efficiency electronic ballasts for fluorescent lighting was approximately 30% in 2002, up from about 8% in 1996 [4.42]. PROCEL and individual utilities helped to stimulate the use of these products through R&D and demonstration programmes, audits and educational activities.

4.2.4. Electric motors

Motors account for about half the industrial electricity use, about 40% of electricity use in commercial buildings (through air conditioning, refrigeration and pumping systems) and about 40% of electricity consumption in homes (through refrigerators and other appliances). Brazilian manufacturers started producing high efficiency motors containing silicon steel for export in the 1980s. These motors were first offered on the domestic market around 1990, but high efficiency motors represented only approximately 4% of all three-phase induction motors sold in Brazil as of 2001 [4.44]. On the other hand, manufacturers have increased the efficiency of standard motors produced in Brazil over the past decade, in part responding to the testing and labelling programme sponsored by PROCEL [4.41].

Relatively little has been done to improve the efficiency of motor systems — the combination of motors, pumps, compressors, blowers, etc. In fact, surveys in the late 1980s showed that many motors are oversized and consume excess power because of poor operating conditions and maintenance practices [4.45]. Better sizing of motors, correcting voltage and other operating problems, and using motor speed controls in applications with highly varying load could save a significant amount of electricity in Brazil [4.46].

Adjustable speed drives (ASDs) are produced in Brazil and imported by a wide range of multinational companies. Sales of modern ASDs increased from around 9000 units in 1993 to over 50 000 units in 1997 as import restrictions were lifted, the economy rebounded, the quality of ASDs improved and prices declined [4.47]. The chemicals, automotive, and food and beverages industries were the main buyers of ASDs. Nonetheless, the potential for energy savings through the use of ASDs remains large [4.47].

4.2.5. Automobiles

In the case of automobiles, although no specific policy has ever been enacted to promote the efficient use of fuel, in 1993 a tax incentive introduced in Brazil encouraging the production of automobiles with small engines (less than 1 litre) had precisely this effect. This cut in the tax on industrialized products was intended to encourage the output of smaller automobiles that were accessible to lower income sectors of the population. By 2001, almost three quarters of domestic sales of new automobiles consisted of automobiles with 1 litre engines. As a consequence, there were over five million 1 litre engine vehicles on the road in Brazil by 2000 [4.48]. To some degree, this fact, together with other technological developments in the period, explains some estimates that put the average fuel economy of an automobile run on gasoline (in fact, a blend of approximately 25% anhydrous ethanol and 75% gasoline) in Brazil today at 12.6 km/L, compared with an average fuel economy of 7.6 km/L in 1971 [4.49], or some 2.36 MJ/km today compared with 4.24 MJ/km in 1971.

4.2.6. Key industrial processes

The specific energy consumption (SEC) of most key industrial processes in Brazil is also being reduced over time as technology evolves. In fact, it is precisely the competitiveness of some of these sectors in terms of energy efficiency (e.g. the case of the iron and steel industry, as portrayed in Ref. [4.50]) that guarantees their important role in Brazilian exports (see Chapter 5 for details).

Figures 4.5–4.9 show the evolution over time of the SEC of selected industrial sectors. As can be seen in these figures, the general tendency over time is a continuous, and substantial, reduction in the SEC (or increase in energy efficiency) of those sectors.

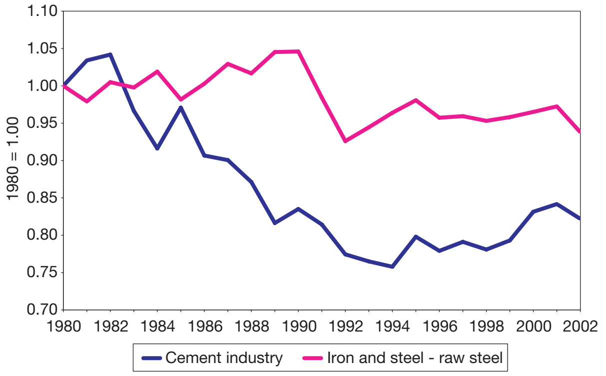

FIG. 4.5. Indices of specific thermal energy use in the cement and iron and steel industries [4.51–4.53].

Note: *In 1980, the specific thermal energy use in the cement industry was 4.32 MJ/kg and the specific thermal energy use in the iron and steel industry was 23.79 MJ/kg.*

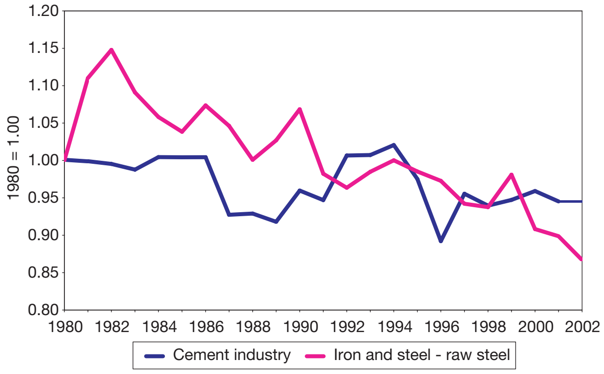

FIG. 4.6. Indices of specific electricity consumption in the cement and iron and steel industry [4.51–4.53].

Note: *In 1980, the specific electricity consumption in the cement industry was 118 kW·h/t and the specific electricity consumption in the iron and steel industry was 581 kW·h/t.*

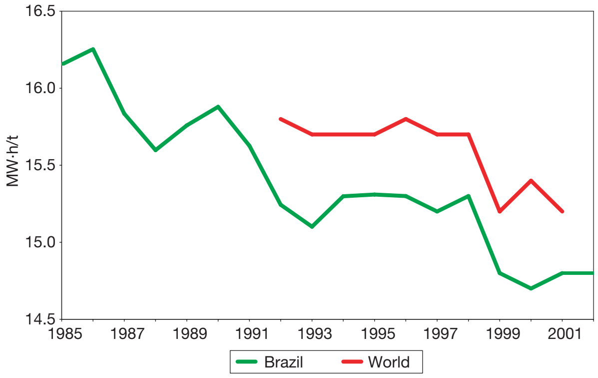

FIG. 4.7. Specific electricity consumption in the aluminium industry in Brazil and worldwide [4.52, 4.54].

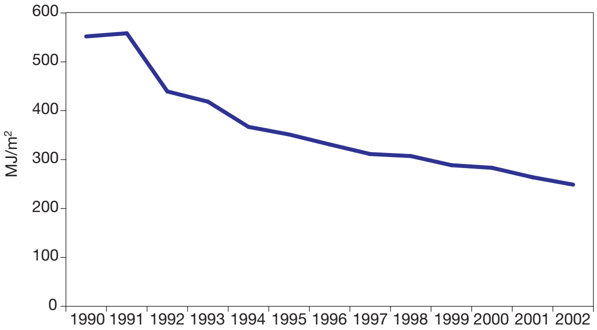

FIG. 4.8. Specific thermal energy use in the ceramics industry [4.52, 4.55].

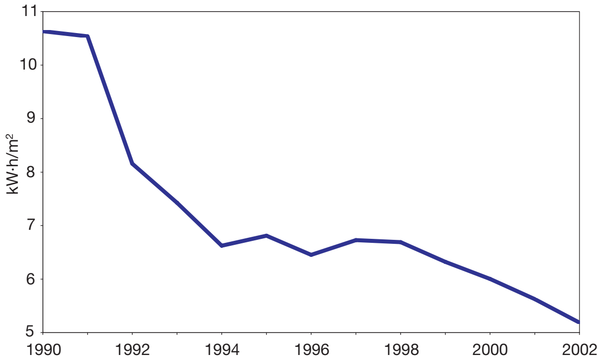

FIG. 4.9. Specific electricity consumption in the ceramics industry [4.52, 4.55].

4.3. MAIN ISSUES

Some of the major issues related to indigenous and adapted energy technologies and energy efficiency are the following:

- The use of alcohol in Brazil's transport sector is a good example of the real possibilities for modern biomass use in a developing country. PROALCOOL, the Brazilian Alcohol Programme, is the world's largest commercial biomass to energy programme. Alcohol from sugar cane is now competitive with gasoline without any subsidies. Besides alcohol fuel, the sugar cane sector also generates electricity from bagasse, a by-product of sugar cane crushing; thus the mills do not need to 'import' energy (fossil fuels or electricity), which is the main reason why alcohol production costs are low. Moreover, the mills export electricity to the grid.

- Another significant experience with biomass in Brazil is the use of charcoal to replace coal in the iron and steel industry. In this sector, charcoal is produced in a sustainable way, using reforested wood. Special programmes in support of wood production from reforestation have been introduced in Brazil, together with more efficient technologies for charcoal production.
- Around 80% of Brazil's electricity supply (around 62.5 GW in 2002) comes from hydropower, requiring a large transmission/distribution system to supply energy to most States (only the northern States are not linked to this grid). A strong industry segment was developed to produce equipment and transmission lines for this supply system.
- Most of Brazil's oil production comes from deep and ultra-deep water, and this proportion is rising as exploration pushes into deeper water. Most exploration is performed by Petrobras, Brazil's national oil company. This is a good example of a huge technological task faced by many developing countries, namely, to acquire a place on the technology frontier that parallels those more commonly taken by industrialized countries.
- Regarding energy efficiency, Brazil uses many of the technologies used worldwide. Most of these end use technologies are produced locally by Brazilian and/or multinational companies. The PROCEL programme on energy efficiency introduced the labelling system for some end use technologies, but much still needs to be done to promote energy efficiency in general.

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Chapter 5

ENERGY AND ECONOMIC DEVELOPMENT

G. MACHADO, R. SCHAEFFER

When energy specialists discuss the relationships between energy use and economic development, the focus is usually on how energy supports economic growth, alleviates poverty and increases people's well-being. On rare occasions, though, the effect that a country's choices for promoting economic development have on energy production and use is a matter of concern. The purpose of this chapter is to evaluate the way Brazil's choices for promoting economic development over time have impacted primary and final energy use in the country. Economic growth has different levels of quality, which lead to different economic development paths. Some paths are more effective than others in creating wealth and in protecting and preserving natural resources and the environment for future generations. Quality actually matters as much for economic development as for energy.

This chapter is divided into four sections covering energy and economic development relationships, the evolution of final energy use in Brazil, strategies to enhance sustainable energy development in the country and a summary of main issues. In Section 5.1, energy and economic development relationships are discussed, setting the background for the analysis of the impacts on final energy use of some of Brazil's choices for promoting economic development. The section begins by focusing on the basics of energy and economic development relationships. It should be noted that most energy specialists usually discuss only the basics of energy and economic development (the 'energy in support of economic development' theme), but this approach alone is not enough to explain differences in countries' final energy use patterns, or to identify strategies to enhance sustainable energy development. In this sense, the main contribution of this section is to further illuminate the role of social and economic choices in determining the effectiveness of a given country's economic development and that country's primary and final energy use patterns.

Section 5.2 assesses energy use in Brazil by analysing energy intensities. A decomposition analysis technique is applied to final energy use figures to help identify the factors affecting final energy use in the Brazilian economy. Such a technique allows the decomposition of energy use changes into three basic effects: activity, structure and intensity. The activity effect results from the impact of overall economic growth on final energy use. The structure effect derives from the impact that the sectoral composition of the economy has on the final energy use of a country. The intensity effect refers to the final energy requirements per unit of activity of each sector considered (sectoral breakdown). Findings are contrasted with historical events and circumstances to provide a better understanding of the impacts of Brazil's economic and social choices on its final energy use patterns.

Section 5.3 recommends synergetic strategies to enhance sustainable energy development in Brazil based on what has been learned from the country's previous economic and social choices and from the experiences of other countries. The final section is a summary of the main issues related to Brazil's energy system and its economic development.

The chapter presents indicators mainly related to energy intensity. Other important economic indicators that are part of the Energy Indicators for Sustainable Development (EISD) set (see Chapter 1, Table 1.1) are addressed in other parts of the report: fuel mix in Chapter 2, reserves to production ratios in Chapter 3, technology efficiencies in Chapter 4, per capita energy use in Chapter 7 and import dependence in Chapter 8.

5.1. ENERGY AND ECONOMIC DEVELOPMENT RELATIONSHIPS

Modern energy sources are needed to support economic growth in contemporary societies, because most of their production activities (modern agriculture, industry, transport and services) rely on or demand them. Thus, ceteris paribus, a shortage of modern energy supply affects economic growth. In

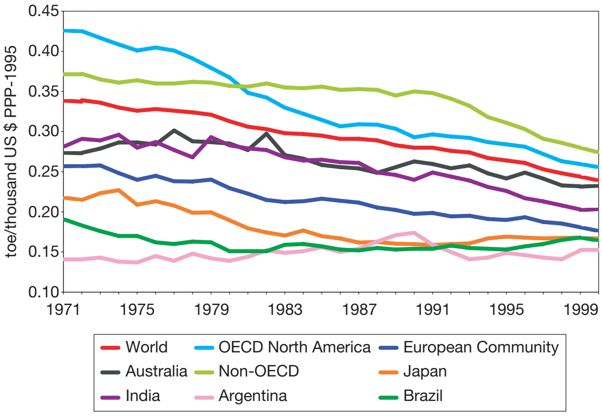

FIG. 5.1. *Overall primary energy intensity in selected countries and regions of the world [5.1, 5.2].*

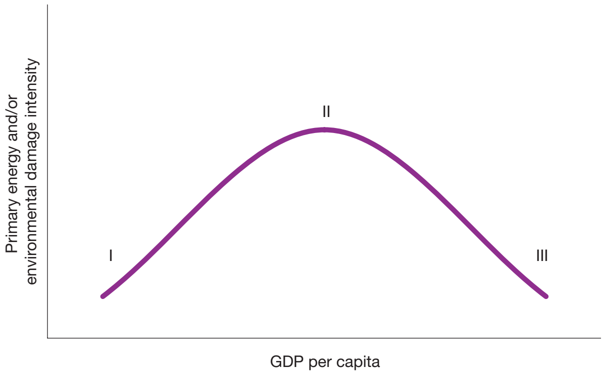

FIG. 5.2. *Energy–environmental Kuznets curve (based on Refs [5.4, 5.5]). Stage I = evolution from traditional to industrial societies; Stage II = maturation of industrial societies; Stage III = change from industrial to information societies.*

addition, uncertainty about the future availability of modern energy supply to support higher levels of activity discourages expansion in production capacity by corporations, reinforcing negative impacts on current economic growth and constraining potential economic growth in the future. However, the fact that energy is needed to support economic activities does not imply that there is a universally and strictly fixed ratio between energy use and economic activity for all societies in the world at all times. On the contrary, such a ratio varies significantly across countries and over time, as Fig. 5.1 reveals.

Weather conditions, demography, territorial extension, natural resource availability, technological development, cultural patterns, management standards, energy matrix and prices, economic structure, income distribution and lifestyles all affect the primary and final energy use/economic activity coefficients of countries. Some of those factors, such as weather and resource endowment, are driven by nature. However, others are socially and economically determined and change, or might change, from time to time, being a result of each country's previous choices and decisions. Therefore, identifying the drivers of those changes and understanding how choices and circumstances have affected such drivers are essential to building a more sustainable energy development path for the future of any country.

Figure 5.1 presents the trends in the overall primary energy intensity of Brazil and selected countries and regions of the world over the past three decades. It shows that Brazil registers one of the lowest overall primary energy intensities of the entire set of selected countries and regions during most of this time period, which is largely explained by its heavy reliance on hydropower and on other modern energy sources and their end use technologies (see Chapter 2). This reliance also contributes to a high overall primary to final energy conversion efficiency in Brazil, which hovers around 90%.[1] In spite of this high conversion efficiency, Brazil does not show any significant downward trend in its primary energy intensity over the period considered. On the contrary, over the second half of the period, Brazil's overall primary energy intensity even increased slightly.

Figure 5.2 shows the theoretical energy–environmental Kuznets curve. This curve traces the evolution of three different economic development stages: evolution from traditional to industrial societies, maturation of industrial societies and change from industrial to information societies [5.6, 5.7]. Some might argue that Brazil is a middle income country with significant energy needs that must still be fulfilled before it enters a period of lower energy intensity and higher per capita income.

At first glance, such an argument could sound reasonable. In such a case, as predicted by the energy–environmental Kuznets curve, more economic growth in the future would lead to an upward trend in Brazil's overall energy intensity before a downward trend could be achieved.

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[1] Primary to final energy conversion efficiency is measured by the ratio of total final consumption to total primary energy supply, as defined by the International Energy Agency [5.3].

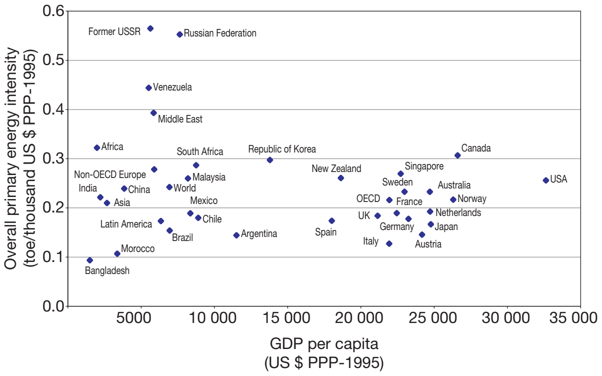

FIG. 5.3. Overall primary energy intensity versus per capita GDP in selected countries and regions of the world in 2000 [5.3].

However, relationships between primary energy use and economic activity are very complex, comprising qualitative social and economic changes rather than simple, quantitative per capita income growth. Figure 5.3 shows the overall primary energy intensity versus per capita gross domestic product (GDP) for Brazil and selected countries and regions of the world in 2000.

It is not mandatory that the inverted U shaped trajectory of the energy–environmental Kuznets curve be replicated step by step. As pointed out by Goldemberg [5.8] and Yang [5.9], leapfrogging over some steps is possible, not only through the prompt adoption of some energy efficient, and environmentally sound, technologies, but also through the promotion of structural economic changes away from energy intensive and materials intensive industries and environmentally sensitive activities. Today's developing countries have better technological opportunities than developed countries did when they were at similar per capita income levels; thus developing countries face a flatter curve and can achieve the turning point at lower levels of intensity (for both primary energy and environmental damage). In this sense, it is possible to build a tunnel through the 'hill', expressed by the energy–environmental Kuznets curve, by learning from the experiences of developed countries.

Understanding the impact previous choices and circumstances have on the relationships between energy and economic activity is a fundamental step in building a more sustainable energy development path for any country. To a great extent, future long term changes in a country's energy profile will be a result of choices made today and in the near future.

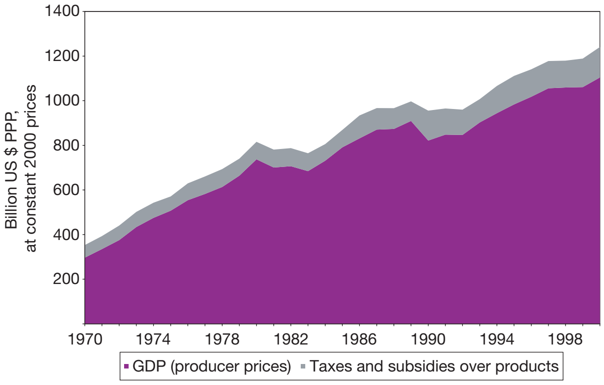

FIG. 5.4. Evolution of GDP at producer prices and at market prices (producer prices plus taxes and subsidies over products) [5.11–5.14].

5.2. EVOLUTION OF THE FINAL ENERGY USE PATTERN OF THE BRAZILIAN ECONOMY

Although nature might be a major driver in forging a country's energy profile (climate, natural resource endowment, geography, distances, etc.), previous social and economic choices play a fundamental role in the evolution of final energy uses and environmental damage patterns. It does not matter whether or not such choices are conscious, or whether they are motivated by economic factors, by cultural lifestyle, by market trends or by government intervention (or the lack thereof); the fact is that, to a great extent, previous social and economic choices (by people, corporations and governments) determine the evolution of energy use and environmental profiles. The objective of this section is to analyse the impacts of Brazil's economic development choices on the evolution of its energy use over the past few decades, with the aim of identifying issues that should be explored further in designing strategies to enhance the country's sustainable energy development. To achieve this objective, a decomposition analysis technique, the so-called divisia index method, is used [5.10]. This method is applied to Brazil's final energy figures to reveal the role of economic growth, structural changes and sectoral final energy intensity indicators in the evolution of the country's final energy use.

5.2.1. Decomposition analysis of changes in the final energy use of the Brazilian economy

Figure 5.4 shows the evolution of Brazil's GDP at producer prices and at market prices

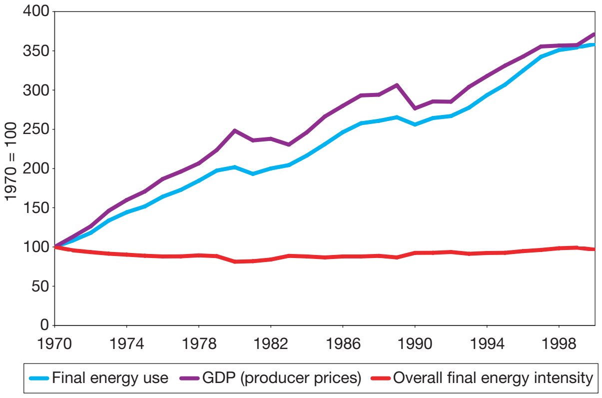

FIG. 5.5. Indices of final energy use, GDP at producer prices (US $ PPP-2000) and final energy intensity of the Brazilian economy [5.11–5.15].
Note: *Final energy figures do not include final energy use by households.*

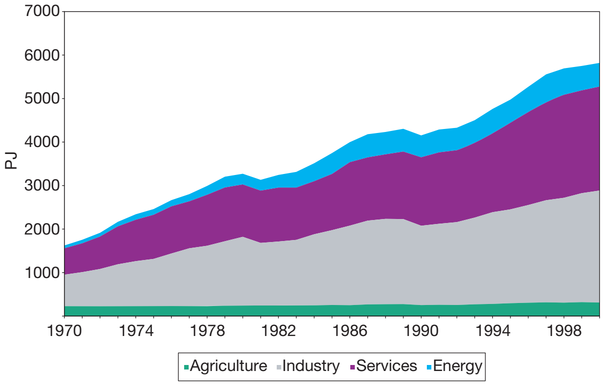

FIG. 5.6. Final energy use of the Brazilian economy by sector [5.15].
Note: *Transport is included in services. Data exclude final energy use by households.*

(producer prices plus taxes and subsidies over products).

Figure 5.5 presents indices of final energy use, GDP at producer prices and final energy intensity of the Brazilian economy over the past three decades (unless otherwise stated, final energy figures in this section exclude final energy use by households). Both the final energy use and the GDP at producer prices more than tripled during the 1970–2000 period. Furthermore, final energy use and the GDP at producer prices were highly correlated throughout the 30 year period. As a consequence, the final energy intensity of the economy is fairly stable for the whole period.

These data do not, however, provide sufficient insights about underlying factors and possible future changes [5.16]. Therefore, a more disaggregated analysis is useful for assessing issues such as the sectoral contributions to final energy use and to the overall final energy intensity, and the factors affecting sectoral activities and energy efficiencies. Among the questions that need to be addressed are the following: What circumstances are hidden by the aggregate final energy figures of Brazil? Why is a desirable decoupling trend between final energy use and GDP not occurring in Brazil? What key driving forces would enable Brazil to leapfrog some steps and decouple final energy use and GDP? Is Brazil adopting less efficient energy technologies? What is happening to the economic structure in Brazil? Are Brazil's choices, hidden in the country's final energy intensity path, leading to a sustainable energy future? To answer these questions, a more systematic and disaggregated approach is necessary. The decomposition technique applied here to the country's sectoral final energy data allows energy use changes to be separated into their basic effects (activity, structure and intensity), which helps to identify the major drivers that affect final energy use variations in an economy.

The decomposition of the Brazilian economy's final energy use changes is performed at two different levels. First, the technique is applied to the final energy use of the economy as a whole, breaking the Brazilian economy down into four sectors: agriculture, industry, services and energy. Then, a closer examination is made of the industrial and services sectors. The industrial sector is further divided into nine branches: mining and quarrying, non-metallic minerals, iron and steel, non-ferrous metals and metalworking (hereinafter, non-ferrous metals), chemicals, food and beverages, textiles, pulp and paper, and other industries. The services sector is divided into three branches: public (including public administration, and sewage and water), transport and other services (including commerce).

Figure 5.6 presents the evolution of the final energy use of the Brazilian economy by sector. The average growth rate of final energy use was 4.3% per year during the 1970–2000 period. Short term declines in the general trends are observed for the 1980–1983 and 1989–1992 periods and for the change in pace for the 1998–2000 period. During the whole period analysed, final energy used by the energy sector increased at an average rate of 7.3% per year, while the industrial and services sectors registered average annual growth rates of 4.3% and 4.7%, respectively. The agricultural sector grew at the average rate of only 1.1% per year in this period.

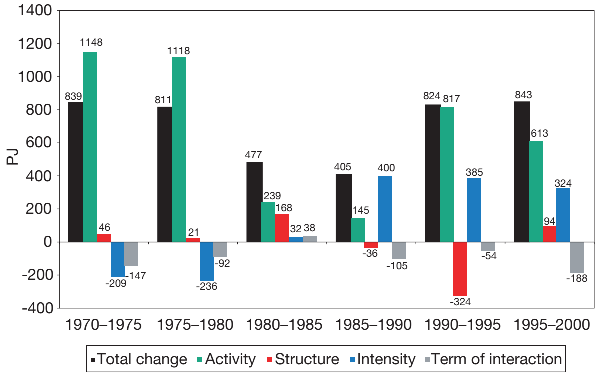

FIG. 5.7. Decomposition of energy use changes in the Brazilian economy [5.11–5.15].

The dynamics of final energy use by sector presented in Fig. 5.6 would be better understood with a simultaneous analysis of the evolution of Brazil's GDP and its sectoral composition, and of the evolution of the sectoral final energy intensity over the period. However, there are different and even contradictory sectoral trends (structural changes and energy intensity coefficients) that make a direct empirical inspection difficult to perform, resulting in a somewhat confused analysis. In this sense, it is better to present the findings of the decomposition analysis first, and then discuss the effects on the GDP, sectoral composition and sectoral final energy intensities.

Figure 5.7 shows the results of the final energy use decomposition analysis for the economy from 1970 to 2000 divided into five-year periods. The figure shows the basic effects (activity, structure and intensity) and the term of interaction.[2]

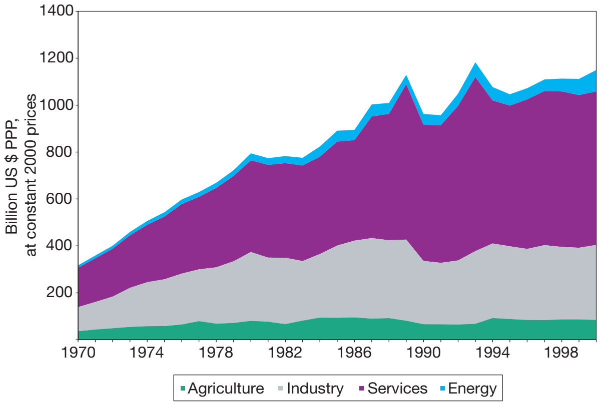

FIG. 5.8. Evolution of value added at producer prices by sector [5.11–5.14].
Note: *Transport is included in services.*

The activity effect was the most important effect behind energy use changes in the economy throughout the 1970–2000 period, except for the 1985–1990 period. The same holds true for the more detailed decomposition analysis performed for this study: overall economic growth was the most important driver of final energy use changes in Brazil during the 1970–2000 period. However, structural changes and energy intensity improvements had smaller but significant effects on energy use during this period — effects that, if understood with respect to their causality and consequences, could guide future decisions about strategies to enhance sustainable energy development in Brazil. These strategies must consider not only the impact of economic growth on energy use, but also the influence that structural changes and sectoral final energy intensity might have on total energy use.

5.2.1.1. Activity effect

Figure 5.8, which shows the evolution of value added (at producer prices) by sector from 1970 to 2000, helps to explain the results for the activity effect, including the minor influence of such an effect on the total energy use changes in the 1980–1985 and 1985–1990 periods.

The economic performance of Brazil in the 1980–1985 and 1985–1990 periods was strongly impacted by tight economic policies implemented by the Government to deal with the balance of payments crises in 1981–1983 and the exacerbated inflation in the late 1980s, respectively [5.17, 5.18]. Such circumstances strongly influenced the magnitude of the activity effect in the 1980s (a negative environment for investments and business

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[2] The term of interaction accounts for changes not explained by a single effect alone; that is, it reflects the simultaneous movement of more than one basic factor (activity, structure and intensity). In the divisia index approach used here, it can be either calculated itself by varying two or more factors simultaneously or reckoned as a residue. In any case, unlike other decomposition techniques, the term of interaction is not an error residue, but a real effect that cannot be cleanly attributed to one variable or the other. A new aluminium plant in an economy, for instance, would, ceteris paribus, simultaneously increase the activity level, shift the economic structure towards energy intensive branches and affect the overall final energy intensity of the economy (both by introducing a more efficient technology in the aluminium branch and by changing the sectoral weights that influence the overall final energy intensity). For details, see Ref. [5.10].

uncertainties) in comparison with other sub-periods. However, the average growth rate of GDP for the entire period was 4.3% per year (the same as the growth rate of final energy use in the Brazilian economy). It is important to note the difference in the economic growth rates in the 1970s, 1980s and 1990s. During the 1970s, the average annual growth rate of GDP was 10.1% in the early part of the decade and fell to around 7.4% by the end of the period. The 1980s and 1990s brought economic crises and diminishing expectations; annual economic growth in these two decades fluctuated between 1.3% and 3.1%, averaging around 2%. Such differences in economic performance are related not only to international events, such as the oil shocks of 1973 and 1979 and international debt crises (beginning with Mexico's default in 1982), but also to choices made to deal with the modifications in the market conditions (both international and domestic) and the economic distortions that resulted from those choices.

The 1970s were the time of the 'Brazilian economic miracle', an economic boom lasting from 1968 to 1973, and the Second National Development Plan, or II PND, launched in 1974. During the 'economic miracle', Brazil registered impressive economic performance, based first on the easing of a previously tight economic policy (to stimulate economic activity in the face of high idle capacity) and then on high private (until 1975) and public investment rates (see Fig. 5.9). In contrast, the II PND aimed at implementing and/or expanding basic industrial branches that were constraining economic growth and generating relevant deficits in the trade accounts, counting on foreign capital and public debt. In addition, during its implementation, the II PND was supposed to (and in fact did) contribute to maintaining the high economic performance by offsetting the decline in private investments (due to the new market conditions and the incipient deterioration of the macroeconomic fundamentals) with higher public investment in basic industrial branches and infrastructure, such as roads, power plants and buildings. [5.19–5.21].

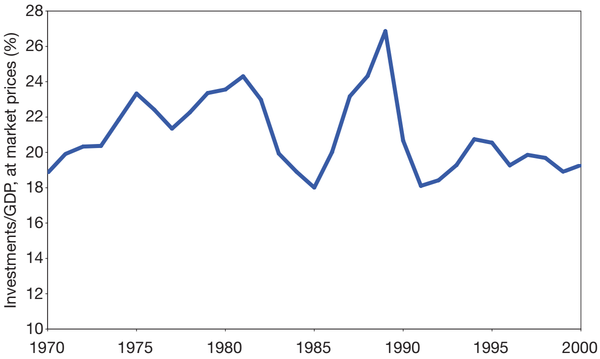

FIG. 5.9. Investment as a percentage of GDP at market prices (US $ PPP-2000) (based on Ref. [5.12]).

Note: *Investment here excludes inventory changes, meaning it considers only gross fixed capital formation.*

In the 1980s, Brazil's macroeconomic performance was strongly impacted by the balance of payments crises in 1981–1983, worsening inflation and the tight economic policies implemented by the Government to deal with these two issues [5.17, 5.18]. Delays in dealing with balance of payments problems, changes in US monetary policy in the 1980s, the new international financial environment worsened by Mexico's default (1982) and delays in changing domestic economic policies led to Brazil's debt crisis and to the so-called 'lost decade' of the 1980s, where a series of financial adjustments and monetary reform plans (Cruzado in 1986, Cruzado II in 1986–1987, Bresser in 1987, Verão in 1989 and Collor in 1990) based on stop-and-go policies failed to re-establish economic stability and exacerbated inflation.

Short term necessity rather than consistent long term development strategy guided public policies in Brazil after the 1980s [5.22]. Even relatively successful policies, such as the consolidation of capital and the development of indigenous energy technology and markets, were considerably distorted by arrangements set to address short term needs (underpricing of energy and material resources to control inflation, excessive subsidies, fiscal and domestic industrial protection schemes, etc.).

During the 1990s, the economic adjustments continued with ambitious State reform and a market liberalization strategy, which included the privatization of several State owned companies and market deregulation [5.23]. The privatization and market liberalization programme continued throughout the 1990s, and the Government concluded the national debt renegotiations, improved the public accounts and further stabilized inflation with the so-called Real Plan [5.24, 5.25]. Such a new environment was fundamental for raising the economic expectations of both national and foreign investors and for increasing economic growth in Brazil during the 1990s compared with the 1980s. However, the economic performance of the 1970s was not achieved again.

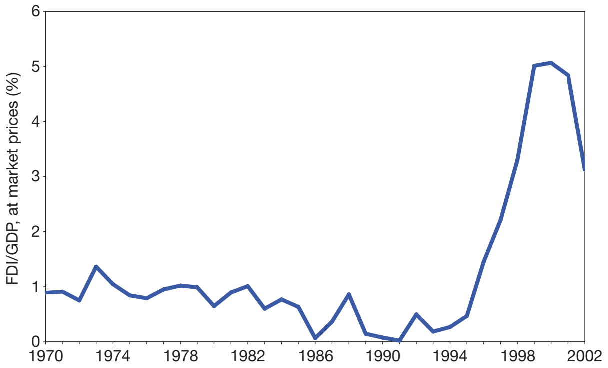

FIG. 5.10. Evolution of the ratio of foreign direct investment (FDI) to GDP at market prices (based on Ref. [5.12]).

The privatization and market liberalization programme was deepened and consolidated during the 1998–2000 period [5.23, 5.26]. Although some institutional arrangements in the power system were not successful [5.27, 5.28], several market distortions were reduced and new sectoral regulatory regimes were set (see Chapter 2 for a discussion of energy regulatory reform). Favourable international market conditions during this time made it possible to attract foreign investment (see Fig. 5.10) and to boost economic growth in Brazil.

However, delays in promoting structural adjustments in the country's public and foreign accounts left the Brazilian economy vulnerable to external shocks (see Fig. 5.11). Overvaluation of the Brazilian real and successive financial crises worldwide (in Mexico, East Asia and the Russian Federation, and with Brazil's own devaluation crisis in 1999) contributed to the decline in economic growth throughout the 1990s [5.23].

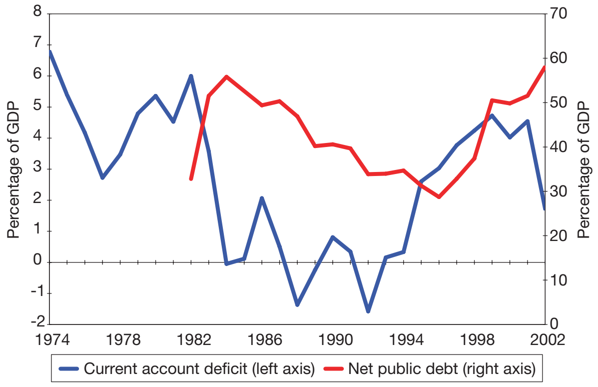

FIG. 5.11. Evolution of net public debt and deficit in current account (based on Refs [5.12, 5.14]). Net public debt = gross public debt – public assets; current account = merchandise account (goods exports and imports) + service account + unilateral (current) transfers. Negative figures mean surpluses in current account in the relevant year.

The bottom line of the analysis of the contribution of the activity effect to energy use changes in Brazil is that higher economic growth has led to higher energy use. Nevertheless, structure and intensity effects have either magnified or offset the activity effect. Thus, a fundamental task in deciphering the energy profile of a country is to further analyse how structure and intensity effects evolve.

5.2.1.2. Structure effect

The decomposition in Fig. 5.7 shows that the structure effect for the Brazilian economy as a whole was negligible during the 1970s and in the 1985–1990 period, and modest during the 1995–2000 period. However, the structure effect was relevant during the 1980–1985 and 1990–1995 periods. Table 5.1 presents the contribution of each sector in

TABLE 5.1. COMPOSITION OF GDP BY SECTOR[a] (%) [5.11–5.14]

Sector	1970	1975	1980	1985	1990	1995	2000
Agriculture	12.3	11.5	11.0	11.9	8.1	9.0	7.7
Industry	34.6	39.3	39.7	38.9	32.8	31.5	28.9
Services[b]	56.4	52.7	53.0	56.0	70.6	61.0	59.2
Energy	3.5	3.6	4.0	5.9	5.6	4.9	8.3
Financial dummy (FISIM)[c]	–6.9	–7.2	–7.8	–12.7	–17.1	–6.4	–4.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] GDP at producer prices based on US $ PPP, at constant 2000 prices.
[b] Transport is included in the services sector.
[c] Financial dummy — financial intermediation services indirectly measured (FISIM), an adjustment introduced to prevent double counting (see footnote 3). For detailed information, see Ref. [5.29].

terms of value added to GDP at producer prices. The trends in energy use in each of these sectors are depicted in Fig. 5.6.

Note that the sum of the sectoral shares exceeds 100% in Table 5.1. This is due to a term identified as the financial dummy, which is a negative share considered in the calculations.[3]

Table 5.1 shows that the value added share of the industrial sector in GDP increased during the 1970s and decreased during the 1980s and 1990s. Good overall economic performance, mainly due to the 'Brazilian economic miracle' and the II PND, was behind the shift towards the higher industrial share in the economic structure of Brazil in the 1970s. Poor economic growth, price controls on basic materials produced by State owned companies (mainly steel and petrochemicals), industrial commodities price collapse and changes in relative prices due to inflation in favour of some services (financial services and dwelling rents, for instance) explain the reduction of the industrial sector's share of GDP in the late 1980s and 1990s.

The share of the agricultural sector registered a downward trend through the period as a whole (except for temporary increases in 1985 and 1995). The long term decline in agricultural commodity prices, a policy bias towards industry in the 1970s, changes in relative prices in favour of services due to inflation in the 1980s and 1990s (including strict price controls on agricultural products as part of stabilization plans to combat inflation) and the lack of consistent long term policies for agriculture explain the shift away from agriculture in the 1970–2000 period. The exceptions in 1985 and 1995 were mainly motivated by short term policies to increase domestic supply (through financing schemes and fiscal incentives or compensations for price controls to help control inflation) and exports (to deal with imbalances in the balance of payments).

Despite large investments in energy supply (see Fig. 5.12), the contribution of the energy sector to GDP presented a modest upward trend until 1985, when Government interventions in energy prices became more frequent and generalized debts among power corporations (generators and distributors) eroded profitability (see Chapter 2). The institutional restructuring from 1995 to 2000, including privatization and market liberalization, improved the energy sector's profitability and value added. Also, during the late 1990s, the increase of petroleum production in Brazil by Petrobras and the company's strategy of shifting the oil product mix towards higher value added products also contributed to increasing the share of the energy sector in the GDP at producer prices [5.34].

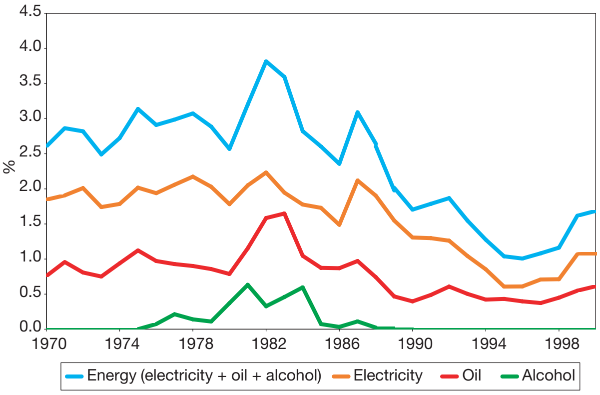

FIG. 5.12. Investment in the energy sector as a percentage of GDP at market prices (US $ PPP-2000) (based on Refs [5.12, 5.28, 5.30–5.33]).

The II PND, launched in 1974, set as a priority target an increase in the production capacity of capital goods, basic materials, energy, transport and communication. The construction of Itaipu (12.6 GW) and Tucuruí (4.0 GW), Brazil's two largest hydropower plants, and the offshore upstream investment programme of Petrobras started at that time. The investments in capital goods, basic materials and energy promoted by the II PND were consolidated in the early 1980s, explaining the relevant structure effect in the 1980–1985 period. The fall in the industrial and energy sector shares was behind the negative structure effect in energy use in the 1990–1995 period. The energy sector's share of GDP increased from 4.9% in 1995 to 8.3% in 2000, explaining the positive structure effect in 2000. In summary, structural changes resulting from policies and decisions made as well as economic circumstances have affected the overall energy intensity and energy use of the Brazilian economy.

After a decrease in the 1970s, the contribution of services to GDP increased sharply in the late

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[3] 'Financial dummy' is how the System of National Accounts of Brazil denominates the so-called financial intermediation services indirectly measured (FISIM), which is the value of the services provided by financial intermediaries for which no explicit charges are made [5.29]. The apparent differences between GDP at producer prices in Figs 5.4 and 5.8 arise because the financial dummy is not made explicit in the latter (total value added at producer prices + financial dummy = GDP at producer prices).

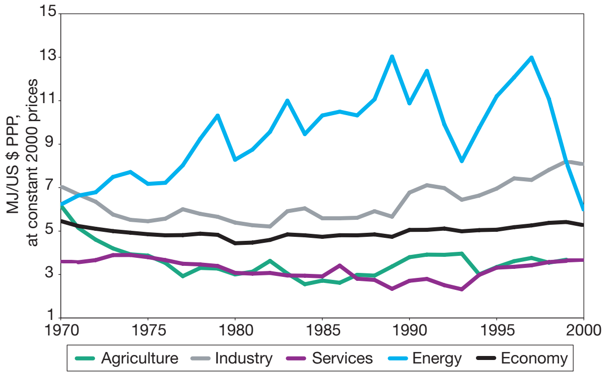

FIG. 5.13. Evolution of overall and sectoral final energy intensity indicators [5.11–5.15].

Note: *Economy excludes household sector. Non-energy use is not included.*

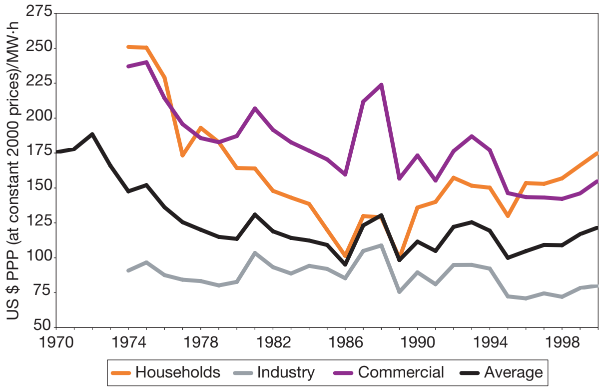

FIG. 5.14. Electricity prices by sector [5.12, 5.14, 5.36].

1980s and early 1990s (the financial services and dwelling rental branches led to this rise as a result of high inflation). This contribution then decreased as inflation was controlled (the financial dummy is highly correlated to inflation[4]).

5.2.1.3. Intensity effect

The decomposition of overall energy use presented in Fig. 5.7 shows that the intensity effect was negative during the 1970s and positive through the 1980s and 1990s. In the 1970s, the intensity effect partially offset the activity effect, while during the 1980s and 1990s the intensity effect reinforced the activity effect.

Figure 5.13 shows the evolution of final energy intensity by sector (agriculture, industry, services and energy) and for the economy as a whole. The relative stability of the overall final energy intensity of the Brazilian economy results from complex movements of sectoral growth and many factors that compensate one another. The differences in sectoral final energy intensity trajectories reflect the impact of several factors, including the sectors' own activity, structural and efficiency changes and conflicting intra-sectoral trends.

Since the industrial and services sectors will be further analysed in later sections of this chapter, only the energy intensities of agriculture and energy are discussed here. The trajectory of the final energy intensity of agriculture can be split into two major trends [5.35]. From 1970 to 1985, the substitution of modern energy carriers for fuelwood and the introduction of more efficient technologies set into motion a downward trend in the agricultural energy intensity indicator. From 1985 to 2000, increased mechanization in the countryside induced an upward trend in the agricultural energy intensity. Changes in the agriculture product mix and in the average prices of agricultural products have also affected agriculture's final energy intensity trajectory, but further evidence is needed to allow a more precise analysis of the path observed in this sectoral indicator.

The evolution of the final energy intensity of the energy sector did not follow a stable trend during the 1970–2000 period. This seems to be related to the fact that the Brazilian Government has used energy prices to control inflation several times over the past three decades. In this sense, the impact of energy price deterioration and recuperation affected the value added of the energy sector deeply (see Fig. 5.8), leading to the fluctuations in the sectoral final energy intensity indicator (see Fig. 5.14 for changes in electricity prices). A closer look at the 1995–2000 period, in particular, seems to support such an explanation: the final energy use of the Brazilian energy sector stayed steady at about 540 PJ, while its value added increased at an impressive 13.8% per year through the period (from US $ PPP 47.9 billion to US $ PPP 91.2 billion, at constant 2000 prices).

Intra-sectoral changes (due to oil shocks, energy savings, Brazil's automotive ethanol programme, etc.) and energy import substitutions, which increase the final energy requirements for the energy sector to supply the same amount of energy to the other sectors (see Fig. 5.15), affected the evolution of the final energy intensity of this sector

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[4] The impact that the stabilization of the economy had on the financial dummy should be stressed: the financial dummy changed from –17.1% in 1990 to an impressive –31.0% in 1993 and to –6.4% in 1995.

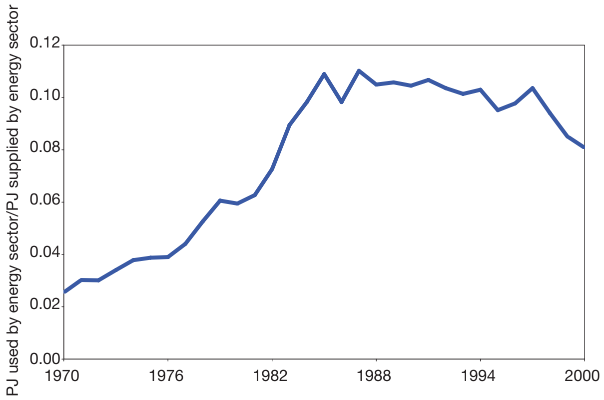

FIG. 5.15. Ratio of final energy use by the energy sector to final energy supplied to all other sectors (including household and non-energy use) [5.15].

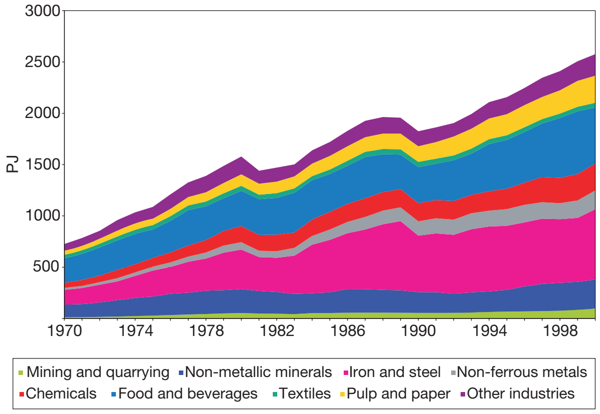

FIG. 5.16. Final energy use of the Brazilian industrial sector by branch [5.15].

as well. However, further evidence is needed to allow a more precise analysis of the trends observed in this sectoral indicator.

In summary, it is possible to say that overall economic growth was the most important effect influencing final energy use changes in Brazil during the 1970–2000 period as a whole, by pushing energy use up during the 1970s and 1990s and down during the 1980s. Nevertheless, structure and intensity effects have also influenced the energy use changes of the Brazilian economy during the past three decades, albeit to a lesser extent. In this sense, a strategy to enhance sustainable energy development in Brazil should consider not only the impact of economic growth on energy use, but also the influence that structural changes and sectoral final energy intensity might have.

5.2.2. Decomposition analysis of changes in final energy use of the industrial sector

5.2.2.1. Activity effect

Figure 5.16 presents the evolution of the final energy use of Brazil's industrial sector by branch and as a whole. The average overall growth rate of the final energy use for this sector was 4.3% per year during the 1970–2000 period. Figure 5.16 shows the impact of the 1981–1983 and 1990–1992 economic recessions in the overall trends. During the period considered here, final energy use by the non-ferrous metals, mining and quarrying, pulp and paper, chemicals, and iron and steel branches increased at growth rates above the average growth rate of the overall industrial sector.

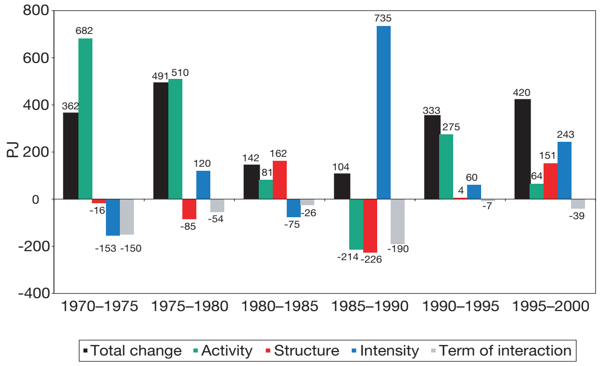

FIG. 5.17. Decomposition of final energy use changes in the Brazilian industrial sector [5.11–5.15].

Figure 5.17 shows the results of the final energy use decomposition analysis for the industrial sector, including the activity, structure and intensity effects and the term of interaction. The activity effect was the most important effect behind final energy use changes in industry during the 1970s and in the 1990–1995 period. During the 1980s and in the 1995–2000 period, structure and intensity effects were more important.

The activity effect was minor in the 1980–1985, 1985–1990 and 1995–2000 periods. The economic performance of the industrial sector in these periods was strongly impacted by tight economic policies implemented by the Government to deal with the balance of payments crises in 1981–1983, the exacerbated inflation in the late 1980s and early 1990s, and the international financial crises in the second half of the 1990s, respectively. Such factors, as well as international price fluctuations, have strongly influenced the magnitude of the activity effect over the past three decades.

TABLE 5.2. INDUSTRIAL SECTOR VALUE ADDED* BY BRANCH (%) [5.11–5.14]

Sector branch	1970	1975	1980	1985	1990	1995	2000
Mining and quarrying	1.3	1.5	2.2	3.2	1.8	1.4	1.2
Non-metallic minerals	4.8	4.9	4.8	3.7	4.0	3.6	3.4
Iron and steel	4.2	4.3	2.9	3.7	3.0	3.1	3.6
Non-ferrous metals	5.6	5.9	6.9	6.8	6.0	5.6	4.7
Chemicals	7.2	8.1	8.0	10.9	9.3	8.3	8.5
Food and beverages	12.9	11.8	10.5	11.5	9.5	10.8	11.0
Textiles	8.0	5.2	5.6	5.4	4.8	2.7	1.6
Pulp and paper	2.1	2.1	2.4	2.5	1.9	2.1	3.1
Other industries	53.8	56.2	56.6	52.3	59.7	62.4	62.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Based on producer prices.

5.2.2.2. *Structure effect*

Table 5.2 shows the industrial value added shares for the 1970–2000 period. Figure 5.18 shows the evolution of industrial value added by branch during this period. Throughout the period, the greatest structural change in the industrial sector was in the ‘other industries’ category, with a 9% gain. ‘Other industries’ include machinery, equipment, electrical devices and construction. All other branches experienced marginal share reductions over the whole period, except for marginal gains in chemicals and in pulp and paper.

The impact of the II PND on the industrial structure from 1975 to 1985 is revealed in the increased shares of some of the energy intensive branches (non-ferrous metals, chemicals, and pulp and paper), but also in the higher shares of other industries up to 1980. From 1985 on, the energy intensive branches started exporting significant shares of their production, not only because of the poor economic growth of the Brazilian economy (which reduced domestic demand for basic materials), but also because of Government incentives to export associated with the balance of payments crises and electricity underpricing (especially in the case of aluminium). The Government tax incentive schemes have not yet been entirely removed (see, for instance, Complementary Law 87 of 13 September 1996, the so-called Kandir Law), nor have the electricity prices been totally corrected for energy intensive branches (cross-subsidies with other industrial branches and with the residential and commercial sectors; see Fig. 5.14).

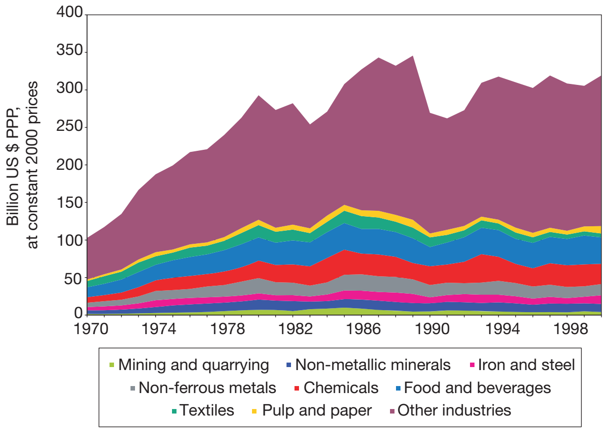

FIG. 5.18. Industrial sector: Value added at producer prices [5.11–5.14].

Although the value added shares of the energy intensive branches (non-metallic minerals, iron and steel, non-ferrous metals, chemicals, and pulp and paper) remained below 28% during the whole period, those branches accounted for the lion’s share of the industrial sector’s final energy use — rising from 51.8% in 1970 to 65.1% in 2000. This trend points towards increasing energy intensities in the energy intensive branches of the industrial sector. However, if the situation for some branches is analysed using physical output instead of value added, the structural stability of energy intensive branches may be misleading. Figure 5.19 shows the evolution of iron and steel’s value added and crude steel production. While the value added of this branch remained relatively constant at US $ PPP 8–12 billion, the production increased from 8 Mt in 1975 to about 28 Mt in 2000. The profitability of the iron and steel branch was affected by long term

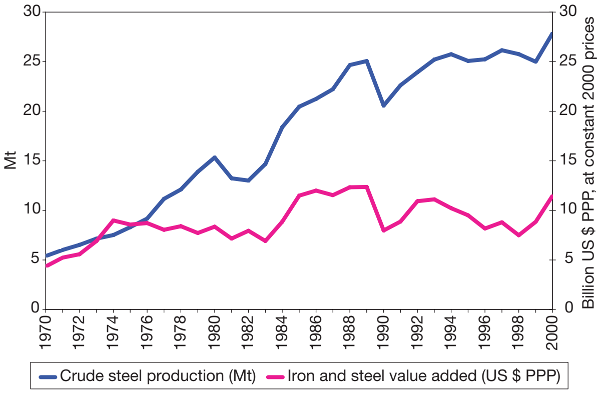

FIG. 5.19. Iron and steel branch: Value added at producer prices and crude steel production [5.11–5.14, 5.37].

downward trends in international steel prices, by a shift towards low value added steel products in the product mix and, as in the energy sector, by the Government's use of State owned steel companies to control inflation in the 1980s and early 1990s, before these companies were privatized [5.38]. Such circumstances hide the actual growth in the production of the iron and steel branch in Brazil, as well as its impact on the country's economic structure.

5.2.2.3. *Intensity effect*

As shown in Fig. 5.17, the intensity effect on the industrial sector was negative in the 1970–1975 and 1980–1985 periods, but positive in all other periods. In particular, from 1990 to 2000 the intensity effect in Brazil did not offset the activity effect. On the contrary, it actually reinforced the activity effect. In fact, in 1985–1990, when the activity, the structure and the term of interaction effects were all negative, the intensity effect compensated for all of them. Nevertheless, a more detailed analysis of the situation shows that the industrial sector as a whole was not so inefficient in this period.

Figure 5.20 shows the evolution of final energy intensity by branch and for the industrial sector as a whole. Some branches — such as iron and steel, and pulp and paper — experienced volatile but net upward trends in their energy intensities. Other branches had relatively stable trends throughout the period. The resulting overall final energy intensity of the industrial sector registered a slightly upward trend of about 0.4% per year. Such a trend, in fact, results from a complex combination of intra-sectoral trends, since the overall industrial energy intensity is an average of the energy intensity coefficients of the different branches weighted by the share of each branch in the industrial sector.

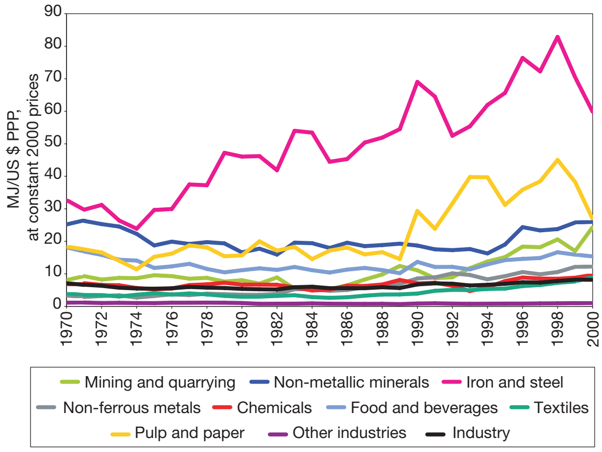

FIG. 5.20. Evolution of final energy intensity by industrial branch [5.11–5.15].

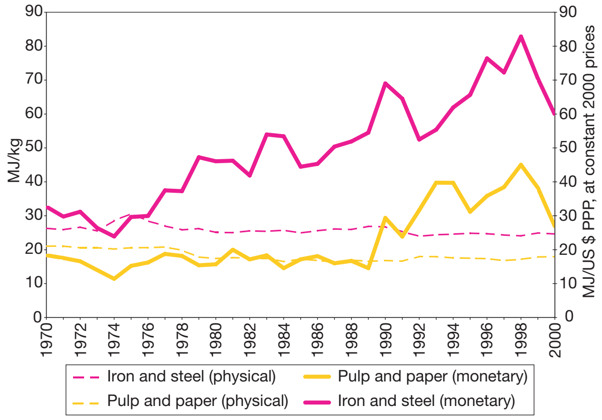

FIG. 5.21. Final energy intensity versus specific final energy use (physical final energy intensity) in the iron and steel and pulp and paper branches [5.11–5.14, 5.37, 5.39].

Although energy intensities for the energy intensive branches show an increasing trend, there is evidence that such trends are related more to international price depressions and changes in product mix towards lower value added products than to inefficient energy technologies. Figure 5.21 compares final energy intensity and specific final energy use for the iron and steel and the pulp and paper branches. In the case of iron and steel, a major difference is observed between the energy intensity (based on value added) and the specific final energy use (based on physical output). In the case of pulp and paper, the two indicators were highly correlated until 1989, when a major increase in the energy intensity (based on value added) took place. According to some industrial competitiveness surveys performed in Brazil, similar trends were observed in most of the energy intensive industrial branches in the country [5.40, 5.41].

A strategy that aims at enhancing sustainable energy development in Brazil should be aware of such evidence. Promoting structural changes towards less energy intensive industries and towards a higher value added industrial product mix is as important as promoting energy efficiency to enhance sustainable energy development in the country.

On the one hand, the development of a shipbuilding industry that exports ferry boats, and of the Embraer Corporation, which builds and exports aircraft, are two examples of downstream expansion that have added value to Brazilian natural resources (it is not mandatory that the same corporation be involved in all steps, but it is fundamental to develop downstream links in the production chain). On the other hand, the steel and aluminium industries are two examples of industries that have shifted to a lower value product mix as part of a business strategy on the international market. Both strategies are possible; it is a matter of choice and of whether the proper environment exists (public policies and sectoral regulation play important roles in establishing such an environment).

5.2.3. Decomposition analysis of changes in final energy use of the services sector

5.2.3.1. Activity effect

Figure 5.22 shows the evolution of the final energy use of the services sector by branch (public, transport and other services). The average annual growth rate of the final energy use of Brazil's services sector as a whole was 4.7% during the 1970–2000 period. Transport accounted for by far the largest share of energy use for the entire period, though its share fell from 91% in 1970 to 86% in 2000.

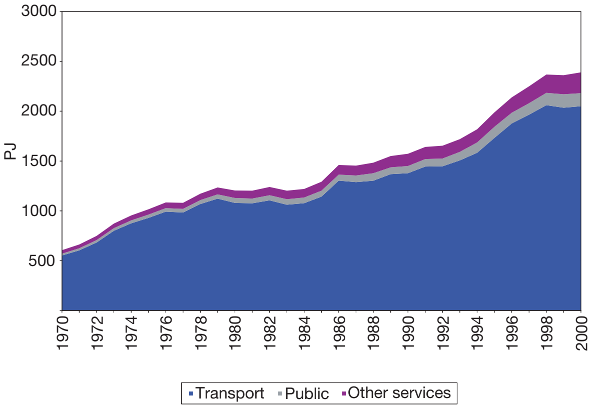

FIG. 5.22. Final energy use of the services sector by branch [5.15].

Note: *Public includes public administration and sewage and water.*

Figure 5.23 presents the results of the final energy use decomposition analysis of Brazil's services sector. The figures show that the activity effect was the primary force in final energy use changes throughout the 1980s. During the 1990s, intensity and structure effects were more important than the activity effect.

Figure 5.24 shows the evolution of the value added of the services sector in the 1970–2000 period. The overall value added of this sector grew at an average annual rate of 4.6%, similar to the sector's average final energy use growth rate. Different driving forces have affected the economic performance of this sector over the past three decades. During the 1970s, the sector's value added increased as a result of economic spillovers associated with the strong overall economic

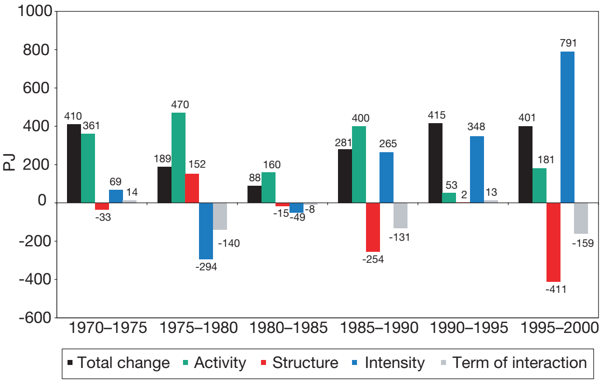

FIG. 5.23. Decomposition of final energy use changes in services sector [5.11–5.15].

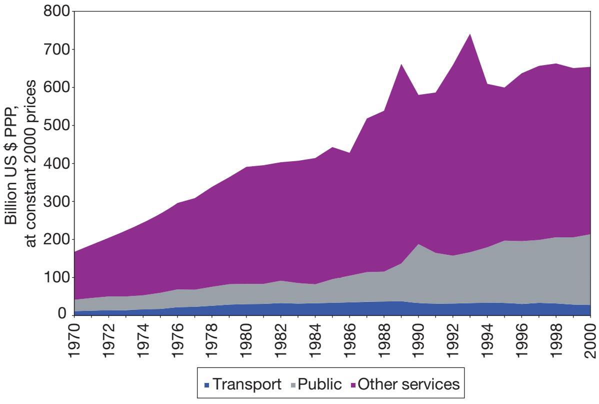

FIG. 5.24. Services sector: Value added at producer prices by branch [5.11–5.14].

TABLE 5.3. SERVICES SECTOR VALUE ADDED* BY BRANCH (%) [5.11–5.14]

Sector branch	1970	1975	1980	1985	1990	1995	2000
Public sector	17.8	15.8	13.7	14	26.8	27.2	28.4
Transport	7.0	6.6	7.7	7.6	5.6	5.6	4.3
Other services	75.2	77.6	78.6	78.4	67.6	67.2	67.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Based on producer prices.

performance of Brazil. In the 1970s, commerce, services to families, services to corporations and non-profit services contributed some 25% to the overall GDP (producer prices), while financial services and dwelling rentals held around 15% during the same period [5.11, 5.13].

During the 1980s and the 1990s, the driving forces affecting the economic performance of the services sector changed, mainly due to increases in inflation, public expenditure and economic uncertainties [5.23]. The poor overall economic performance of Brazil, combined with inflation, high interest rates (associated with both foreign and public debts) and economic uncertainties, drained significant amounts of capital from the overall economy towards the financial services and dwelling rental segments. These two segments increased their contribution to GDP from around 15% during the 1970s to some 24% through the past two decades, reaching a high of 35% of GDP in years of higher inflation (1989, 1992 and 1993). Yet the public administration branch also increased its contribution to GDP during the 1990s, reaching 16.5% in 2000 [5.11, 5.13].

5.2.3.2. Structure effect

Figure 5.23 shows that the structure effect was usually significant (except for the 1990–1995 period). The value added for the public services branch grew at an average rate of 6.3% per year during the 1970–2000 period, compared with 2.9% per year for transport and 4.3% for other services. Table 5.3 shows the value added shares for the 1970–2000 period.

When split into periods, the annual value added growth rate figures for public services varied greatly, from a low of 1.0% in 1990–1995 to an impressive 20.1% in 1985–1990. These fluctuations resulted mainly from successive periods of tight and loose fiscal discipline imposed in response to external shocks, public account deterioration and political pressure, which impacted the economic performance of the public services branch throughout this period. In particular, the major programmes implemented in 1985–1990 for rapid universalization of social welfare explain the impressive public services value added growth rate during this subperiod. However, since other public expenditures were not cut off to counterbalance the total public expenditure, the public services value added growth rate decreased sharply in the following subperiods. Nevertheless, the share of public services out of the services sector's total value added continued to increase throughout the 1990s.

The share of value added for transport decreased after 1980. This trend was related to low efficiency in the freight transport system, a deterioration of the public transport system that led to a fall in the load factor (number of passengers per vehicle) and a decrease of total revenue, tariff underpricing to control inflation during the 1980s and early 1990s, and an increase in fuel prices, which affected the profitability of transport.

The share of value added for other services also declined throughout the 1980s and 1990s. The main driving forces behind this trend were poor economic performance and inflation during this period.

5.2.3.3. Intensity effect

Figure 5.25 shows the evolution of the final energy intensity of the services sector by branch. The intensity of other services remained fairly stable throughout the period. Minor fluctuations in the intensity of this branch are related to the changes in the share of financial services in other services' value added, to the higher use of electricity in this branch and to intra-sectoral changes towards more energy intensive service segments (shopping malls, high profile hotels and commercial buildings, etc.).

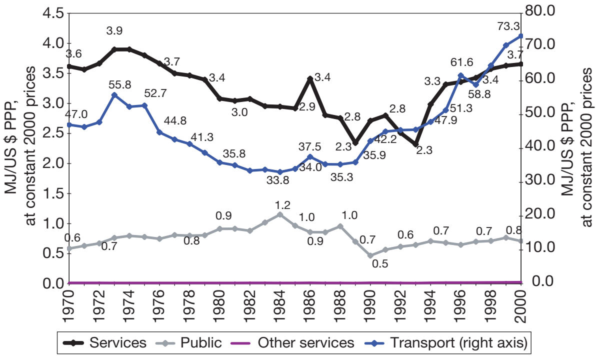

FIG. 5.25. Evolution of final energy intensity of the services sector by branch [5.11–5.15].

The energy intensity in the transport branch increased from 47 MJ/US $ PPP in 1987 to 73 MJ/ US $ PPP in 2000. This trend is related to inter-mode substitution towards road freight transport and private transport (away from public passenger transport), and to a fall in value added resulting from tariff control and deterioration of the public transport system that reinforced preferences for private and alternative transport.

Road transport makes up the largest part of both the public passenger and freight transport categories, accounting for around 95% and 60%, respectively. According to CNT [5.42, 5.43], this type of structure is responsible for the low efficiency of the transport sector in Brazil and leads to a higher fuel demand than would be needed with an adequate structure. The economic costs of time wasted in urban traffic jams in ten cities of Brazil is estimated to be around US $100 million per year, and the additional fuel costs are appraised at approximately US $55 million per year — US $43 million per year in São Paulo alone [5.44].

A strategy that aims at enhancing sustainable energy development in Brazil should take this into account. Promoting inter-mode transport substitution away from private transport and energy efficient technologies in energy intensive segments of the services sector are relevant steps in enhancing sustainable energy development in Brazil.

5.3. STRATEGIES TO ENHANCE SUSTAINABLE ENERGY DEVELOPMENT IN BRAZIL

Governments must select an appropriate portfolio of targeted policies to satisfy future energy demand in a sustainable way. This will entail embracing multiple and often conflicting objectives, including promoting efficiency and competition in energy markets; remedying market and government policy failures; ensuring that people with low incomes have access to modern energy sources at affordable prices; securing long term investments in modern energy infrastructure (either by providing an attractive market environment or through State owned companies); promoting technology to stimulate structural changes (dematerialization of the economy and upgrading of exports); promoting investment to leapfrog energy technologies in developing country markets; and serving generally as a catalyst in coordinating different social and economic strategies and stakeholder interests.

The scenarios defined and discussed in Chapter 10 explore future economic strategies and their consequences across a broad spectrum of assumptions and constraints. These scenarios deal with possible futures rather than forecasts and are intended to provide insight into policy implications and consequences of selected strategies.

5.3.1. Fostering macroeconomic stability

The first lesson to be drawn from the past three decades in Brazil is that, without a good environment for business, economic performance will be poor. A good environment for business includes macroeconomic stability, appropriate and stable institutions and market regulations, adequate long term funding for infrastructure investments and satisfactory human capital development. Absent these preconditions, the ‘stop-and-go’ pattern of economic growth that characterized the 1980s and the 1990s in Brazil may continue.

Changes in economic policies introduced with the Real Plan in 1994 and additional policy corrections and reorientations (such as the devaluation of the Brazilian real, the funding of exports and the introduction of the budget responsibility law) were initial steps towards long term macroeconomic stability (characterized by low inflation, balanced public debt and external accounts, and lower interest rates) to promote long term economic growth. Studies of the macroeconomic conditions that would be needed for long term economic growth of 3–5% per year in Brazil[5]

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[5] For a detailed analysis of macroeconomic conditions to promote long term economic growth in Brazil, see Refs [5.45–5.48].

envision public debt reduction to some 40% of GDP by 2011 and a growth rate for investment of some 20–30% above the growth rate for GDP. Macroeconomic indicator targets currently defined by the Government are in line with these conditions [5.49–5.51]. The scenarios in Chapter 10 assume that these basic macroeconomic stability conditions prevail. Assuming this as a starting point for all future policy developments, scenario differences arise because of different assumptions about resource and political constraints and policy initiatives, all of which will have consequences in terms of supply and demand, industrial structure, investment patterns, corporate debt and profitability, infrastructure needs, human resources and allocation of public spending. Regulatory measures (subsidies, incentives, debt forgiveness and public spending allocations) will also have an impact on future growth patterns

5.3.2. Promoting efficiency and competition in energy markets

The second lesson learned from the past 30 years is that distorting energy prices not only undermines the economic health, operative efficiency and expansion of the energy sector, but also leads to inefficient energy use and to environmental damage. Since the 1930s, Brazil has devoted considerable public resources to developing a broad modern energy delivery system and nationwide commercial energy markets. The efficacy of this investment is clearly seen by comparing Brazil's energy sector with those of other developing countries [5.52]. Nevertheless, over time, the Government's regular use of the energy sector as a vehicle for imposing development policies, controlling inflation and reducing debt has damaged the efficiency and skewed the costs of the energy system.

The energy market liberalization begun in the 1990s aimed at dealing with these problems and removing government failures created during the development of the Brazilian energy sector. However, some mistakes were made during the transition to a more liberalized energy market, mainly in the electricity sector, where privatization and market liberalization were established before market and institutional arrangements had been restructured, including implementation of the regulatory agency [5.23, 5.27, 5.28].

There are still many improvements to be made in energy market regulations to ensure continuous stimulation of technical (including energy service quality and environmental performance aspects) and economic efficiency (increasing competition or regulating market power in relevant segments). This is particularly true in the electricity sector, where a significant institutional restructuring is currently taking place. In any case, the main lesson learned from the past 30 years is that distorting energy prices, mainly through generalized subsidies and the failure to internalize environmental costs, not only undermines the economic health, operative efficiency and expanding capacity of the energy sector, but also leads to wasteful and/or excessive energy use (preventing or reducing investments in energy efficiency) and to environmental damage. Interestingly enough, as pointed out by Verbruggen [5.53], higher energy prices (including increases from internalizing environment costs) do not necessarily mean higher energy bills, since higher prices stimulate greater energy efficiency and prevent wasteful and excessive use of energy. On the contrary, low prices lead to spillage and excessive use of energy such that energy bills could be even higher. In this sense, a proper discussion about affordability should focus on energy bills rather than on energy prices.

Enhancing sustainable energy development requires that market and government failures be removed from energy markets, including cross-subsidies in energy prices that favour energy intensive activities, which gives the wrong market signals and prevents or retards structural changes away from energy intensive activities or uses (households) and upgrades in the product mix, and increases environmental damage. It is also important to note that unbalanced market regulations in favour of either corporations or consumers are always unsustainable in the long run, creating pressure to change regulations sooner or later, which introduces uncertainties for investors. In this sense, the main challenge to be faced by energy regulators in the new energy market institutional arrangements and regulations in Brazil is to establish balanced (rights and duties of economic agents, including an appropriate price level and a fairer price structure) and stable regulations that induce energy and economic efficiency by removing both market and government failures (including environmental externalities). Defining appropriate energy price levels that balance the interests of producers and consumers, ensure energy and economic efficiencies, and minimize environmental damage, on the one hand, and establishing a fairer price structure that balances different consumers' interests, on the other hand, are key elements of enhancing sustainable energy development.

5.3.3. Promoting access to modern energy at affordable prices for low income groups

While reducing price distortions (including those created by subsidies) is necessary to enhance sustainable energy development, promoting modern energy accessibility and affordability for low income groups is a fundamental step towards sustainable energy development. The lack of accessibility for people in rural areas may be overcome by local generation or by extending the grid into the countryside, choosing the more cost effective programme (see Chapter 9). Regarding affordability, the solution to this apparent paradox is that the Government should provide income transfers directly to low income families to cover the amount needed to pay for modern energy carriers.

This kind of approach has been applied effectively in several recent social programmes in Brazil. For instance, after the oil market liberalization when subsidies were removed, the Brazilian Government established the liquefied petroleum gas (LPG) grant to offset negative economic impacts for low income families.[6] This sort of 'subsidy' is much more efficient and focused on low income groups than a wide subsidy system, although monitoring problems can arise (efficient monitoring schemes are needed to prevent distortions). Extensive subsidy systems waste public resources by giving subsidies to those that can pay for modern energy carriers (here, LPG), stimulating wasteful, excessive or inappropriate use of such carriers. Furthermore, since people with low incomes receive money rather than LPG bottles or coupons, they may decide to use LPG more rationally by preventing wasteful and excessive habits and investing in more efficient stoves and pans (such as pressure cookers) in order to save money to buy other things. In this sense, besides being more cost effective for the Government, this kind of mechanism may even encourage energy efficiency.

In the case of electricity, the prices are structured so that consumers that use up to 100 kW·h per month and monophasic connections receive price discounts. This arrangement works as a subsidy for low income groups (actually a cross-subsidy, because other consumers are overcharged). However, such mechanisms do not stimulate energy efficiency or prevent the loss of the proper social focus (protecting low income groups) due to their general approach. As argued before, broad subsidy approaches generally lead to a loss of focus, which leads to excessive economic costs for reaching the policy objective. For instance, there are people with high incomes that own countryside and beach houses in Brazil that fit the price discount conditions established by the Brazilian Government (electricity usage below 100 kW·h/month and monophasic connections).

5.3.4. Ensuring long term investment in energy infrastructure

Modern energy supply is usually needed to improve people's well-being and to support economic growth in contemporary societies. Therefore, ceteris paribus, a shortage of modern energy supply affects economic growth and people's well-being, and uncertainty about the future availability of modern energy to support higher levels of activity discourages expansion in production capacity by non-energy corporations, which constrains potential future economic growth. A lack of investment in modern energy infrastructure also retards broader access to modern carriers (particularly to low income groups in remote rural areas), keeping millions of people at low standards of living.

In this sense, ensuring long term investments in modern energy infrastructure to satisfy future modern energy demand is a key step in enhancing sustainable energy development. Long term investments demand capital availability (both domestic and foreign), an attractive market environment and long term financing schemes.

Brazil does not have a mature long term domestic private capital market, mainly because the opportunity cost of capital is simply too high (private capital obtains high profits by lending money to the Government in the short term). In this sense, Brazil will continue to depend on public money (especially from the Brazilian National

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[6] Accepting Resolution No. 4 of 5 December 2001 of the National Council for Energy Policy (CNPE), President Fernando Henrique Cardoso established in Decree No. 4102 of 24 January 2002 that people with low incomes enrolled in any social programme of the Federal Government of Brazil will receive resources through direct income transfers from the Brazilian Government to help them purchase LPG. Recently, such income transfers were incorporated into a broader welfare scheme, the so-called bolsa família (family grant).

Development Bank and the State owned companies — self-funding) and foreign money for long term investments, at least in the coming years.

The amount of long term investment necessary to satisfy future modern energy demand is a function of the primary and final energy use patterns of each country, as well as the effectiveness of their economic development paths. Thus, the amount of long term investment in modern energy infrastructure required to satisfy future modern energy demand in Brazil will depend on whether or not the country's primary and final energy use patterns change and, if they do, in which direction. Most estimations of investment needs in modern energy infrastructure in Brazil assume that the final energy use pattern will not change significantly (usually changes are considered only in the energy mix). This is usually correct for the short and medium terms, due to structural inertia (for planned medium term investments in the power and oil sectors, see Table 5.4), but not necessarily for the long term.

Progressively charging the actual energy prices (including environmental costs) and promoting energy efficiency and structural changes away from energy intensive activities by dematerializing the economy and upgrading exports (all of which reinforce one another) will definitely modify Brazil's final energy use pattern in the long term, as well as the investment needs for expanding modern energy infrastructure. These are the bases of the qualitative differences between the 'Reference' and 'Shift' scenarios developed for this study (see Chapter 10 for details). Thus, those scenarios make explicit the consequences of alternative choices (economic development paths) for Brazil that imply different final energy use patterns in the long term. Reducing long term investment needs in modern energy infrastructure through a less energy intensive profile enhances sustainable energy development by making it cheaper to satisfy future energy demand and by liberating economic resources for other uses (such as water supply, education, public transport, high technology products, and research and development).

TABLE 5.4. PLANNED MEDIUM TERM (2003–2010)* INVESTMENTS IN THE POWER AND OIL SECTORS
(based on Refs [5.36, 5.54, 5.55])

Sector	Planned investments (10^9 US $)
Power	
Generation	40.0
Transmission	20.0
Distribution	36.0
Total	96.0
Oil	
Exploration and production (total)	22.4
Exploration and production (domestic)	18.0
Downstream (total)	7.9
Distribution (total)	1.3
Gas and energy (total)	1.8
Corporative areas (total)	0.9
Total domestic	29.9
Total	34.3

* 2003–2007 for the oil sector (Petrobras only).

5.3.5. Promoting technological innovation and a new, more dynamic market

A sustainable future requires that each hour of work create more value, while using less energy and generating less pollution. However, Brazil is progressively using more primary and final energy than creating value (GDP). Although environmental issues have not been addressed here, there is evidence to suggest that the same is also true for the generation of pollution [5.56].

As a matter of fact, a significant part of the upward trends in the overall primary and final energy intensities of Brazil is related to both sectoral structural and product mix changes towards low value added, energy intensive activities.

Consider the contrast between Brazil and the Republic of Korea, which had similar long term strategies from the late 1960s until the early 1980s, with Government promotion of heavy industries (basic, intermediate and capital). During the 1980s, the Republic of Korea focused on maintaining price stability, promoting exports, strictly managing industrial policies, developing human capital and technological capabilities, providing a good economic environment for investments and absorbing new technology and innovation. Today, the Republic of Korea has reached important development goals based on dynamic markets and technological innovation. Brazil, in contrast, has not been able to achieve the same level of development in the same period of time. To provide an illustration, in the early 1970s GDP per capita (in US $ PPP-2000) was 50% higher in Brazil than in the

Republic of Korea, but in 2000, Brazil's GDP per capita was around 50% that of the Republic of Korea [5.14]. Furthermore, in 2000, the share of high technology exports in total manufactured exports reached 19% in Brazil, compared with 35% in the Republic of Korea [5.14]. Focusing on high technology rather than energy intensive goods has important implications for the trajectory of the overall primary energy intensity and for sustainable energy development.

To enhance sustainable energy development, Brazil needs to promote technological innovation and to develop new and/or more dynamic markets, to dematerialize its economy and to upgrade exports. However, doing so will require long term public policies, incorporating both educational and technology policies in an integrated approach to further develop human and technological capability. Macroeconomic stability, openness, long term funding and competitive pressure constitute the proper environment to induce technological innovation and dynamic markets.

Some markets have already developed this integration on their own, such as the aircraft industry, the oil industry, and some segments of agriculture and the textiles and clothing industries. Much more is necessary to further develop integration and to improve the institutional supports and networks in areas where Brazil has high potential to develop strong comparative advantages. The Brazilian Government has contracted several studies on sectoral competitiveness since the late 1980s and has already designed and implemented some programmes to improve potentially attractive areas. Those studies and programmes were the bases for elaborating the scenarios described in Chapter 10.[7]

5.4. MAIN ISSUES

5.4.1. Decoupling energy use and economic growth

A sustainable future implies creating more value added, while using factors of production wisely and efficiently and generating less pollution. Promoting energy efficiency and renewable modern energy sources generates a wide range of economic, environmental and social benefits. Brazil has taken important steps to improve sectoral energy efficiencies and to take advantage of its low cost hydropower to fuel industrial development, and hence to fund a general rise in living conditions without major air pollution emissions. Still, the overall primary and final energy intensities have been showing small upward trends. Thus, there are concerns about how to stimulate energy intensive industries to seek innovation and a higher value added product mix, as well as to promote new dynamic industries and services competitively, which will contribute decisively to decoupling energy use and economic growth. However, such shifts, which must be a top priority in Brazil, will require investment, appropriate institutional designs and time.

5.4.2. Efficient energy pricing and social inequities

Like many developing countries, Brazil faces the dilemma of needing to achieve efficient energy pricing and ensure sufficient investment to provide adequate energy supply while providing affordable access to commercial energy for low income groups. Resolving these problems is considered a fundamental step towards sustainable energy development. Such a dilemma (efficient energy pricing versus affordability) may be solved by focusing the support schemes (such as energy subsidies, income transfers for energy spending — family awards, for instance — and energy efficiency funding) on low income groups.

5.4.3. Financing infrastructure

Aside from recent shortcomings, Brazil has been relatively successful in attracting or providing investment, both for industrial and energy sector development and for infrastructure. In the future, the key will be for Brazil to compete successfully by being an attractive place for investment. This requires considered and consistent Government policies. Some policies must focus on mobilizing domestic capital, and others, on attracting foreign investment; however, in either case some basic common principles are to be followed. A stable economic and energy regulation environment is essential, and rapid, transparent and fair decision making processes are needed.

There will also be occasions when public capital will be the only possible resort. There may well be infrastructure projects that have no immediate wealth creation potential, but are still

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[7] See, for instance, Refs [5.40, 5.41].

crucial to long term development. In such instances, the Government's decision to invest in energy and infrastructure projects must compete within the available budget with other public needs, just as projects have to compete for private capital. Government investment decisions must necessarily balance these competing needs. They should also reflect the same considerations as those of private investors as to the appropriateness of the investment plan, possible preferable alternatives, least cost considerations and cost–benefit/cost effectiveness assessments.

5.4.4. Seeking synergies

Enhancing sustainable energy development requires a broad set of measures and policies affecting the full spectrum of society. Governments have the task of coordinating the policies and actions that aim to improve living standards and balance stakeholders' interests, reducing market and government failures, transaction costs and information asymmetries that frustrate actions to further sustainable energy development.

Important synergies among different strategies suggested here are possible. For instance, the removal of price distortions (including for environmental externalities) will encourage improvements in energy efficiency, changes in patterns of energy use, restructuring of transport systems and spatial organization, structural changes towards higher value added activities and exports, and technological innovation. In the same way, a more rational use of energy, an integrated transport system and a better use of spatial organization might in turn reduce energy costs, thus increasing energy affordability, postponing energy investments and liberating economic resources for other uses. Taken in isolation, these strategies may not perform so well. Coordination is needed to ensure that strategies are consistent with one another.

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Chapter 6
ENERGY, THE ENVIRONMENT AND HEALTH

O. LUCON, S.T. COELHO

This chapter focuses on environmental and human health aspects of energy use. Section 6.1 provides an overview of the main energy related environmental concerns, and recent policy and legislative efforts to address them. This is followed by a detailed assessment of the environmental and health implications associated with the full energy chains based on the renewable (Section 6.2) and non-renewable (Section 6.3) sources most commonly used in Brazil. The main conclusions are summarized in Section 6.4.

Environmental and health concerns are prominently represented among the Energy Indicators for Sustainable Development (EISD). Table 1.1 in Chapter 1 presents the full list of ten environment related indicators under three themes: atmosphere (covering climate change and air quality), water (consisting of water quality) and land (including soil quality, forests and solid waste generation and management). Many of these indicators are used in this chapter to present the environmental characteristics of the energy system in Brazil.

6.1. AN OVERVIEW OF BRAZIL'S ENERGY RELATED ENVIRONMENTAL ISSUES

Energy production and use in Brazil have caused major environmental burdens, such as extensive flooding, air pollution and biodiversity losses. This has brought about the need for increasingly active protection of the country's environment through both legislative and enforcement measures. A law approved in 1999 established severe penalties for environmental crimes, including liabilities for public agents and companies, and other types of legal entities. Today, environmental impact studies are mandatory for all potentially impacting projects. Public hearings and a permit process are also involved. However, many of the laws still lack proper regulation, hampering field implementation of public policies.[1] Although at present greenhouse gas (GHG) emissions are not a major issue, an Interministerial Commission on Global Climate Change was established to introduce climate change considerations into the public policy making activities of the energy, transport, agriculture, forestry, industry and waste management sectors.

Air pollution control is carried out through the use of instruments such as emission factors and maximum emission levels stipulated for polluting sources. Provision is also made for the use of air quality standards to establish legal limits for the atmospheric concentrations of total suspended particles, sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), black smoke, inhalable particles and nitrogen dioxide (NO_2) [6.1]. Additionally, some emission standards have been set for mobile and stationary combustion sources [6.1, 6.2]. Vehicle emissions are subject to a national control programme (PROCONVE), while industries, large commercial premises (e.g. shopping centres and malls) and power plants are subject to legislation concerning emissions of SO_2 and particulate matter. CO emission rates are not directly regulated, because they are considered to be limited under normal operating conditions. Emission standards for nitrogen oxides (NO_x) still have not been set for stationary sources at the Federal level. This is considered an especially relevant issue, in view of the environmental impacts of NO_x.[2]

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[1] More enforcement is necessary, but there are several flaws or conflicts in legislation that demand regulation. An example is the lack of a national emission standard for nitrogen oxides from stationary sources.

[2] NO_x emissions pose a hazard to humans and other living organisms, both directly and as an ozone precursor. NO_x and volatile organic compounds form ozone through their photochemical reactions with sunlight. Ozone and particulate matter are the urban air pollutants of main concern today.

6.2. ENVIRONMENTAL IMPACTS OF RENEWABLE ENERGY

6.2.1. Hydropower impacts

In Brazil, as in most other countries, water resource utilization — especially of large rivers — is linked to electric power generated in large dams. In São Paulo, for example, the two reservoirs responsible for supplying a major part of the metropolitan area's water — Billings and Guarapiranga — were originally built in the early 20th century to provide energy for streetcars. Large dams were subsequently built, without much attention being given to their environmental and social impacts, because awareness about the effects of such civil works simply did not exist. Rather, such large units were considered to be proof of the country's engineering accomplishments. At a time when significant amounts of land were available, these infrastructure works were constructed without major conflicts. Starting in the 1950s, however, with increased levels of urbanization and industrialization, the construction of large hydropower projects became a constant feature along Brazilian rivers, especially in heavily industrialized regions. Hydropower was seen as a major energy source in the country, so the development of large projects was part of the national development strategy [6.3].

Factors such as flooding of delicate ecosystems and riparian population displacement brought about strong opposition to further large hydropower projects. Society became aware that flooding the forest leads to losses of timber and natural ecosystems,[3] as well as to increased GHG emissions. Aquatic ecosystems are heavily affected by the blockage of fish migration pathways and anoxic water conditions, which corrode turbines, produce methane (CH_4) and favour the mercury methylation process. The use of defoliant agents to remove forests in flooded areas is an issue, while controversy over the impacts of herbicides used to prevent regrowth along the transmission lines continues [6.4].

Hydropower dams are reported to have halted the long distance upstream migration of several fish species and have interrupted the downstream migration of their larvae. Other species have increased, creating an imbalance in natural ecosystems.[4] According to McAllister et al. [6.6], dams on the Paraná River have obstructed migration of some commercially valuable fish species. The authors also report significant impacts of dams and their associated reservoirs on freshwater biodiversity, such as blocked movement of migratory species; changes in turbidity and sediment levels to which species and ecosystems are adapted; deprivation of sediments and nutrients in downstream deltas and estuaries; fostering of exotic species that tend to displace indigenous biodiversity; proliferation of human and animal disease vectors; and modification of downstream water quality and flow patterns. These are the most serious factors when one considers the cumulative effect of a series of dams, especially when the impact footprint of one dam overlaps that of the next one immediately downstream. The World Commission on Dams has carried out several studies and assessments of the environmental impacts of hydropower reservoirs throughout the world [6.7]. In Brazil they found important inputs, especially from past lessons concerning the impacts of the Tucuruí Dam (see Box 6.1 for more information on the Tucuruí Dam).

Figure 6.1 shows the installed capacity of the country's 46 largest hydropower dams and their corresponding flooded area intensities (in kW/km^2). The total flooded area is estimated at 2.8 million ha. These dams have had severe social and

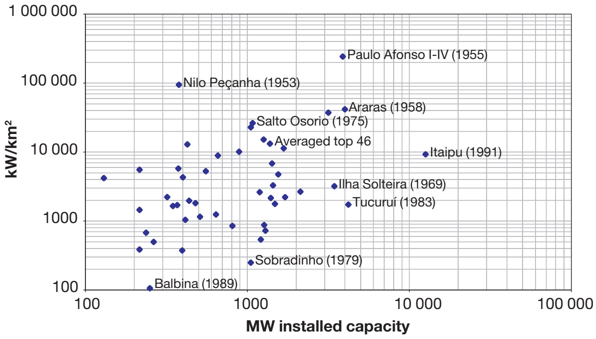

FIG. 6.1. Brazil's 46 largest dams, according to startup year, installed capacity and flooded area intensity [6.10–6.12].

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[3] There are about 270 000 scientifically described species of vascular plants, but the true number may be of the order of 300 000–350 000 species. Of these, Brazil has between 40 000 and 80 000.

[4] Vieira and Pompeu [6.5] report that tucunarés (*Cichla* spp.), corvinas (*Plagioscion squamosissimus*), piranhas (*Pygocentrus nattereri*) and tilapia (*Oreochromis* sp., *Tilapia* sp.) have modified native fish communities or even eliminated some species, while carp (*Cyprinus carpio*) have introduced new parasites.

Box 6.1. Case Study — The Tucuruí Dam and new projects in Amazonia

The 4.2 GW Tucuruí I hydropower plant was opened in 1984. It has since had substantial social and environmental impacts, and now serves as an important reference for discussions on future hydropower projects in the Amazon region (Amazonia). This dam predates Brazil's 1986 requirement for an environmental impact assessment. Despite limitations, post-construction research — sponsored by the electrical authority — has provided valuable information for future dams. According to Fearnside [6.4], flooding of the forest has led to the loss of timber and to damage to natural ecosystems. Fish migration blockages and the creation of an anoxic environment in the reservoir have adversely affected aquatic ecosystems. Decay of submerged vegetation has created anoxic areas (which may corrode turbines), produced methane and provided conditions favouring mercury methylation. Use of defoliants was once considered for removing the forest in the submerged area, but plans were aborted amid public controversy. However, herbicides have been used to prevent regrowth along the transmission line. Mitigating measures included archaeological and faunal salvage operations and the creation of a 'gene bank'. Tucuruí's social costs also include impacts on indigenous people; the need to resettle the displaced population; loss of fish and other resources for downstream residents; and health problems such as malaria, a plague of Mansonia mosquitoes and bioaccumulation of mercury in fish in the reservoir and in the people who eat them. The country's subsidized aluminium export industry consumes two thirds of Tucuruí's power, leading to side effects, as other dams (such as the Balbina Dam) have been built to supply power to cities that could otherwise have been supplied by Tucuruí [6.4]. Two energy intensive aluminium companies being supplied by Tucuruí produce 770 000 t/year (mostly exported). While Tucuruí's generation costs are US $50/MW·h, half the output (around 12 TW·h) is sold to aluminium industries for US $20/MW·h. The proposed 11 GW Belo Monte hydropower plant (on the Xingu River) has been under discussion since 2001. Technological design improvements have helped reduce potential impacts related to the flooded area, but they have also brought decreased installed capacity. Construction of an alternative 7 GW project — embodying two plants — in the Madeira River is being considered. This would help integrate the transport infrastructure of Brazil, Peru and Bolivia (providing access all the way to the sea through navigable rivers) and improve Brazilian soybean export conditions [6.8]. Energy conservation and recycling strategies could also reduce such impacts. An example is aluminium recycling, which provides local jobs for poorer families. In 2002, recycling of 121 000 t of aluminium (9 billion cans) saved 1700 GW·h — 0.5% of all national generation and enough for a city with a population of 1 million inhabitants for one year [6.9].

environmental consequences, such as the displacement of local communities and the loss of biodiversity. The case of the Tocantins River, in the North region, illustrates many of the impacts associated with large dams. It has already been affected by the building of two large reservoirs, Tucuruí and Serra da Mesa. The 2003–2012 Ten Year Expansion Plan [6.13] foresees more dams that will flood extensive areas. This is the case with the Estreito (1087 MW), Serra Quebrada (1328 MW) and Tupiratins (820 MW) Dams, and with the Belo Monte Dam (11 181 MW) in particular.

Environmental impact assessments are beginning to play a more significant role as a planning and decision making tool. Moreover, Brazil's national water resources policy now requires dam operators to abide by the guidelines and involve all the different actors in the management of dam projects [6.3].

Despite the extraordinary level of know-how on the part of Brazilian engineering with respect to dam building, there has been a delay in adoption of methodologies for physical, ecological and social impact assessments. In recent decades, thanks to the requirements of and pressure from the environmental sector of the World Bank, professionals, scientists and the Government have become aware of the urgent need to assess development project impacts [6.14].

The 2003–2012 Ten Year Expansion Plan [6.13] has a special chapter concerning environmental assessment, where 50 hydropower plants are classified according to level of environmental complexity, as summarized in Table 6.1. The projects in the North region are the largest (including Belo Monte) and cause the greatest environmental concern.

The role played by small and medium sized hydropower plants has increased owing to their greater environmental friendliness and to privatization and more flexible regulations [6.15]. Integrated operational management of the hydropower system

TABLE 6.1. ENVIRONMENTAL CLASSIFICATION OF THE HYDROPOWER PLANTS CONSIDERED WITHIN THE 2003–2012 EXPANSION HORIZON [6.13]

Region	Capacity (MW), according to complexity			Number of projects	
	Low	Medium	High	Up to 500 MW	>500 MW
Southeast	1 081	1 739	0	17	0
South	660	1 840	0	5	2
Midwest	343	822	0	11	0
Northeast	0	82	450	4	1
North	393	452	15 016	5	5
Brazil (total)	2 477	4 935	15 466	42	8

that takes into consideration multiple water uses now opens new possibilities for rivers and reservoirs — for example, improving landscaping, recreation, irrigation and tourism, and controlling floods [6.16].

In recent decades, the Brazilian Government’s way of dealing with environmental and social issues has changed noticeably. The 1988 Constitution introduced stricter environmental regulations. In 1997, a National Water Resources Policy established new instruments for watershed environmental management, stressing the importance of decentralized planning and management strategies, as well as public participation [6.16].

6.2.2. Non-sustainable biomass impacts

Biomass, the most important energy source in several developing countries, can only be considered to be sustainable under certain conditions. It is only ‘renewable’ if fully replaced by nature, spontaneously or through human intervention. Much biomass use in developing countries is leading to deforestation, either for small scale domestic use or large scale industrial use. Traditional biomass use, although primitive and inefficient, may be sustainable, as, for instance, when trees and branches are collected by small communities at a rate below natural forest recovery rates [6.17].

The use of fuelwood as an energy source is not the driving force behind deforestation in Brazil.[5] There are some ‘hot spot’ regions in Brazil where wood collection for energy use is occurring faster than the natural recovery rate. This is the case in the outskirts of many urban areas, including the São Paulo metropolitan region, home to 16 million people. This is also the case in the semiarid Northeast region, where there are considerable limitations to reforestation. During the dry season, fuelwood is the only source of income for tens of thousands of collectors, according to a field survey conducted by Francelino et al. [6.18].[6] In the 1982–2002 period, the forest coverage in this region declined from 55.3% to 44.6%, a deforestation rate higher than that of the Amazon forest (0.3% per year). Protected areas account for 0.41% of the Northeast region, compared with the national average of 4% [6.20].

Exports of grains are pushing the agricultural frontier into natural ecosystems, also implying deforestation, mainly by soybean plantations. In 2003, Brazil’s largest soybean processing company proposed a US $150 million project in Piauí State that was opposed by the Attorney General (Ministério Público). Although it would have created 11 000 jobs, it would also have deforested almost 11 000 ha/year. The energy source proposed for the plant’s boilers and for drying the grain was primarily fuelwood removed from the areas of cerrado cleared for plantations. Natural gas was available but would have cost eight times as much. Small producers also utilize fuelwood in this way, since dried soybeans are easier to store and therefore bring better prices. Soybean oil is basically a food commodity; however, together with

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[5] For further details on the driving forces of Amazon deforestation, see Chapter 2, Sections 2.1.1 and 2.2.3.5.

[6] In Piauí State in the Northeast region, 20 m^3 (estéreis) of fuelwood, equivalent to 8 t, can be obtained from 1 ha of the native cerrado vegetation; this can be sold by deforesters for as much as US $8/$m^3$ [6.19].

castor oil, it is being considered by policy makers for the large scale production of biodiesel.[7]

Next to the Cerrados is the Amazon region (Amazonia), which has one tenth of the world's plant and animal species and almost one third of the world's remaining tropical rainforests. There, most of the deforestation process is occurring not as a result of energy needs, but as a consequence of demand for pasture areas (64%), inappropriate land uses (temporary crops take up 22% of the area, while permanent ones take only 3%) and timber exploitation (6%) [6.21].

In the past, charcoal production led to the destruction of many native forests, not only in Amazonia but also in other areas, such as the Northeast coastal region. Today, most of Brazil's charcoal comes from planted forests, the result of both more stringent legislation and local areas showing natural resource exhaustion. For instance, the share of non-sustainable (traditional) fuelwood consumed for charcoal production decreased from 86% in 1980 to 28% in 2000 [6.22].

In 1990, 66% of the 36 million m^3 of charcoal (or about 90 million m^3 of wood) consumed came from native forests. By 2000, this figure had dropped to 29.6% of the 25.4 million m^3 of charcoal produced.[8] By 2001, reforested areas used for charcoal amounted to 50 000 ha [6.24]. Most charcoal production (94% in 2001) is used to meet the demand of the iron and steel industry. The production technology varies by region and in many places is still primitive, with little qualitative or quantitative production control. In the future, Brazil will almost certainly maintain a charcoal based iron and steel industry, as well as other coal consuming segments within the industrial sector, but environmental concerns are expected to improve the charcoal industry's standards and practices.

More than 90% of the nearly 7000 ceramics industries in Brazil utilize fuelwood in their traditional processes, several of which are of low efficiency. In the Northeast region, indiscriminate fuelwood use affects more than 20 native species — including mango and cashew trees — and also increases desertification [6.25].

6.2.3. Sustainable biomass use

A major benefit of replacing fossil fuels with biomass, if done in a sustainable fashion, would be greatly reduced GHG emissions. The amount of carbon dioxide (CO_2) released through biomass burning is always less than the amount required to sustain plant growth to produce that biomass. Thus, in a sustainable fuel cycle there would be negative or at least no net CO_2 emissions, except those from the use of fossil fuel inputs to biomass planting, harvesting, transport and processing operations. Yet, if efficient cultivation and conversion processes are used, the resulting specific emissions should be small. As an example, the ratio of energy output to input for ethanol production in Brazil ranged between 8.3 and 10.2 in a comprehensive study conducted by Macedo et al. [6.26].[9] If the energy needed for biomass production and processing comes from renewable sources in the first place, then the net contribution to global warming will be close to zero. Similarly, if biomass wastes such as crop residues or municipal solid waste are used for energy production, only a small amount of CO_2 emissions should remain, compared with energy production from fossil fuels. There would even be a slight greenhouse benefit in some cases, since when landfill wastes are not burned, CH_4, a potent GHG, may be released through anaerobic decay [6.27].

In Brazil, sustainable biomass use is already significant and could be easily increased.[10] Not all renewable energy technologies are universally

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[7] Sugar cane production does not have the same impacts, because sugar cane plantations generally (a) produce energy more intensively, (b) utilize their own residues as an energy source for the production process and (c) are located in regions that were deforested decades or even centuries ago.

[8] Fuelwood production varies by region, ranging between 20 m^3/ha in Piauí State in the Northeast region and 60 m^3/ha in Santa Catarina State in the South region [6.23]. In the charcoal producing regions, 40 m^3 of fuelwood are produced per hectare and 0.4 m^3 of charcoal is produced per cubic metre of fuelwood. Deforestation is then around 0.5 million ha. The actual figure may be lower, considering that charcoal can be produced from tree branches, etc. Brazil deforests around 2 million ha/year, mainly for agriculture and cattle raising. Global deforestation was around 16 million ha/year over the past decade.

[9] Net avoided emissions from the replacement of gasoline with ethanol fuel led to results ranging between 2.6 and 2.7 t of CO_2 per cubic metre. Replacement of fuel oil with sugar cane bagasse amounted to net avoided emissions of 1.7–1.9 t of CO_2 equivalent per cubic metre [6.26].

[10] A case study worth mentioning concerns the PLANTAR project. In 1999, Brazil's top charcoal producer, PLANTAR, a diversified timber company producing high quality barbecue charcoal products, was certified by the Forest Stewardship Council [6.28].

applicable, and all have environmental impacts, including land use impacts. The seriousness of such impacts will depend on how carefully the resource is managed.

Net CO_2 emissions from the biomass life cycle, including direct and indirect fossil fuel consumption, are around 6500 kg of carbon per kilowatt-hour for wood and between 7800 and 21 700 kg C/kW·h for sugar cane. As a comparison, without considering emissions from the production process, natural gas combustion emits 114 000 kg C/kW·h, and fuel oil, 303 600 kg C/kW·h.[11] The pulp and paper industry is another sector where electricity surpluses are a viable alternative for emission reduction certification [6.29].

6.2.3.1. Reforested/sustainable fuelwood

Silvicultural practices for energy generation have changed dramatically in the past 20 years. Classic eucalyptus plantations — with their low densities and long cutting cycles (up to 20 years) — changed with the introduction of new species, the use of improved seeds, genetic improvements, improved fertilization methods, and the use of soil preparation and forest management practices. Today's forests are denser (5000 trees/ha) and have shorter cutting cycles (3–5 years). The secondary industrial sector consumes 45% of Brazil's fuelwood; 96% of this fuelwood is used as charcoal in the metallurgy sector. Small scale, unsustainable and inefficient (with energy conversion efficiencies of around 15%) charcoal production processes are gradually being replaced by modern and better managed techniques [6.30].

Ascertaining the environmental impacts from biomass use and production is a complex task, because the impacts of using biomass for energy must be considered in the context of alternative energy options, while the impacts of producing energy crops must be considered in the context of alternative land uses [6.31]. Energy crops could be used to stabilize cropland or rangeland once prone to erosion and flooding, since tree roots and leaf litter help stabilize the soil. Planting self-regenerating varieties would minimize the need for disruptive tilling and planting practices. However, if improperly managed, energy farming could also have harmful environmental impacts. Although these crops can be grown with less pesticide and fertilizer use than conventional food crops, large scale energy farming could lead to increased chemical use simply because more land would be under cultivation. It could also affect biodiversity through the destruction of species habitats, especially if forests were more intensively managed [6.27]. Forestry codes and plantation management procedures prohibiting the conversion of natural forest to forestry plantations are currently being developed and implemented. Many of the natural forests occur in areas with relatively poor soils, and destruction of natural forests is now recognized to have environmental costs in terms of biodiversity, environmental quality and economic sustainability that far outweigh short term economic gains from forest clearing.

6.2.3.2. Sugar cane products and other biofuels

In Brazil, early mistakes in the establishment and operation of sugar cane plantations, along with increasing environmental sensitivity, have led to substantial regulation of the sugar cane industry. As extensive biomass plantations of a single species can be extremely destructive to biodiversity when they displace natural habitats, biodiversity corridors must be preserved. The effect of biomass plantations on biodiversity may depend as much on how they fit into the landscape as on the particular species and management systems selected.

Total land area used for sugar cane production jumped from 1.9 million ha in 1975 to 4.3 million ha by 1987, but then increased very slowly to 5.0 million ha by 2001 [6.30, 6.32]. Although the introduction of sugar cane into Brazil by the Portuguese was an early deforestation factor, this is no longer the case, as yields have increased over time, reaching 70 t/ha by 2001, and sugar cane plantations still represent less than 2% of the agricultural area in the country. For the entire historical series under consideration here, regardless of whether the sugar cane was grown to produce sugar or ethanol, it is quite clear that only a small fraction of Brazil's arable land has been used for this crop (see Fig. 6.2).

Extensive alcohol fuel use has been credited to PROALCOOL, the Brazilian Alcohol Programme. Originally devised in 1975 to address the strategic need to reduce Brazil's dependence on petroleum imports, the programme has also led to

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[11] At 20–50 kW·h per tonne of sugar cane and with the production of 200 Mt/year in São Paulo State alone, sugar cane mills have enough surplus production capacity to allow the avoidance of carbon emissions in the range of 0.4 to over 1 million kt C per year, even taking into consideration that electricity production occurs only during the harvest season.

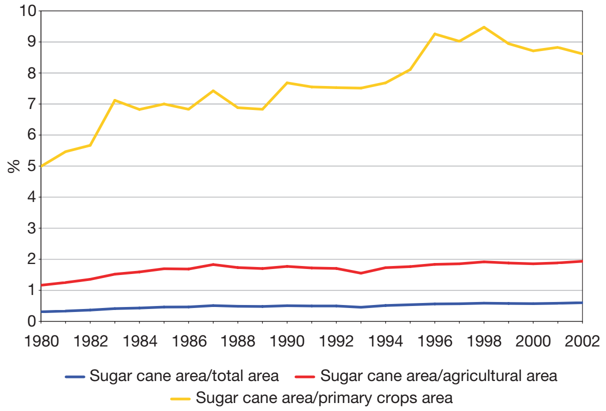

FIG. 6.2. Land used for sugar cane in Brazil [6.33].

significant air pollution abatement benefits with the use of ethanol instead of conventional gasoline [6.34]. It has reduced emissions of CO and hydrocarbons (HCs), especially polycyclic and aromatic HCs, which have a higher carcinogenicity and toxicity than ethanol. Ethanol powered vehicles emit predominantly acetaldehyde, which is less hazardous to human health than the formaldehyde emitted by gasoline powered vehicles.[12] Since ethanol is almost sulphur free, its use reduces the generation of sulphuric acid (H_2SO_4), one of the components of 'acid rain'.

Guarnieri and Jannuzzi [6.38] identify the following series of impacts due to sugar cane ethanol production: (a) increased erosion during and after the harvest season (40% of tropical rainfall falls at erosive rates (above 25 mm/h) according to the Bioenergy Information Network [6.39]); (b) reduced water quality and availability due to increased runoff; (c) increased chemical pollution due to fertilizer and pesticide use; (d) degradation of soil quality/productivity; (e) reduced biodiversity; (f) air emissions, stillage and wash-up waters resulting from industrialized alcohol production; (g) use of land for large scale monocultures; and (h) threats of blackouts due to plantation burning practices affecting electricity transmission lines. However, emissions directly related to alcohol mill production have fallen drastically with the use of sugar cane bagasse as a fuel and the use of stillage and filter cake as fertilizers. Other impacts are also being systematically reduced by efficient enforcement policies and technological developments.

Sugar cane is a major source of air pollution owing to the practice of burning the fields prior to manual harvesting.[13] In São Paulo State, for instance, emissions of particulate matter (PM) are estimated to be approximately 625 000 t/year, equivalent to almost 70% of industrial emissions. NO_x emissions are also high, equivalent to 10% of all industrial figures inventoried by the State Environmental Sanitation Technology Company (CETESB) in São Paulo [6.40].[14] São Paulo State has recently enacted legislation calling for the phaseout of all sugar cane burning practices by 2020, with consequent labour force reallocation (State Law 10 547/2000 and Decree 48 869/2001). Estimates are that 20% of all Brazilian sugar cane was harvested mechanically in 2004, without burning practices [6.45].

6.2.3.3. Energy from municipal solid waste

Brazil has relatively high emissions of CH_4 due to anaerobic digestion of solid waste and liquid effluents, which are associated with the country's high population and intense industrial activities. São Paulo State currently treats a higher percentage of its waste and effluents than any other State in Brazil, which translates into increased GHG emissions. Emissions of CH_4 from waste in Brazil amount to about 7 kg CH_4 per capita per year [6.40].

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[12] According to the Lindane Education and Research Network [6.35, 6.36], there is inadequate evidence for the carcinogenicity of acetaldehyde for humans, while there is sufficient evidence that benzene is carcinogenic to humans. However, the Brazilian Government recognizes the carcinogenic potential of acetaldehyde as 0.01 mg per kilogram of body weight per day, compared with 0.1 mg per kilogram of body weight per day for benzene [6.37].

[13] The practice of sugar cane burning was adopted by manual harvesters because (a) green sugar cane leaves have sharp edges hazardous to workers; (b) fires usually drive away snakes and control agricultural plagues; (c) fires also clean up the area for the next plantation cycle, dispensing with the need for herbicides; and (d) mechanized planting is more expensive and requires flat areas, whereas manually harvested crops do not require that the land be levelled.

[14] Such estimates considered sugar cane production (209 Mt per year with 30% bagasse, according to UNICA [6.41]). Each tonne of sugar cane burned releases about 0.08 kg of methane, 3 kg of PM (2.1 kg as PM10), 35 kg of CO, 8 kg of HCs, 0.16 kg of NO_x and virtually no SO_2 [6.29, 6.42]. São Paulo State's 2002 air emissions due to sugar cane burning were estimated to be 625 000 t of PM and 34 000 t of NO_x. For comparison, corresponding emission data for industrial sources [6.43] were 919 000 t of PM and 330 000 t of NO_x. In 2000, about 208 000 t of NO_x were emitted due to fuel oil, diesel and natural gas combustion alone [6.44].

If energy from municipal solid waste were harnessed, the 13 largest Brazilian landfills could potentially provide 150 MW of electricity generation installed capacity, taking advantage of the energy potential of urban waste [6.46].[15]

Facilities burning raw municipal waste present a unique pollution control problem. This waste often contains toxic metals, chlorinated compounds and plastics, which generate harmful emissions. In the past, negative local perceptions about the pollution potential of the incineration process seriously affected several decisions regarding waste treatment–disposal alternatives, without consideration being given to modern technological achievements and the fact that landfill space around large cities is fast becoming exhausted. In 1994, a waste disposal project prepared for the city of São Paulo, involving the construction of two large capacity (2500 t/d each) incinerators, met with severe public opposition. Actions by environmental non-governmental organizations, combined with contractual and permitting uncertainties, helped mobilize public opinion against the project's implementation. Pollution problems are much less severe in facilities burning refuse derived fuel, pelletized or shredded paper and other waste with most of the inorganic material removed. Most waste to energy plants built in the future are likely to use this fuel [6.27]. The use of tires, solvents and other wastes in cement kilns is permitted in some States in the country (e.g. Paraná), but environmental licences have not been issued yet in São Paulo owing to uncertainties about the toxicities and loads of air pollutants released. These factors limit the types of residue acceptable for joint processing [6.48].

6.2.4. Wind

Wind power produces no air or water pollution and involves no toxic or hazardous substances (other than those commonly found in large machines and their building materials). The main impacts of wind energy are noise and visual nuisance (changes in landscape), as well as electromagnetic interference (EMI) and bird strikes. These vary according to the technology applied (modern materials cause less interference in transmission waves) and the installation site. The sound impacts of wind turbines are due to blade noise, which depends on equipment design. Multi-blade turbines are usually less efficient — and thus noisier — than high speed propeller aero-generators. To avoid causing a nuisance to nearby communities, turbines have to comply with existing noise regulations. Visual impacts are the result of large concentrations of turbine towers in wind farms and are largely subjective, depending on plant location, general arrangement and turbine specifications. Paradoxically, the same impacts that alter natural landscapes also function as a tourist attraction in some areas, helping to promote regional employment and income. A possible impact is that represented by EMI with communications equipment. The magnitude of such interference is also very site specific and depends on equipment specifications. Little is known about EMI's effects on human beings, and this issue has been the subject of much debate. A far more serious impact involves the possibility of site location interfering in the routes of migratory birds [6.49]. To avoid such interference, large wind farms are subject to an environmental permitting procedure, with environmental impact studies being a mandatory requirement.

6.2.5. Solar

Thermal collectors are the most widespread solar technology in Brazil, with 1.5 million m^2 installed and 0.26 million m^2 sold in 2000 alone. Studies about large scale thermoelectric solar systems have already been conducted in the country [6.50]. Since solar power systems generate no air pollution during operation, the primary environmental, health and safety issues involve how they are manufactured, installed and ultimately disposed of. The energy balance throughout their life cycle is generally favourable to solar systems in most applications[16] — both thermal and photovoltaic (PV) — and is improving with each successive technology generation [6.51].

Solar water heaters increase the amount of hot water generated per unit of fossil energy invested by

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[15] Recently in São Paulo, the Bandeirantes landfill began recovering biogas for electricity generation, producing 170 GW·h/year with an installed capacity of 22.6 MW, sufficient to supply power for 200 000 people. Carbon emission savings are expected to reach 8 Mt in 15 years [6.47].

[16] The energy input for the structural materials of a photovoltaic system delivering 1 billion kW·h is calculated to be approximately 300 kW·h/m^2. The energy input–output ratio for production is about 1:9, assuming a life of 20 years. For solar–thermal systems, the energy input–output ratio is calculated to be 1:10 [6.51].

at least a factor of two compared with the water heating capacity of natural gas, and by at least a factor of eight compared with direct electric water heating [6.27].

One environmental argument against the option is the toxicity of some of the materials used in PV cells, such as arsenic and cadmium used in components and batteries. The assessment of the environmental impacts of producing and decommissioning PV batteries depends on the type of batteries used. Lead acid batteries are the type most commonly found in developing countries, being less expensive than the alternatives. The battery manufacturing process involves heavy metals. Other PV batteries use cadmium, a very toxic chemical that should be recycled. The most appropriate use of exhausted batteries is to reuse the lead contained in them, or to recycle the batteries [6.52][17]. Inadequate disposal of PV cells after their useful life (generally 30 years) could present some waste disposal problems, but most of the toxic materials in any cell type can probably be recycled. The large amount of land required for utility scale solar power plants — approximately 1 km^2 for every 20–60 MW generated — does not pose an additional problem in Brazil. Small scale, dispersed applications are a better match to the resource. PV arrays could be placed on roofs or on bare land with little other value, such as deserts. PVs are a very promising technology for generating electricity in the future. During their operation, PV cells use no fuel other than sunlight, emit no atmospheric or water pollutants, require no cooling water, do not contribute to global warming or acid rain and present no radioactive risks.

6.2.6. Geothermal

The applicability of geothermal energy is currently extremely limited in Brazil. So far, natural water heating is only being used for recreational purposes in some tourist areas, with negligible environmental impacts. Many of these hot water sources were discovered in São Paulo State during an unsuccessful oil drilling programme in the mid-1980s.

6.3. IMPACTS OF ENERGY PRODUCTION FROM NON-RENEWABLE SOURCES

6.3.1. Global scale: Greenhouse gas emissions

By 2000, Brazil was the largest total energy consumer in Latin America and the world's tenth largest consumer (accounting for about 2.3% of the global total fuel consumption).[18] However, because of its use of hydropower and ethanol automotive fuels, the country accounts for only 1.3% of the world's energy related carbon emissions. In terms of economy output, Brazilian emissions are also low, as shown in Fig. 6.3.

Brazil's total GHG emissions have been growing steadily since the early 1980s (see Table 6.2). According to Marland et al. [6.60], in 2000, the 83.9 Mt of carbon emitted from fuel use came from gas fuels (5.9%), liquid fuels (69.5%), solid fuels (16.7%), cement production (6.4%) and gas flaring (1.7%). Natural gas consumption is expected to rise significantly, increasing Brazil's overall fossil fuel CO_2 emissions.

Although GHG emissions rose in absolute terms over the period under analysis, total per capita GHG emissions dropped.[19] The increase in per capita energy use has not translated into an increase in per capita CO_2 emissions because the national electricity demand has been met mostly

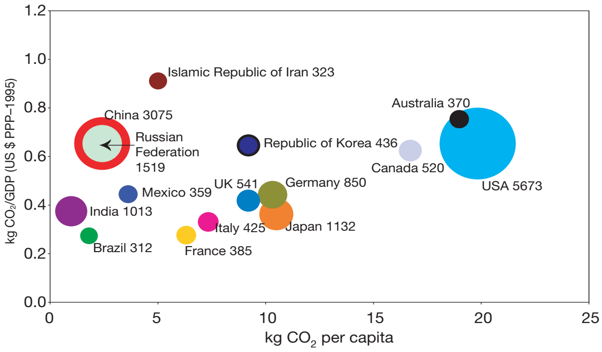

FIG. 6.3. Emissions of CO_2 per capita and per GDP (US $ PPP-1995) from fuel consumption from the world's 15 top emitting countries [6.55]. Numbers after country names are the total emissions in million tonnes; total emissions are also represented by the area of the circles next to the country names.

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[17] Aguado-Monsonet [6.52] provides an interesting life cycle analysis of PV cells in Spain.

[18] After the United States of America, China, the Russian Federation, India, Japan, Germany, Canada, France and the United Kingdom, in that order [6.53, 6.54].

[19] See Chapter 2, Section 2.2.3.2.

TABLE 6.2. ESTIMATED ANNUAL EMISSIONS FROM THE ENERGY SYSTEM (Mt OF CO_2 EQUIVALENT) [6.56]

Year	CO_2	CH_4[a]	N_2O[b]	Total GHG
1980	263.6	2.0	0.4	266.0
1985	269.5	2.5	0.3	272.3
1990	273.9	2.6	0.3	276.9
1995	288.4	2.8	0.5	291.7
2000	334.5	2.5	0.6	337.6

Note: Estimates are based on Refs [6.57, 6.58]; figures were calculated utilizing the Intergovernmental Panel on Climate Change bottom-up methodology applied in the Brazilian National Communication [6.59]. Considering non-renewable biomass burning (from deforestation) as well, these numbers are much higher than those published by the Oak Ridge National Laboratory [6.60] for CO_2 emissions due to fossil fuel combustion, cement manufacture and gas flaring in Brazil in the 1980–2000 period: 46 Mt (1980), 48 Mt (1985), 55 Mt (1990), 68 Mt (1995) and 84 Mt (2000).

[a] Methane emissions are slightly underestimated because of the lack of emission factors for some non-major types of energy consumption.

[b] Because a considerable portion of emissions deriving from fossil fuels have not been included, the N_2O values are underestimates, calculated almost entirely for fossil fuel consumption under the process heat heading and for the transport sector.

through increased hydropower generation,[20] and gasoline demand has been held down by policies requiring the addition of 20–26% ethanol to the fuel mix. Although fossil fuel use has been increasing, Brazilian CO_2 emissions per capita from energy use are still relatively low, at around 1.94 t of CO_2 per inhabitant (CO_2 only) in 1998, lower than the world average (3.89 t CO_2 per inhabitant) and the average for Organisation for Economic Co-operation and Development (OECD) countries (10.93 t CO_2 per inhabitant) for the same year.

6.3.2. Fuel combustion and air pollution

Air pollution is a side effect of energy production and end use. Energy and economic development have brought many benefits to society, but not without environmental burdens, such as air pollution in large cities. Most energy related air pollution arises from combustion of fuel for either power generation or transport.

6.3.2.1. Thermal plants and their impacts

Policies for expanding electricity generation have recently focused on hydropower or natural gas fired thermal plants. The latter were in evidence during the 2001 electricity rationing incident, which accelerated discussions on the Thermoelectric Priority Programme (PPT) [6.13].

Thermal plants utilizing natural gas emit virtually no sulphur, lead or heavy metals, which are the typical emissions of plants fuelled by coal, fuel oil and diesel. However, natural gas (as well as biomass) still results in considerable NO_x emissions, which are tropospheric ozone precursors.[21] Ozone is a major problem in urban areas where sunlight is abundant and local wind and rain conditions are not favourable for dispersion and abatement. This is the case for at least 25 million people living within a 100 km radius of the São Paulo city centre, in three metropolitan areas and other conurbations. An important issue under discussion is the establishment of realistic NO_x emission factors for power plants and industrial processes that are appropriate for Brazilian fuels and technologies. Knowledge about baseline emissions is a fundamental prerequisite, requiring many assessments

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[20] There is still much uncertainty concerning GHG emissions from hydropower plants (see Refs [6.61, 6.62]). However, according to the preliminary estimates, except in a very few cases, GHG emissions from hydropower plants are far lower (in fact, almost negligible) than those produced by thermoelectric power plants burning fossil fuels [6.62].

[21] Other topospheric ozone precursors are CO, SO_2 and non-methane volatile organic compounds (NMVOCs).

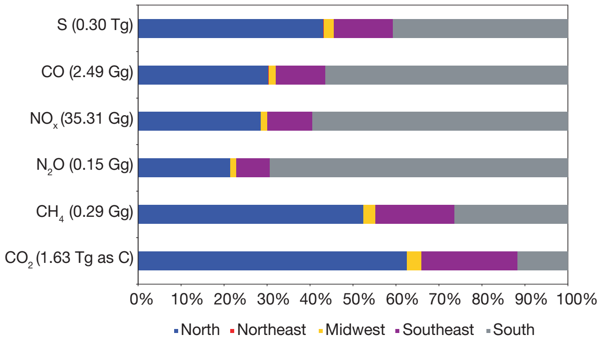

FIG. 6.4. Thermal power plant emissions, total and shares by region for 1997 [6.63].

in terms of source inventories, characterization of several processes and emission monitoring.[22] Figure 6.4 presents national levels and regional shares of thermal power plant emissions as communicated by the Brazilian national inventory to the Intergovernmental Panel on Climate Change (IPCC).

A large thermal power plant (500 MW or more) is considered a commercial investment 'anchor' for a natural gas pipeline project. Cost effectiveness criteria stipulate that thermoelectric plants are to be located as close as possible to end users (saving electricity transmission and gas pipelines), that is, in densely urbanized and industrialized regions. However, location must meet certain environmental requirements, especially in large urban areas. In the light of several academic, public and institutional discussions on this matter, there is a trend in legislation towards taking into account environmental permits and local maximum allowable environmental capacity, which involves inventorying multiple source emissions, modelling atmospheric processes and predicting major impacts.

The substitution of natural gas for other fossil fuels confers environmental advantages, namely, reductions of smoke and sulphurous gases. Depending upon plant operating conditions and air to fuel ratios, decreased emissions of HCs and incomplete combustion products also result. However, increased fugitive HC (from gas transfer operations) and CO and NO_x emissions are likely to occur, although these would be lower than those from other fossil and biomass fuels.

In the southern States of Santa Catarina and Rio Grande do Sul, there are a few coal fired power plants (taking advantage of local coal availability). These plants are significant polluters, since Brazilian coal has high contents of ash (20–55%) and sulphur (0.8–6.5%). Because these plants operate at lower boiler temperatures, their NO_x emissions are relatively low compared with those of natural gas fired plants. An assessment of four plants — Charqueadas, Candiota, Jorge Lacerda and Cambuí — showed emission levels of 1300–5175 kg of SO_2 per terajoule, 100–233 kg of NO_x per terajoule and 0.5–1.1 kg of N_2O per terajoule. Calorific values for the most commonly used coal ranged between 13 and 19 TJ/kt [6.64].

It is expected that the recently discovered offshore natural gas resources in São Paulo, combined with gas imports and gas consumption incentive policies, will lead to more emissions of global and local pollutants. This problem could intensify air pollution in populated areas, forcing the adoption of stronger enforcement policies and actions. A future challenge is the control of ozone, mainly caused by emissions of NO_x and volatile organic compounds (VOCs). As in developed countries, emission offset policies will have to be instituted, forcing older facilities to be upgraded and new ones (seeking environmental permits) to adopt pollution abatement measures.[23]

There are few studies of local pollution emissions from sugar cane bagasse fired boilers in Brazil. Coelho [6.29] provides an estimate of 0.6 kg of NO_x — and the same amount of PM — per tonne of bagasse burned. In many cases, particularly in São Paulo State, different kinds of air pollution control equipment (baghouses, electrostatic precipitators) are used for PM abatement, especially in the pulp and paper and sugar cane–alcohol sectors.

Furthermore, combustion of biomass and biomass derived fuels still generates air pollutants, including CO, NO_x and PM such as soot and ash. The amount of pollution emitted per unit of energy generated varies widely according to the technology used, but wood burning in traditional stoves is generally the worst offender, since the pollution occurs indoors. More advanced technologies with appropriate control devices generate far fewer emissions [6.65].

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[22] As natural gas fired power plants have high fuel consumption rates, local emissions have to be modelled to avoid excessive concentration of pollutants in certain areas.

[23] São Paulo State has already issued a law (2004 Decree No. 48 523) implementing an air pollution emissions offset scheme, where new enterprises have to balance their emissions with those of existing firms.

6.3.2.2. Transport related emissions

Automotive fuels have shown considerable improvement since the introduction of ethanol in 1975, especially since the late 1980s with the continuous removal of lead and sulphur. In general, automotive emissions have been reduced by blending all gasoline with 20–26% ethanol. The improvement of fuel quality has brought about a substantial reduction in CO, HC and GHG emissions from new vehicles. The addition of ethanol to gasoline at a percentage regulated by law has also helped Brazilian refineries to ban the use of tetraethyl lead, thus eliminating an extremely hazardous emission [6.66].

Ethanol use as an automotive fuel yields considerable GHG abatement benefits. Yet, an ethanol or natural gas fuelled automobile may emit more NO_x, for example. Other problems include the inadequate conversion of gasoline engines to natural gas fuelled engines; the use, by some automobile owners, of excessive quantities of ethanol in their fuel mix to minimize costs; and the use of fake, illegally obtained catalytic converters. It is expected that, in the future, Brazil's vehicle inspection and maintenance programme will adequately address these concerns.

In 1986 the National Vehicle Emission Control Programme (PROCONVE) was instituted. It has since become a benchmark in terms of improvements in vehicle technology. Since 1992, two-way catalytic converters (oxidizing both CO and HC) have been installed in new Brazilian light vehicles. Since 1997, vehicles have been equipped with both three-way units (oxidizing CO and HC, while also reducing NO_x emissions) and electronically controlled fuel injection and ignition systems, which have contributed towards more efficient engines that are more tolerant of fuel composition fluctuations.

This kind of technology constitutes the basis for flex-fuel vehicles, capable of automatically analysing fuel alcohol to gasoline composition ratios and adapting the ignition system accordingly. Flex-fuel vehicles can run on gasoline, alcohol or any kind of 'gasohol' blend. Besides allowing users to choose their fuel based on the prevailing fuelling and pricing conditions, such vehicles may bring considerable environmental gains if they stimulate the use of ethanol fuel. Figure 6.5 illustrates the air emission abatement levels obtained for light vehicles with the implementation of PROCONVE.

Sulphur emissions (as well as sulphate emissions, emitted as PM) from diesel vehicles are very high. According to CETESB, the inhalable particle emissions from the light vehicle fleet in the São Paulo metropolitan region amount to 51% of total emissions, including stationary sources. The much smaller diesel powered fleet, composed predominantly of heavy duty vehicles, is responsible for 30%.[24] Moreover, the Government has recently required the diesel fuelled fleet to use a lower sulphur diesel fuel, called 'metropolitan diesel', for urban areas.[25] Government policies are systematically reducing the sulphur content in gasoline as well.[26] Even with the increased consumption, total emissions are decreasing more intensively, as shown in Table 6.3. In addition to reducing emissions, this lower sulphur content permits compliance with particle emission standards that are a tenth of the current standards, and it is less damaging to engine components.

Several experimental vehicle pollution abatement programmes can also be cited, such as the introduction of hybrid diesel–electric buses,[27] biodiesel use[28] and research into the potential use of hydrogen fuel derived from sugar cane ethanol.[29] Biodiesel is a promising energy option, but the pros and cons are still not balanced in the environmental dimension: there are the advantages of reduced carbon and pollutant emissions,[30] but the risks include the potential for agricultural expansion, especially the expansion of soybeans in Amazonia.[31]

Proper management of emissions from mobile sources also requires an integrated inspection and

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[24] New models of automobiles are not allowed to be fuelled by diesel, a subsidized fuel for use in cargo and public transport.

[25] The 2004 levels of sulphur in diesel were 3500 ppm in regular diesel and 2000 ppm in metropolitan diesel. Petrobras expects to reduce such levels to 500 ppm by 2006 and, if economically feasible, to 50 ppm by 2009.

[26] The maximum allowable level of sulphur in gasoline is 1000 ppm (400 ppm gasoline can be found in filling stations); the target for 2008 is 80 ppm.

[27] Supported by the William and Flora Hewlett Foundation [6.67].

[28] PROBIODIESEL, the National Biodiesel Programme, was launched in 2002 [6.68].

[29] For more information, see Ref. [6.69].

[30] Biodiesel fuel has led to a significant emission reduction — 23% less black smoke — compared with the same amount of regular diesel fuel [6.70].

[31] See discussion in Section 6.2; for more information, see Ref. [6.71].

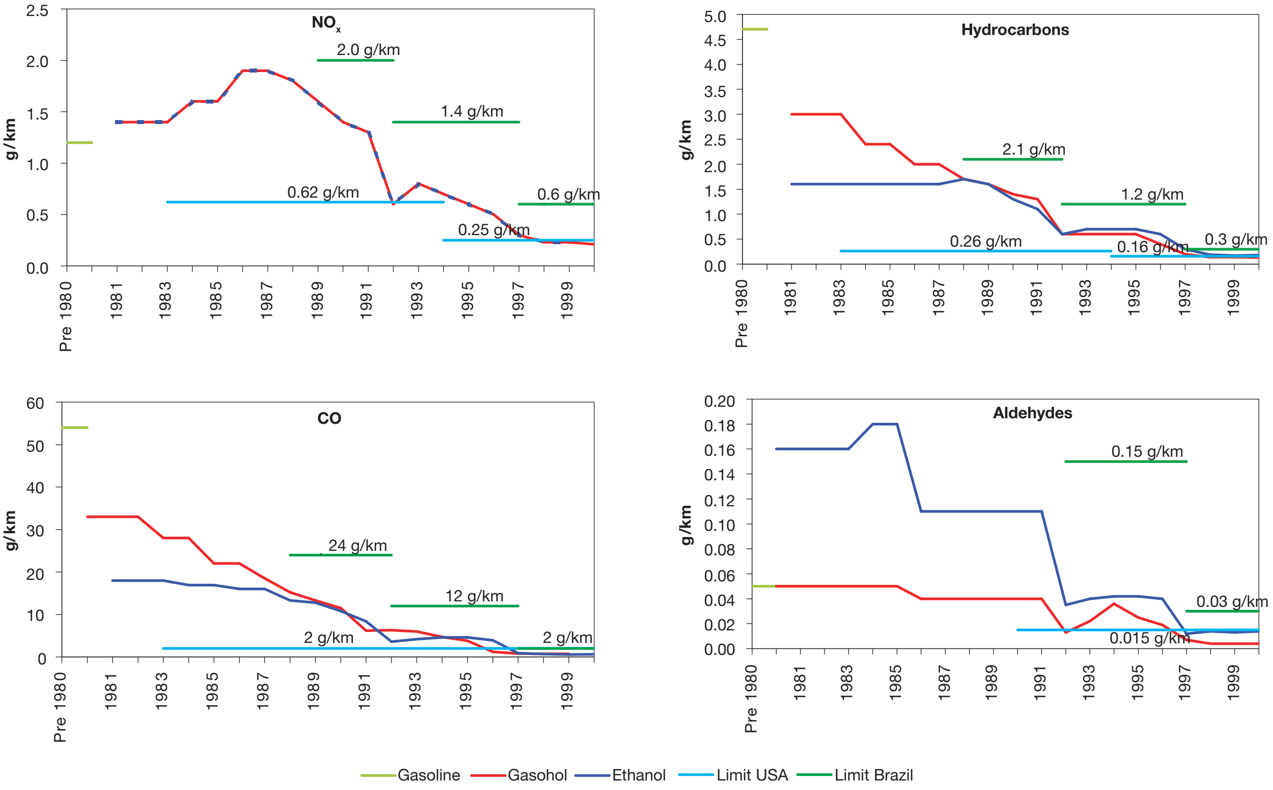

FIG. 6.5. Average emission evolution for new Brazilian light vehicles [6.43].

TABLE 6.3. SULPHUR REDUCTION IN FUELS AND CORRESPONDING ESTIMATED EMISSIONS

Year	Diesel					Gasoline			
	S content[a] (ppm)		Consumption (10^6 m^3)	S emissions[b]		S content[a] (ppm)	Consumption (10^6 m^3)	S emissions[b]	
	Regular	Metropolitan[c]		kt/year	kg/m^3			kt/year	kg/m^3
1990	13 000	—	25	276	11.1	2 500	11.5	21	1.8
2002	3 500	2 000	36	107	3.0	1 000	22	16	0.7
2004[d]	2 000	500	38	65	1.7	400	25	7	0.3
2008[d]	500	50	43	18	0.4	80	30	2	0.1

Note: Diesel density is 0.85 t/m^3 and gasoline density is 0.72 t/m^3.

[a] The sulphur content reported here is the maximum in the given year.
[b] Sulphur emissions are represented as S, but in reality are sulphate (SO_4^{-2}) and mainly SO_2.
[c] The volume of metropolitan diesel/gasoline was considered to be half the volume of regular diesel/gasoline.
[d] Scenarios for 2004 and 2008 are based on annual growth rates of 3.1% for diesel and 5.6% for gasoline.

maintenance programme[32] and the management of fugitive emissions of non-methane volatile organic compounds (NMVOCs), for example, at gasoline pumps and storage tanks.

6.3.2.3. *Impacts and their costs*

Air pollutants include CO, tropospheric ozone, SO_2, NO_x and PM. These pollutants are primarily the result of fossil fuel combustion, mainly in vehicles and industrial processes. Ambient air in most urban areas typically contains a mixture of

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[32] The city of Rio de Janeiro has started such a scheme, but it is still in the initial phase. Although the Federal Government plans to establish a national inspection programme, a legislative deadlock has been delaying the implementation of an inspection and maintenance programme at the State level [6.72].

pollutants, each of which may increase a person's vulnerability to the effects of the others (a synergistic effect). Exposure to CO lowers reflexes and causes drowsiness, since CO molecules constitute an unbreakable bind to haemoglobin, reducing the amount of oxygen carried by red blood cells. NO_x may aggravate the effects of asthma and reduce the lung's gaseous exchange performance, as well as make a person's airways more sensitive to allergens. Ozone also causes lung inflammation and reduces lung function and exercise capacity. Fine inhalable particles, especially those with a diameter of 10 µm or smaller (PM10), may become lodged in the lung's alveolar sacs. Most hospitalizations due to respiratory diseases are associated with exposure to PM, as are increased mortality rates due to respiratory and cardiovascular maladies. The ozone and particulate levels commonly present in large cities increase death rates, the number of hospitalizations and medical visits, the complications of asthma and bronchitis, and the number of days of work lost and work restrictions, and may cause lung damage [6.43].

According to Weaver [6.73], in São Paulo about 10% of all hospitalizations of children, as well as 8% of fatalities among the elderly, are due to respiratory diseases related to high PM levels. Estimates from IPEA/ANTP [6.74] report that emissions from the São Paulo metropolitan region's transport system cause yearly average economic losses of 340 million Brazilian reals, mainly due to delays, excessive fuel consumption, air pollution and the need for excessive road repairs. Table 6.4 summarizes the health costs associated with air pollution in the São Paulo metropolitan region, calculated using different methods. As a reference, in 2001, 65.3 kt of PM were emitted in the region [6.40], where 308 inventoried industries accounted for 31.1 kt of PM, diesel vehicles for 19.7 kt of PM and gasoline automobiles for 5.1 kt of PM.

Evaluations have been conducted in Brazil concerning the economic values of mortality and morbidity cases, as well as the benefits of air pollution abatement. In the São Paulo metropolitan region, with a population of 18 million, studies have found significant harmful pollutant effects, especially for babies, children and elderly people. Fine inhalable particles were the pollutants most frequently related to respiratory and cardiovascular damage. Records indicate that, during the most polluted days in São Paulo, child morbidity in hospitals increases by 30%, the mortality of elderly people increases by 15% and cardiovascular problems increase by 10%. Such studies supported by epidemiological findings have shown that current air quality standards are inadequate to protect those population groups most sensitive to pollution. Associated health costs would decrease by half if international air quality standards were attained in the region [6.76, 6.77].

Rapid population increase without corresponding infrastructure development to support it has caused serious traffic jams and air pollution incidents in São Paulo. In 1989, 50% of the city's smog resulted from fixed sources, while 50% came from motor vehicle emissions. By 1999, these rates had been altered to 10% and 90%, respectively [6.77].

Another study evaluated air pollution costs incurred as a result of fine inhalable PM (PM2.5). Air pollution health costs were estimated by

TABLE 6.4. HEALTH COSTS ASSOCIATED WITH FINE PARTICULATE MATTER (PM2.5) AIR POLLUTION IN THE SÃO PAULO METROPOLITAN REGION (10^3 US $ (1997)) [6.75]

Age	Morbidity		Mortality				
	R	C	R, C (SPM)	R (HPM)	C (HPM)	R (TSLV)	C (TSLV)
0–13	1.1	n.a.	0.0	n.a.	n.a.	n.a.	n.a.
14–65	2.0	7.3	73.1–197.7	0.04–0.12	0.05–0.13	3.1–13.1	3.6–14.9
65+	2.3	7.6	9.3–11.0	0.02–0.06	n.a.	1.6–6.6	n.a.

Note: n.a. = not available; R = respiratory; C = cardiovascular; SPM = sacrificed production method, or the human capital for future production lost due to disease; HPM = hedonic prices method, a comparison of two real goods differing only by the environmental characteristic that the analyst seeks to evaluate; TSLV = transfer of statistical life value method, or the willingness to pay for the risk of death from a given activity.

summing up total hospitalization costs (per age group and pollution occurrence), taking into consideration the number of days of work lost due to disease and average regional wages. Total annual costs associated with atmospheric pollution by fine particles in the São Paulo metropolitan area average US $100 million (1997 value) in terms of heart and respiratory diseases alone. Preventive costs were not quantified as disease costs in this particular study [6.75].

6.3.2.4. *Water pollution*

With regard to thermal power plants, one important issue is their high water consumption for gas turbine cooling. These demands tend to compound the existing problems of meeting demands for multiple watercourse uses — such as residential, commercial and industrial supply; wastewater discharges; irrigation; navigation; and energy generation — and could cause shortages downstream. In São Paulo State, six natural gas fired plants — amounting to a total capacity of 3600 MW — are to be installed in the already overexploited Capivari, Piracicaba and Jundiaí watersheds. It is estimated these plants will take out 4100 m^3 of water per hour (enough to supply 400 000 inhabitants), of which two thirds will evaporate [6.78]. Dry cooling towers and closed cycle units are technological options that, although more expensive, would help in tackling such problems, as shown in Fig. 6.6.[33]

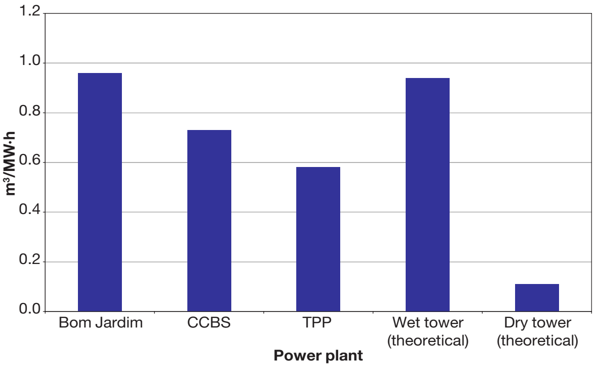

FIG. 6.6. Water consumption estimates for three natural gas fired thermal power plants with wet cooling towers in São Paulo State compared with theoretical factors for wet and dry towers [6.79].
Note*: The Bom Jardim power plant was proposed for the city of Jundiaí, but was not built because of environmental restrictions; the Central de Cogeração da Baixada Santista (CCBS) was implemented in the city of Cubatão; and the Termoelétrica do Planalto Paulista (TPP) was implemented in Paulínia.*

6.3.2.5. *Pollution prevention and control strategies*

Solutions for the problem of urban air pollution are not difficult to identify. Improved air pollution regulations and enforcement as well as improved technologies as described above can go a long way to improving the situation and are reasonably influenced by legislation and economic incentives. More difficult to impose are lifestyle changes. Individuals could reduce automobile use by bicycling, walking and using public transport; they could also make use of more fuel efficient automobiles.[34] Urban planning commissions and regional governments could redirect transportation funding towards public transport options: light rail, heavy rail or express buses. Zoning laws and other regulatory tools could be used to encourage higher density development, which is more conducive to increased public transport usage.

In 1995, a pollution control programme was instituted in São Paulo involving an automobile rotation scheme, whereby drivers were obliged to leave their vehicles at home one day a week. This system has contributed to reducing traffic volume and daily main pollutant emissions (see Chapter 9). However, after a few years, some drivers simply bought additional automobiles — sometimes older and more polluting models — to get around the regulation. Current Government initiatives to improve local environmental conditions include building a bypass around the metropolitan area (expected to reduce city traffic by 20%) and additional subway lines, and making improvements to the rail system. Other measures include progressive reductions in the sulphur content of all diesel fuel used within the metropolitan area and establishing a vehicle inspection and maintenance programme.

The city of Curitiba has adopted urban planning approaches to mitigate adverse environmental effects. The main goal is to reduce the

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[33] Since there currently are few operational natural gas fired thermal power plants in Brazil, assessments commonly utilize emission factors provided by equipment suppliers. Literature sources, such as those of the US EPA [6.42], provide theoretical results for the local situation.

[34] Policies are proposed and discussed in more detail in Chapter 9.

population's reliance on automobiles through the introduction of dedicated bus corridors; the use of extra-large buses on heavily used routes; the construction of tube shaped bus stops, where passenger fares are paid in advance (similar to subway systems); and the creation of a major road network radiating out of the edge of a downtown 'pedestrian only' zone. Today, about 70% of Curitiba's commuters make use of the public transport system, despite the city's high automobile ownership rate and per capita income — well above the national average. Although its population has doubled since 1974, city traffic has actually decreased by approximately 30%, with 55% of private trips in the city being made on public transport [6.80].

6.3.3. Coal mining impacts

Surface and underground coal mining has caused significant environmental impacts in Santa Catarina State in southern Brazil. During 1985, several cases of pneumoconiosis, a disease caused by the accumulation of fine dust particles in the lung's bronchiole and alveoli, were registered among coal miners. Pneumoconiosis is an incapacitating illness and, in its advanced stages, may cause death due to extensive damage to the patient's respiratory capacity.

At first, coal was mostly mined using surface mining techniques, without reclamation. The original topsoil was simply thrown aside and covered by several layers of sandy sedimentary rocks, silt and carbonaceous pyrites (iron disulfide), which make up coal refuse. Pyrites react with water and oxygen, producing sulphurous gases, iron composites and sulphuric acid. In some regions, open coal mining areas now stretch across more than 2100 ha of desolate expanses of sterile soil. There have been a few attempts at area recovery, with basic groundwork and the seeding of artificial forests (eucalyptus); but these have fared poorly owing to factors such as low nutrient soil, inadequate project management and the presence of acidic waters. Usually, these problems do not cease with mine closure, but may linger for decades — or for as long as contaminants remain in concentrations higher than occur naturally. Some two thirds of the watersheds crossing the mining region are now considered to be degraded by acid contamination, with losses to agriculture and fisheries. Severe silting of many rivers has also occurred, and some rivers have been rendered unusable for drinking purposes. In the Criciúma municipality, for instance, all drinking water has to be taken up from the São Bento River, located 20 km farther away than the more easily accessible, but heavily polluted, Araranguá River [6.81]. The Tubarão River has similar problems, but there the environmental impact is aggravated by the fact that its waters feed the State's largest and most vulnerable lake system, which also houses Brazil's largest natural shrimp nursery. Effluents discharged into the river's waters can have high solid and toxic metal concentrations, affecting the limited natural recovery capacity of the lakes [6.82].

The environmental effects and health impacts of coal mining and possible mining accidents, and the health impacts of emissions from coal fired power plants all present social issues related to the fourth EISD social indicator (accident fatalities per energy produced by fuel chain [SOC4]) (see Table 1.1 in Chapter 1 of this report). In Santa Catarina State, coal mining has contaminated surface and underground water sources through the solubilization of metallic compounds. The very limited amount of calcium in the soil of this region and the high sulphur and ash content of the coal combine to produce the aggressive phenomenon of sedimentary soil lixiviation. In 2001, coal production reached 11.2 Mt, which means that 40–50 Mt of sterile material were dumped on top of the large aquifer in the region, representing a high risk of soil contamination, in addition to the high concentration of mercury and arsenic caused by the ustulation of the pyrite.

The total agricultural area affected by coal mining is around 42 800 ha. Environmental liabilities in Brazilian coal mines amount to more than US $112 million [6.83]. As a result of increased pressure by environmental agencies and the public, some modest internationally funded recovery activities have been started. Some areas have been recovered, but the process will probably be long. A site recovery plan is under way in Santa Catarina State, including the mapping of impacted areas and the proposal of site recovery measures [6.84].

6.3.4. Nuclear energy

Brazil has recently started discussions about reactivating its nuclear energy programme. The benefits of reduced air pollution and GHG emissions are not in dispute; the main controversies concern economic factors and long term radioactive waste disposal issues. Nuclear waste is not yet

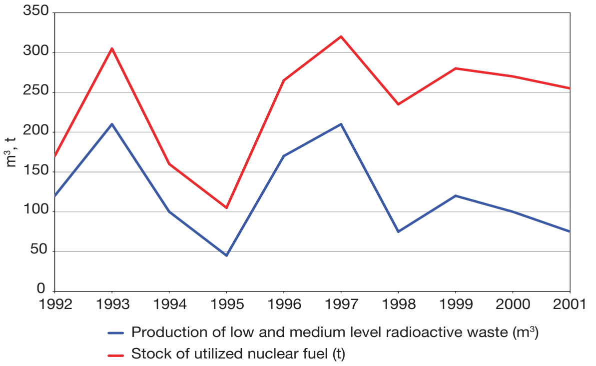

FIG. 6.7. Nuclear fuel and radioactive waste from electricity production at the Angra I power plant [6.85].

considered a major problem, but the issue of ultimate disposal has yet to be resolved.

Environmental issues are raised during the following phases of the nuclear fuel cycle: (a) uranium mining, (b) enrichment, (c) plant operation, (d) spent fuel management/waste disposal and (e) plant decommissioning.

The Brazilian Nuclear Energy Commission (CNEN) is the Federal institution charged with monitoring and approving permits for nuclear and radioactive facilities, and establishing guidelines for managing radioactive waste. Spent nuclear fuel from the Angra I power plant is not officially considered nuclear waste, because it still contains residual uranium that can be used to produce more fuel (see Fig. 6.7). As of 2001, there were 1635 m^3 of accumulated spent fuel. This fuel is stored in pools within the plant's boundaries and corresponds to 466 nuclear fuel elements. Except for the disposal site containing contaminated material from the Goiânia accident, there are no other radioactive waste disposal sites in Brazil. Waste from the decommissioned Osamu Utsumi uranium mine, in Poços de Caldas (Minas Gerais State), is stored in the mine. Some thorium processing waste is held in a provisional storage area in São Paulo State.

6.3.5. Accidents and security issues

Environmental safety basically concerns the prevention of environmental accidents. Brazil's experience is illustrated by some relevant events, as discussed below.

Brazil has not reported any major oil spills in the sea; however, there have been significant casualties reported in the oil industry in the past 20 years [6.86]. In 1982, a railway accident at the Camaçari petrochemical complex (Bahia State) caused fires, with almost 100 deaths and many more people injured. In 1984, pipeline spills caught fire, killing hundreds of people in Cubatão's Vila Socó slums, located in a mangrove area. Between 1984 and 2001, a further 53 people died — and several more were wounded — as a result of accidents in the petroleum industry.

Risks related to offshore oil drilling are high, especially in the case of deepwater well exploitation along Brazil's continental shelve. During the early operational phase, overpressure threatens to cause explosions and uncontrolled oil spillage into the sea. Deep sea, semi-submersible offshore platforms are much more vulnerable to accidents and rough sea conditions than are conventional platforms, a severe liability in the case of Brazil's petroleum industry. Two major accidents recently occurred on offshore platforms, with losses of life and output, but with no major environmental impacts. Oil pollution due to accidents — although highly visible and sensational — is just a part of the problem. Routine operations like fuel transfer and tanker cleanup procedures pose an even greater threat to the environment, since fugitive emissions and minor spills are to be expected [6.87].

Oil spills are becoming more frequent in Brazil's oil installations, causing severe environmental damage. There were 12 spills in 2000, partly owing to the oil sector's weak environmental oversight. Guanabara Bay is among the areas most threatened by oil pollution in Brazil. In January 2000, a pipeline burst at Petrobras' Duque de Caxias oil refinery, spilling 1.3 million L of crude oil into the bay and affecting the Guapimirim mangrove swamps, an environmental protection area. Besides causing damage to the swamp itself, the spill also severely hurt the local fishing community and left the beaches covered with crude oil. In 1997, the same pipeline spilled 600 000 L of fuel oil. Guanabara Bay is also threatened by oil from ships flushing their fuel tanks in the bay, because local harbours do not have the equipment necessary for proper disposal.

In July 2000, Petrobras was responsible for approximately 4 million L of crude oil from its Presidente Getulio Vargas refinery (Paraná State) that reached the Barigui and Iguaçú Rivers. According to Paraná State officials, this was the worst river contamination ever in Brazil. The spill was contained before it reached any major cities or the well known Iguaçú Falls. Petrobras was fined US $93.8 million for the spill.

In the wake of other incidents, Petrobras has doubled its environmental budget to approximately US $997 million over the next four years and has established a defence and response centre in the Guanabara Bay area, provided with equipment to contain and collect oil, and specialized watercraft and communications equipment.

There have also been some fires and explosions in Brazil, raising security concerns. Most significant, according to SINDIPETRO [6.88], were the 1972 Duque de Caxias refinery explosion (38 deaths); the 1981 São José dos Campos sulphuric acid leak (13 deaths); the 1984 fuel railway tank explosion in Pojuca (45 deaths); the 1984 explosion of the Vila Socó gas pipeline (94 deaths); the 1998 fires at the Betim refinery (6 deaths); an explosion in the same year on the Enchova offshore platform (37 casualties); the 1991 fire in the Manguinhos refinery (1 death); the 1992 fire in a petrochemical plant in Santo André (1 death); and the 2001 explosion of the Petrobras P-36 offshore platform due to a gas leakage (11 deaths).

Within the nuclear sector, while accidents may occur at any stage of the fuel cycle, only at the plant operation level would there be any potentially serious impact. Brazil's only serious radioactive accident to date was not related to energy production. In 1986, a radioactive capsule from old hospital equipment abandoned in a scrap metal dump in the city of Goiânia was broken up by scavengers. Several people were severely contaminated; some died, while others are still being carefully monitored [6.89].

Thermal power plants also present accident risks such as explosions and fires.

6.4. MAIN ISSUES

Brazil has learned about the costs and benefits of energy matrix diversification efforts from its experiences over the past few decades. Some of the major issues related to energy and the environment are as follows:

- Brazil's national energy policy remains anchored in hydropower plants. The country still has a large potential to explore and vast technical expertise. Large hydropower plants built in the 1970s and 1980s have raised public awareness as to their social and environmental impacts. New plants are subject to stricter guidelines and to more democratic debates.
- Natural gas is a growing energy option, and several policies foster its use, especially for transport and for the replacement of industrial fuel oil. The use of coal is extremely limited. New natural gas fired thermal power plants are being proposed, raising concerns in urban areas about air pollution (especially ground level ozone) resulting from fuel combustion and fugitive emissions. Air pollution is also a consequence of policies that benefit the road transport system at the expense of railways and waterways. New developments in terms of air pollution control include improvements in fuel quality (low sulphur diesel) and emissions trading for local pollutants (offset programmes, where new processes compensate for emissions from older ones).
- Multiple usage of water (including for energy production) is already a concern in the Southeast region of Brazil, requiring innovative environmental management and taxes.
- The oil spill in Guanabara Bay was probably the most visible environmental accident of the past decade. As a result, Petrobras has improved its risk management, providing an example to other companies. Environmental inspectors and pollution control agencies have also improved their preparedness. Unfavourable trends may be reversed by recent legislation applying the precautionary and 'polluter pays' principles. Water use is now being taxed, and companies are being sued under the new Law on Environmental Crimes; under the legally defined concept of objective responsibility, polluters' duties are independent of their will.
- PROALCOOL, the Brazilian Alcohol Programme, is a paradigm for cleaner transport, especially with the widespread availability of affordable flex-fuel vehicle technology. New practices are phasing out the burning of sugar cane fields during the harvest season. Productivity has risen and the practice of growing sugar cane organically is showing better performance than that of utilizing pesticides.

Renewable energy has been a focal point for Brazil in the international sustainable energy debate. The country has presented two major proposals for achieving sustainable development in the energy sector: the Clean Development Mechanism presented at the 1992 Rio Convention and the global renewable energy targets and time frames backed up by tradable certificates proposed at the 2002 Johannesburg Summit.[35] Both initiatives may be highlighted as the strongest proposals in terms of global sustainable development, stressing the importance of renewable energy sources. These initiatives may increase the competitiveness of environmentally friendlier energy options that take advantage of their learning curves.[36]

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Chapter 7
ENERGY AND SOCIAL ISSUES

M. MACEDO COSTA, R. SCHAEFFER, C. COHEN

7.1. THE SOCIAL DIMENSION OF SUSTAINABLE ENERGY DEVELOPMENT

Energy production and use can reveal and shape the way life is organized in human societies. Changes in the energy environment are followed, and stimulated, by technological innovations and changes in the economic systems of production and consumption. The very foundation of modern economies is rooted in specific rates of energy and materials production, transformation, exchanges and use, which guarantee the heterogeneous distribution of resources and wealth among and within nations.

Unwanted and unexpected side effects can be suffered by those who do not (or cannot) attain the benefits derived from the extraction and/or production, transformation and use of natural resources and products. For instance, there are territorial and temporal asymmetries between the use of hydropower and fossil fuels, and the burdens of reservoir flooding and global warming, respectively.

In thinking about sustainable energy development in a particular country, as is done here for Brazil, one ultimately must deal with social organizations and people. This chapter relates social issues associated with Brazil's energy use and supply to some of the social Energy Indicators for Sustainable Development (EISD) (see Table 1.1 in Chapter 1) and to some equity, health, education and population indicators.

Energy must be not only accessible and affordable, but also acceptable to society, even if only small portions of the population are involved. Such acceptance is necessary for ethical and democratic reasons. For instance, nuclear energy still raises fears among the Brazilian public. Depending on the social impacts, those wishing to construct large dams in the country could face strong local public opposition and even opposition from people across the country aware of the associated problems. The production of charcoal from native forests and with the use of child labour is absolutely unacceptable in the country today. Coal fired power plants with high atmospheric emission factors no longer receive environmental licences in the country. Brazil needs to increase the energy supply along its forward development path, and the lessons learned from negative experiences of the past in the energy area are relevant, as they have raised civil society in the country to new levels of awareness and organization. There are many good reasons for the changes in the role of public opinion in Brazil over the past decade — in particular, the spread of information and collective political movements, for whom the main social and environmental impacts constitute a starting point.

7.2. BRAZILIAN SOCIAL PROFILE ON ENERGY USE[1]

7.2.1. Social indicators

Between the first half of the 20th century and the beginning of the 21st century, Brazil underwent a transformation from a rural country relying largely on fuelwood for energy use to a mostly urban and industrialized country using modern commercial forms of energy such as electricity, fossil fuels and modern biomass (see Chapter 2 for more details). Still, it has not been economical to extend the power grid to many of Brazil's rural and isolated areas, and currently 12 million people (7% of the country's total population of 172 million in 2001) still have no access to electricity [7.2]. Moreover, even among those with access, a large share of low income families cannot pay for even their most basic needs. Even when household electricity use is less than 100 kW·h/month, some families have serious difficulties paying their electricity bills. The situation is similar for liquefied petroleum gas (LPG) for cooking, as its price is highly dependent

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[1] This section benefited substantially from Ref. [7.1].

TABLE 7.1. DEMOGRAPHIC AND INCOME INDICATORS BY REGION, 1999 [7.3]

	Brazil	North	Northeast	Southeast	South	Midwest
Population (10^6)	171	13	48	73	25	12
GDP per capita (US $ PPP-2000)	6719	3808	3009	8835	7748	6107

TABLE 7.2. URBAN POPULATION BY REGION, 1950–2000 (%) [7.8]

Region	1950	1960	1970	1980	1991	2000
North	29.6	35.5	45.1	51.6	59.0	69.8
Northeast	26.4	34.2	41.8	50.5	60.7	69.0
Southeast	47.5	57.4	72.7	82.8	88.0	90.5
South	29.5	37.6	44.3	62.4	74.1	80.9
Midwest	25.9	37.2	48.1	67.8	81.3	86.7
Brazil	36.2	45.1	55.9	67.6	75.6	81.2

on the international price of oil and the exchange rate between Brazilian reals and US dollars. Moreover, energy affordability concerns are not restricted to the poor. The growing use of expensive natural gas imported from Bolivia for power generation, for example, may affect middle income families as well.

Nonetheless, a persistent theme throughout this chapter is the issue of equity across different groups of the Brazilian population. Unfortunately, a recent study by the Brazilian Institute of Geography and Statistics (IBGE) shows that the income gap between the most and the least affluent segments of the population is immense and growing, with the total earnings of the richest 5% currently equalling those of the poorest 80% [7.3]. It should be noted that the increase in inequality is a new trend that started in 2000 after a seven year trend of decreasing inequality.[2] The challenge for any sustainable development strategy will be to spur income creation for the poorest segments of the population, without jeopardizing the savings and investment capacity of the wealthier segments [7.5].

In addressing this challenge, two particular features of Brazil should be kept in mind. One is the unusual pattern in the intensity of household energy use. A recent study by Cohen et al. [7.6] evaluates empirically the relationship between household expenditure and total (direct plus indirect) energy requirements of Brazilian households at different income levels in 11 capital cities using a generalized input–output model to calculate the energy embodied in purchased goods and services. The study concludes that, on average, the total energy intensity of household expenditure increases with income level, although with a considerable spread in energy intensities within income groups as well as disparities between regions of the country. This suggests an expenditure elasticity[3] for Brazil that is slightly greater than 1.0, in contrast to results for other countries that show expenditure elasticities less than 1.0 [7.7]. One contributing factor may be the pattern of fuel consumption for private automobiles across income groups, as its share of total household energy use increases with household income. In any event, to the extent that income growth for the poor and energy intensity reductions are both considered as part of sustainable development, the Brazilian pattern will require careful analysis.

Second are the consequences of Brazil's income being historically so heavily skewed towards a small fraction of the population. Tables 7.1 and 7.2 show the disparities in income and urbanization across the different regions of Brazil. There is currently a rough positive correlation between

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[2] See Table 7.3. This new trend can be explained by the effect of the economic crisis of 1997–1999, which reduced employment and the purchasing power of the poor [7.4].

[3] The expenditure elasticity measures the variation of energy requirements as expenditures vary. An expenditure elasticity greater than 1.0 means a general tendency for a continuous increase of the energy requirement with rising expenditure.

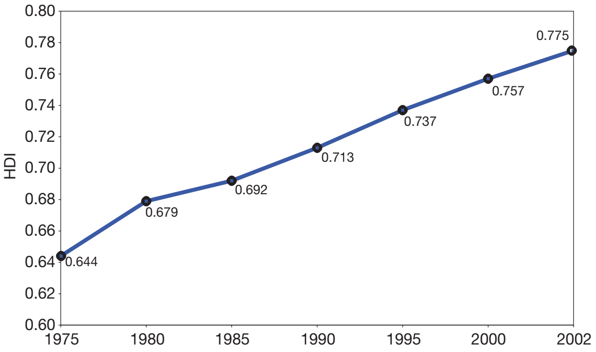

FIG. 7.1. Evolution of the Human Development Index for Brazil [7.9].

urbanization and income, with the Southeast region being both the richest and the most urbanized and the Northeast region being the poorest and the most rural. Until the first half of the 20th century, Brazil was mainly a rural country. But the steady trend for at least half a century, as shown in Table 7.2 (and Fig. 2.11 in Chapter 2), has been one of increasing urbanization in all regions of the country. Now more than 80% of the population lives in urban areas, the majority concentrated in State capitals along the coast. The poorer North and Northeast regions are less urbanized, with some 30% of their populations living in rural areas. The more recent settlement of the Midwest region has given it the highest urban growth rate of all regions.

Figure 7.1 shows the evolution of the Brazilian Human Development Index (HDI) between 1975 and 2002. The HDI is the average of a life expectancy index, an education index combining literacy and school enrolment data, and an income index based on the logarithm of gross domestic product (GDP) per capita in terms of purchasing power parity (PPP) [7.10]. Despite the continuous improvement shown in Fig. 7.1, from 0.644 in 1975 to 0.775 in 2002, Brazil only ranked 72nd in 2002 among the 177 countries for which the index has been calculated. Even with recent improvements, health and education levels were the most important factors limiting Brazil's ranking. Comparing HDI values across regions, disparities again arise. While the Southeast region's HDI rose from 0.765 to 0.822 between 1975 and 2000, the Northeast region's improvement was only from 0.636 to 0.705, the lowest of all regions and bringing it, in 2000, to the level that the country, on average, had reached in the 1980s.

Brazil's Gini index of income inequality, as shown in Table 7.3, is one of the highest (i.e. most unequal) in the world.[4] For the 1992–1999 period examined here, there were only three countries in the world more unequal than Brazil: Central African Republic (0.61), Swaziland (0.61) and Sierra Leone (0.63)[5] [7.11]. Table 7.3 shows a significant increase in inequality from 1992 to 1993 at a time when inflation rates were very high, especially in the second half of 1993 (30% per month), and before the introduction, in 1994, of the Government's so-called 'Real Plan' stabilization plan [7.1]. Here it is important to stress that only the formal economy is included in the analysis; the inclusion of the informal economy would make the final income distribution more equitable; that is, it would decrease the Gini index (for details, see Ref. [7.12]).

The percentage of Brazilians categorized as 'poor' decreased from an average of 43% in the 1980s to 37% in the 1990s [7.13]. Consistent with the pattern shown in Tables 7.1 and 7.2, the percentage of people categorized as poor in urban areas is below the national average, dropping from 34% to 31% in the same period. The Northeast — the most rural region — has the highest proportion of poor people, more than 50%. In addition, in 1987, 1990, 1993 and 1996, the richest 20% of the population absorbed 81% of the total income of the economically active population of the Northeast region, with this proportion dropping to 68% in the Southeast region over these same years.

Table 7.4 shows disparities across regions for various household amenities, ranging from basic services such as water and sewage up to less essential items like Internet connections. The availability of many of the features in the table depends on the availability of electricity and regional infrastructure, as well as on income levels in individual households.

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[4] The Gini index measures the extent to which the distribution of income (or consumption) among individuals or households within a country deviates from a perfectly equal distribution. A Lorenz curve plots the cumulative percentages of total income received against the cumulative number of recipients, starting with the poorest individual or household. The Gini index measures the area between the Lorenz curve and a hypothetical line of absolute equality, expressed as a percentage of the maximum area under the line. A value of zero represents perfect equality; a value of one, perfect inequality.

[5] The figures for the less unequal countries ranged from 0.23 (Austria) to 0.24 (Denmark) to 0.25 (Belgium, Sweden, Norway and Finland), for instance.

TABLE 7.3. MAJOR SOCIAL INDICATORS [7.3, 7.9]

Year	Poverty line[a]	Gini index[b]	Income share of the richest 10% (%)	Income share of the poorest 20% (%)
1992	40.8	0.571	45.81	2.32
1993	41.7	0.600	48.58	2.24
1995[c]	33.9	0.585	47.92	2.29
1996	33.5	0.580	47.59	2.15
1997	33.9	0.580	47.70	2.20
1998	32.8	0.575	47.92	2.25
1999	34.1	0.567	47.45	2.34

[a] Defined as the percentage of people earning less than US $2.00 per day at exchange rate values. There are no data for 2000, except for the Gini index, which was 0.608. In 2001, the poverty line figure was 33.6%.

[b] The degree of income concentration, considering the income distribution for all workers more than 10 years old; it varies between zero (perfect equality) and one (maximum inequality).

[c] No data available for 1994.

TABLE 7.4. SELECTED FEATURES OF HOUSEHOLDS IN BRAZIL, TOTAL AND BY REGION FOR 2001 (%) [7.14]

	Brazil (total)	North (urban)	Northeast	Southeast	South	Midwest
			Water system			
Grid	81.1	63.7	69.2	90.5	81.7	75.5
Other	18.9	36.4	30.7	9.5	18.3	24.5
			Sewage			
Public sewer	45.4	5.8	22.0	73.5	22.9	30.8
Septic tank	21.3	47.0	21.0	11.1	46.9	12.9
Other	25.6	40.6	35.2	13.7	27.3	52.2
None	7.6	6.6	21.8	1.8	2.9	4.1
			Other features			
Garbage collection	83.2	85.3	66.3	92.3	84.5	84.4
Electric lighting	96.0	98.4	89.4	99.1	97.9	96.3
Telephone	58.9	53.4	35.9	70.6	64.9	59.9
Stove	97.6	96.9	93.9	99.3	98.7	98.3
Water filter	52.7	33.0	52.1	65.3	19.2	63.2
Refrigerator	85.1	83.0	64.9	94.0	92.9	87.0
Freezer	18.8	16.4	7.1	19.8	35.1	19.3
Washing machine	33.7	26.0	9.3	44.0	48.8	28.1
Radio	88.0	75.5	81.0	92.3	93.4	83.8
Television	89.0	88.2	78.4	94.4	92.3	88.5
Personal computer	12.6	6.7	5.2	17.3	13.9	10.6
Internet access	8.6	4.1	3.5	12.0	8.8	7.3

Note: Some values in the first column (Brazil total) do not match the total figures for Brazil (e.g. for electricity access) owing to the exclusion, in this table, of the rural areas in the North region, for which data are scarce.

The contrast between urban and rural areas is striking. Even with progressive improvements in water and sewage indicators in the 1990s, in rural areas the share of households with some kind of water grid system (25%) and sewage system (66%) is still much lower than in urban areas (92% and 97%, respectively).

The eradication of poverty in Brazil is an important goal. Still, before this aim is met, more convenient and economically accessible energy services could certainly improve the quality of life and provide better social opportunities for a large part of the population. Pursuing this objective, it is important to reduce the economic burden of energy in the budgets of low income households and to increase access to energy to include all Brazilian households.

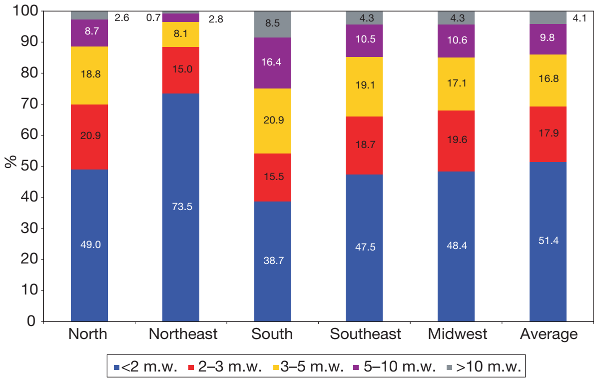

FIG. 7.2. Share of fuelwood consumption by income group and region, 2000 [7.1, 7.9, 7.11].
Note: *m.w. = minimum wage. In 2000, the minimum wage in Brazil was 160.77 Brazilian reals, or US $181.12 at PPP-2000.*

7.2.2. Energy use in the residential sector

From 1980 to 2000, the percentage of households supplied with electricity increased from 44% to 93% (see Table 7.5 and Fig. 2.12). At the same time, the percentage of rural households with access to electricity jumped from 22% to 69%. Regional disparities are again evident, with 39% of rural households in the Northeast region still lacking access to electricity, compared with only 12% of rural households in the Southeast region.

In the same period, the residential sector's share of total energy use dropped from 35% to 17%. This drop was mainly the result of an increase in the industrial sector's use, but also resulted from more efficient appliances and shifts in the mix of primary energy sources (see Chapter 2 for details).

In Brazil, the household energy fuel mix has changed significantly since 1970. Electricity, LPG and, later, natural gas experienced high growth rates from 1970 to 2000, replacing the previously dominant fuelwood consumption (see Chapter 2 for details). However, fossil and biomass fuels still supply 36% of the energy demand in the residential sector, primarily for cooking and heating water. Wood used to be supplied from the Atlantic Forest, heterogeneous tropical forests along the entire Brazilian coast. Although imported coal and oil products have been in the mix since the beginning of the 20th century, fuelwood remained the main energy carrier in the country until the end of the 1960s. At that point, oil products came to the fore, following growing industrialization and strong urban population growth.

Residential fuelwood consumption currently is concentrated in lower income households in all regions of Brazil, as depicted in Fig. 7.2. In the Northeast region, more than 70% of the residential

TABLE 7.5. POPULATION WITH NO ACCESS TO ELECTRICITY, 2003 [7.15]

Region	Total		Urban		Rural	
	10^3	%	10^3	%	10^3	%
North	2 811	20.4	246	2.5	2 565	62.5
Northeast	6 679	13.4	811	1.9	5 868	39.3
Southeast	1 394	1.4	587	0.3	807	11.9
South	657	2.1	173	0.6	484	8.2
Midwest	483	4.3	116	0.8	367	27.6
Brazil	12 023	6.5	1 932	0.9	10 091	31.0

Note: Data from Ref. [7.15] recalculated for December 2002.

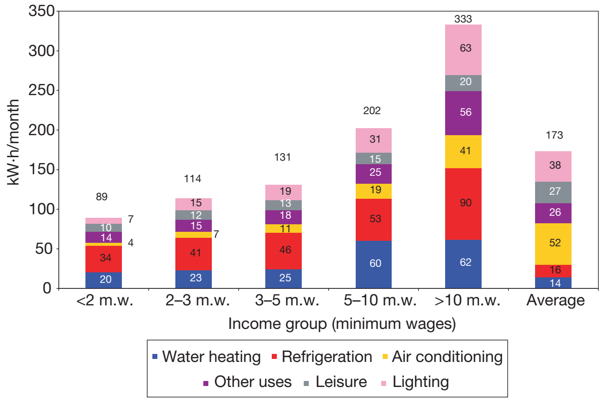

FIG. 7.3. Household electricity use by income group and major end use, 2000. [7.1, 7.9, 7.11].
Note: *m.w. = minimum wage. In 2000, the minimum wage in Brazil was 160.77 Brazilian reals, or US $181.12 at PPP-2000.*

fuelwood consumed is used by families with monthly incomes less than twice the minimum wage, compared with 50% for Brazil as a whole.[6] These figures indicate that wood fuelled ovens are mainly restricted to rural areas and the peripheries of cities, where these families usually live [7.1].

From 1990 to 2000, total electricity use in Brazil increased by 58%. As a result of energy rationing during the electricity shortage in 2001, average residential use dropped from 173 kW·h/month in 2001 to 134 kW·h/month in 2002. Figure 7.3 shows household electricity use by income group and major end use in 2000. Clearly, the higher income groups consume a lot more electricity in all major end uses than the lower income groups. The difference in electricity use between the highest and lowest income groups is greatest for air conditioning (10 times) and for lighting (9 times).

7.2.3. Data suitability for the EISD set of indicators

The data cited in this chapter so far present a picture of Brazil that includes most of the features incorporated in the social indicators within the EISD ‘equity’ theme. To fully quantify the EISD indicators for Brazil and, in particular, to quantify trends over a number of years, more complete data would be needed. Section 7.2.2 refers to the percentage of households without electricity (6.5% in 2000), which is the essential component of the first EISD indicator, concerning accessibility (share of households without electricity or commercial energy (SOC1)). Section 7.2.2 also presents some statistics on household electricity use by income group and on the household fuel mix and how it has changed over time. These are almost exactly the two components of the third EISD indicator (household energy use and fuel mix by income group (SOC3)), but the data are not sufficiently comprehensive to calculate indicator values. Section 7.2.1 includes statistics on inequity in household income, which is one component of the second EISD indicator (share of household income spent on fuel and electricity (SOC2)). Later in this chapter, Tables 7.6 and 7.7 and Figure 7.4 present data related to another component of this indicator, namely, household expenditures on electricity and LPG by income level.

Other statistics in Section 7.2 illustrate features of Brazil’s situation that go beyond energy, such as the share of the population below the poverty line, the Gini index, and the shares of households with sanitation and drinking water. Additional statistics are also presented, such as the HDI and urbanization patterns, which enhance the overall picture of Brazil’s current situation.

7.3. SOCIAL FEATURES OF ENERGY PRODUCTION AND USE

In the aftermath of the financial crisis at the end of the 20th century, Brazil seems willing to pursue a sound development agenda that can promote economic development with higher economic growth rates than those seen in the past two decades. Addressing energy development is an important part of this agenda. To qualify as sustainable energy development from a social standpoint, policy actions require three basic visions, which can also be considered as interlinked energy goals: accessibility, affordability and acceptability. These are visions in the sense that social improvements can be fostered if certain paths are taken for sustainable energy development, such as providing modern energy access for all, that is affordable for all and that is acceptable both to those directly involved and to society in general. They are goals as well, because this agenda has to

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[6] In 2000, the minimum wage in Brazil was 160.77 Brazilian reals, or US $181.12 at 2000 PPP [7.9, 7.11].

envisage some practical achievements that can be measured.[7]

Accessibility of modern energy services means that energy should be somehow available for people, regardless of their income level and the region in which they live. Logistic and economic reasons drive the kinds and volumes of energy carriers accessible at a particular site.

Affordability refers to the conditions by which people can pay for the available energy services. This implies that prices are low enough to allow a minimum level of consumption even for the poorest, and that they reflect the real costs of energy services provided by financially healthy companies.[8]

Acceptability addresses social and environmental issues along the whole energy chain of production, conversion, transport, use and disposal. This relates to those who suffer some local or regional negative effects and to the society as a whole, which can decide whether or not a particular energy fuel should be produced or used. The complexity of this vision is increased if global issues, future generations, cultural phenomena and the political arena are considered.

7.3.1. Accessibility of energy services

7.3.1.1. Fuels for residential use

LPG is used in Brazil mostly for cooking in the residential sector. There is a good national distribution system, and almost 100% of urban areas that are not connected to a pipeline grid have access to LPG. LPG is most commonly distributed by truck in 13 kg bottles. There are now an estimated 70 million of these bottles in Brazil. Over the years, the distribution companies have helped make LPG available throughout the country, establishing some standards for the product, providing technical assistance for consumers and enhancing consumer safety.

The Brazilian Government has effectively adopted a social energy policy that supports the supply of energy to the poorest consumers by cross-subsidizing LPG for domestic use through an additional tax on other fuels such as gasoline. One problem, however, is that low prices distort consumption, leading to, for example, the dangerous and illegal practice of using LPG to heat swimming pools or to run vehicles [7.17].

Between 1984 and 1999, LPG sales doubled, reaching 12 million m^3. During this period, LPG consumption spread widely among low income families because of the cross-subsidies. However, as a result of increasing LPG prices, the trend was reversed in 1999, and LPG consumption decreased over the next three years. In just the one year between 2001 and 2002 it dropped by 4.8%. Brazil still imports 30% of the national LPG demand, and there is no prospect of changing this figure in the near term. In January 2002, the market was opened for oil product imports including LPG, but LPG prices have increased by around 50% since then.[9]

Fuelwood is still widely used for cooking in rural areas. The high urbanization rates of the past decades have led to a continuous substitution of LPG for fuelwood. It is worth noting that many households still use two stoves — one for wood and the other for LPG — as a kind of guarantee for when one or the other fuel is lacking. Although wood can be collected for free in some rural areas, LPG is perceived, correctly, as being better suited for the preparation of quick meals.

Natural gas used in homes is referred to as ‘residential gas’. It is currently available through urban pipelines to households in only a few cities that have existing distribution networks for city gas, most importantly, Rio de Janeiro and São Paulo. The State distribution companies have plans to expand their networks, but the increase in residential gas consumption will also require large investments for conversion and hook-ups, and for adapting home installations. In general, since the beginning of the

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[7] The World Energy Council’s millennium statement ‘Energy for Tomorrow’s World — Acting Now!’ [7.16] considers three energy goals for 2020. In the WEC statement, acceptability is taken in the same way as here, while accessibility is understood as the provision of affordable energy with sustainable prices for the producers and availability relates to continuity and quality of energy supply.

[8] The apparent contradiction between energy prices low enough for everyone and energy prices that reflect the real costs of energy could be dealt with by using direct energy rebates for those who cannot afford high tariffs. This policy would avoid the present situation of subsidizing part of the population that actually could afford normal tariffs and would encourage efficient energy use.

[9] Opening the market should, by itself, cause the price of oil imports to decrease because of competition. However, the actual outcome is also influenced by other Government policies, such as subsidies for national products, and by other factors, such as exchange rate mechanisms, international prices and market structure.

1990s, Brazil's natural gas supply has increased due to both higher national production and imports from Bolivia and Argentina (see Chapter 2).

7.3.1.2. Access to electricity

Access to electricity is essential for promoting economic development and welfare. There is a general commitment in Brazil to provide universal electricity access, and several measures have been taken to this end, some of which are described in this section. However, the development of a legal–institutional framework capable of coping with all the peculiarities that characterize Brazil's energy sector is still some way off. The privatization of the distribution utilities that occurred in the 1990s did not by itself provide universal access to energy services (see Box 7.1).

Most families with no access to electricity live in areas with lower HDI values, and the income of around 90% of these families (most of them in rural areas) is less than three times the minimum wage. In the State of Tocantins, in the North region, 73% of rural households do not have access to electricity.

In 2003, the Federal Government established the 'Light for All' Programme [7.2], under which grid extension costs will not be charged to low income families. There is also now a publicly stated firm commitment to provide access to electricity for all families in Brazil by 2008, an acceleration of the previous goal of extending the electricity grid to the whole country by 2015. Two million new links to the grid, spread out across Brazil and including whole residential sectors in rural areas, will be required. The programme forecasts that electricity will be available to 90% of all rural households in 2006, an ambitious milestone given the present level of 73%.

Subsumed in the 'Light for All' Programme is the Energy Programme for Small Communities (PRODEEM), established in 1994 by the Federal Government to promote the supply of energy to poor rural communities. PRODEEM was mainly based on rural electrification using photovoltaic (PV) arrays. Three types of stand-alone systems were considered: PV electricity generating systems, PV water pumping systems and PV public lighting systems. PRODEEM comprised 8748 systems with a total installed capacity of 5.21 MW [7.19], but as the number of installations increased, it became more difficult to monitor all systems and ensure that maintenance was not neglected. Because of operational and financial problems, PRODEEM

Box 7.1. Social dimensions of power sector reform in Brazil [7.18]

Brazil's reform process is neither complete nor mature enough for a conclusive diagnosis of the social impacts of the reforms as a whole. Privatization of the distribution utilities has not yet contributed significantly towards universal access to energy services, despite the expectations of lower prices that should occur with concurrence, improving access to lower income segments of the population. Although power utility concession contracts state the intention of establishing access targets, these have not yet been set.

Adding to the concessionaires' reluctance to extend service are the removal of subsidies formerly extended to those with low electricity use and a more stringent definition of 'low income consumer'. The regulations of the National Electricity Regulatory Agency (ANEEL) state that anyone wishing to obtain electricity must make a financial contribution to the necessary grid extension. This constrains new connections, particularly in rural areas. The legality of such mandatory contributions is under debate, with opponents arguing that the utilities should absorb the costs of new connections and be reimbursed through tariffs. When State owned electricity companies were being sold, maximization of the companies' sales prices through reduced future obligations, including increased customer access, was priorized. Added to this, many of Brazil's new private utilities have focused only on reducing energy theft in urban and peri-urban areas in order to reduce their commercial losses. According to ANEEL's Regulation 466/99, a utility may cut off a customer who has either committed fraud or failed to pay his or her electricity bill, provided that a warning letter is issued 15 days in advance.

Price caps set by the regulator protect consumers against excessively high prices, but there is no protection in terms of minimum quality standards, and, according to ANEEL's 2002 report on the quality of service, there has been no consistent improvement following privatization. Since 1995, average tariffs have increased in Brazil, reflecting the economic costs of generation, transmission and distribution, but average tariffs have risen much more dramatically for residential consumers.

eventually was restructured, with the main outcomes being the inclusion of the new programme in the 'Light for All' Programme and improved training for technicians responsible for systems maintenance.

The 'Light for All' Programme will now give priority to rural electrification in (a) communities removed from their land because of dam construction; (b) resettlements included in land reform projects; (c) municipalities with lower electrification and HDI indices; (d) public schools, health centres and water wells; and (e) communities around the borders of environmental conservation units.

In isolated communities, some decentralized systems for power generation already exist, with positive regional effects. In the Amazon region (Amazonia), among the products that can be extracted from vegetable species like andiroba, matauá, uricuri and copaíba are oils for electricity generation — a substitute for diesel, which would otherwise have to be transported by river over long distances. For instance, one andiroba tree can produce 140 kg of seeds each year, which produces 20 L of vegetable oil. Assuming 40 trees/ha and a consumption of 0.3 L of oil per kilowatt-hour, an 18 ha plot is sufficient to support around 20 families [7.20].

Lessons from experiences in Amazonia emphasize that decentralized power generation does not really benefit remote communities if it is done in isolation [7.21]. Electricity availability is a necessary but not sufficient condition for promoting local development, and sustainable energy development in these areas must be integrated with other activities related to agriculture, education and infrastructure.

7.3.2. Affordability: Reducing energy use inequalities

A principal challenge in dealing with energy use inequalities is to find the right balance between the argument that open energy market prices should reflect the long term marginal cost of energy and the argument that some degree of subsidies for the poor may be socially desirable. The basic problem is that prices set to cover investment costs may not be affordable to low income households or enterprises. Among other consequences, some low income households and enterprises might therefore continue to use traditional non-commercial energy sources and inefficient energy use technologies, with all their attendant health and environmental hazards. The Government has two main ways of intervening to promote the desired level of affordability: restricting energy prices in some way or providing low income consumers with targeted subsidies. The issue of energy pricing for low income households, for whom energy bills are a significant part of the family budget, is particularly important in those areas of Brazil where LPG and electricity are accessible but not affordable for all families.

Starting in the 1950s, Government intervention in automotive fuel prices was based on price controls and cross-subsidies. Deregulation began in the 1990s, and in 2002 all constraints were lifted on prices, profit margins and freight rates for oil products. For the household sector, natural gas and LPG prices doubled from 1992 to 2000, corrected for inflation and adjusted for 1990 PPP values.

In terms of specific price controls, electricity prices are structured to provide discounted basic and minimal service (up to 100 kW·h/month and monophasic connections) to low income groups through a series of cross-subsidized rates. Policies for inflation control led to a gradual reduction in electricity tariffs during the 1980s, but tariffs then returned to the 1980 level, where they stabilized until 1998, when prices again began to increase. The increases in average residential electricity tariffs by use level from 1996 to 2000 are shown in Table 7.6. As there are still no direct data available for electricity expenditure by income group in 2000, a simulation was made by multiplying the average electricity use (see Fig. 7.3) and LPG consumption by income group by average tariffs for consumption ranges (Table 7.7).

Although this kind of simulation cannot show how much energy each income group is actually using — given that average tariffs do not reflect differences between regions or the particular features of each consumer — it can indicate how much of the family budget would be spent on energy bills if there were no differences in tariffs according to use (see Table 7.6). This simulation gives relevant information, particularly when compared with earlier studies that indicated that in 1996 relative energy expenditures were very similar between the lower income groups (8.8%) and higher income groups (8.0%) [7.6].

Pursuing the simulation exercise, Fig. 7.4 shows that absolute energy expenditures increase from lower to higher income groups, as expected. In this case, the average absolute monthly expenditure

TABLE 7.6. SIMULATED ELECTRICITY AND LPG MONTHLY EXPENDITURE BY INCOME GROUP (US $ PPP-2000) [7.1]

	Income group (minimum wages)					
	<2	2–3	3–5	5–10	>10	Average
Electricity in metropolitan areas (1996)	19.65	22.94	26.62	39.24	52.24	33.85
Electricity in Brazil (2000)	13.22	25.51	29.31	50.35	82.86	38.72
LPG in Brazil (2000)	10.92	14.96	16.90	18.58	21.10	16.49

Note: In 2000, the minimum wage in Brazil was 160.77 Brazilian reals, or US $181.12 at PPP-2000. No data are available for LPG costs for 1996. Figures were obtained through simulations using average tariffs without the current subsidies.

TABLE 7.7. AVERAGE RESIDENTIAL ELECTRICITY TARIFFS BY USE LEVEL [7.1]

Use level (kW·h/month)	Tariff (US $PPP-2000/kW·h)	
	1996	2000
0–30	0.074836	0.087704
31–100	0.12828	0.148551
101–200	0.190185	0.223727
>200	0.213793	0.248782

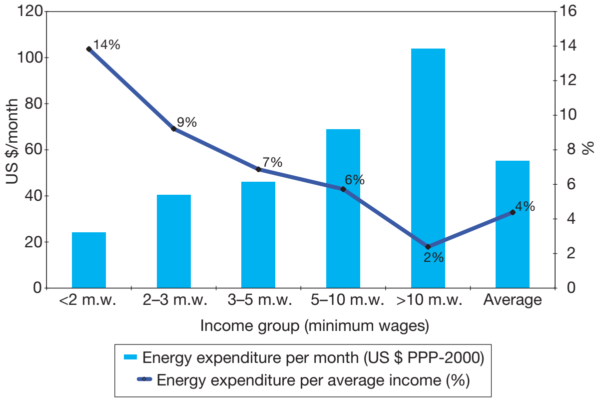

FIG. 7.4. Absolute and relative monthly household energy expenditure by income group, 1996 [7.1]. m.w. = minimum wage.

on electricity and LPG is around US $55 at 2000 PPP. For the relative expenditures, there is an inverse correlation, with the lower income groups spending 14% of the family budget on energy and the higher income groups spending only 2%. The national average is 4%.

Brazil's energy Gini index[10] in 2000 was lower (0.594) than its income Gini index (0.608) (Table 7.8). This can be attributed to energy cross-subsidies among income groups that allow poor people access to commercial energy services.[11] In addition, in rural areas the poor make use of non-commercial fuelwood. Nevertheless, Table 7.8 shows that the energy inequalities in the North and Northeast regions are greater than the income inequalities, which can be attributed to the low accessibility of conventional commercial energy sources in these regions. Thus, energy cross-subsidies do not operate to the same degree in all regions, owing to differences in the commercial energy share of total energy use.

In presenting these figures, it is important to note that, for some distribution companies in Brazil, up to 10% of the electricity supply represents a commercial loss for providers, as it is obtained illegally through middlemen. Since the privatization in the 1990s, distribution companies have made a huge effort to recover the revenues from illegal use. In some cases, common meters have been installed to ensure payment from a larger set of households. In others, no meters have been installed, since the costs were considered too high, and residents are charged a flat rate.

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[10] The energy Gini index is analogous to the Gini index. It measures the extent to which the energy use of individuals or households deviates from a perfectly equal distribution. A Lorenz curve plots the cumulative percentage of total energy use against the cumulative number of consumers, starting with the poorest individual or household. The energy Gini index measures the area between the Lorenz curve and a hypothetical line of absolute equality, expressed as a percentage of the maximum area under the line. A value of zero represents perfect equality, a value of one, perfect inequality.

[11] In addition, there is the impact of the informal economy. Some studies show that, for some low income groups, the real use of electricity is much higher than is reflected in official statistics, as the use of 'unbilled' electricity may be quite high in some situations. For details see Ref. [7.22].

TABLE 7.8. ENERGY AND INCOME GINI INDEX BY REGION, 2000
[7.1] (based on Ref. [7.8])

	Region					
	Brazil	North (urban)	Northeast	South	Southeast	Midwest
Energy Gini index	0.594	0.674	0.769	0.443	0.461	0.555
Income Gini index	0.608	0.598	0.618	0.585	0.592	0.633

In addition to pricing policies, direct income transfers have been used effectively in Brazil since the removal of general fuel subsidies during the oil market liberalization. Targeted direct income subsidies for the poor were established for LPG to offset the negative economic impacts of liberalization on low income families.[12] Targeted income assistance is generally considered to be more efficient than general subsidies and more cost effective for the Government. Broader subsidies attached to product use tend to be more susceptible to abuse by those who do not need subsidies but receive them anyway. On the one hand, with targeted subsidies, people with low incomes receive money rather than LPG bottles or coupons, and may therefore develop more energy efficient use patterns (since they keep any money they save), or invest in more efficient stoves and cooking techniques. On the other hand, there is no guarantee that increased disposable income leads to more rational spending for greater family welfare. Vouchers are sometimes used for targeted income assistance that avoids (at least in theory) this problem. In the end, however, there is no ideal form of subsidy that is free of abuse.

7.3.3. Acceptability: Social impacts of energy supply

It is commonly said that there is no pure or clean energy: every step in energy production, transport and use has drawbacks. This does not mean that all energy fuels are equally desirable. Energy supply does have positive impacts for helping Brazilian development. However, this section focuses on the relevant negative social impacts of the energy supply technologies most important for Brazil. It also touches on political arguments from different social groups in Brazil. Environmental and health aspects are discussed in Chapter 6.

7.3.3.1. Hydropower

Brazil has been building large hydropower plants since the 1960s. By 2002, the total installed hydropower capacity had reached 65 GW. Most of the plants were built during a period when there was very little concern about their environmental and social impacts. Environmental and relocation costs were largely underestimated or not considered at all. There was no prior discussion of technological alternatives for electricity generation, or of the sizes and shapes of the lakes to be created by large dams. People were simply informed that the dam would be constructed and that they would need to move to another place. They were, very often, inadequately indemnified for their losses in an asymmetrical process of negotiation.

Over the years, and after many bad experiences, people have become more concerned about the dam construction process. Grassroots rural unions, Catholic Church representatives and social–environmental groups have begun to raise public awareness about the negative impacts of large dams and to organize themselves for resistance, strengthening their hand in negotiations. More recently, the power sector, under social pressure, has tried to incorporate social organizations into the overall process of building a hydropower plant. At present, there is a well established organization called the Brazilian National Movement of those Affected by Dams that is active throughout the country.

The main negative impacts related to the construction and operation of hydropower plants are normally suffered by those who used to live in the area and have had to move. In most cases, the newly relocated rural populations face a substantial loss relative to their previous standard of living. This includes, in particular, Brazil's experiences with the Itaparica, Tucuruí, Sobradinho (see Box 7.2) and Balbina hydropower projects.

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[12] Decree 4 102 of 24 January 2002 provided for people with low incomes registered in any Federal social programmes to receive direct income transfers from the Brazilian Government to help purchase LPG.

The case of the Balbina plant, which led to an increase in malaria in the local Indian populations and a reduction in fishing catches, and which submerged valuable premium wood and 141 archaeological sites, illustrates some of the other social impacts associated with dam construction, beyond the immediate impacts of relocation [7.24].

7.3.3.2. Nuclear power

Angra dos Reis, where the only two Brazilian nuclear power plants are located, is 130 km west of Rio de Janeiro and 220 km east of São Paulo, Brazil's two most populated cities.

All spent nuclear fuel is stored at the plants, and the storage facilities can be enlarged if new material needs to be accommodated. Brazil does not currently have a plan for the long term storage or disposal of nuclear waste. The emergency plan for accidents is still under critical scrutiny.

As is evident from the range of national decisions on nuclear power around the world — from nuclear bans and phase-outs to heavy reliance on and significant expansion of nuclear power — not all countries think alike. Brazil's Constitution explicitly states that nuclear power can only be used for peaceful purposes. In Brazil, the issue of public acceptance is often raised in connection with nuclear power, and it is difficult to predict whether the public's acceptance of nuclear power will change in the future. No regional or national polls have been carried out to assess public opinion on the nuclear power plants at Angra or the nuclear operations in the country as a whole.

Since 2001, the Ministry of Environment has organized several meetings in connection with the possible completion of Angra III to review the different perspectives of organized institutions and social movements. The Ministry held meetings with three stakeholder groups: entrepreneurs, researchers and scientists, and environmentalists. The principal statements from each group, which should not be taken as representative of the whole of Brazil, are shown in Table 7.9.

7.3.3.3. Coal

The coal sector in Brazil, located in the South region, faces several constraints to growth and must deal with four major issues:

- Environmental liabilities derived from mining activities in western Santa Catarina State that affect sustainability, economic development

Box 7.2. Construction of the Sobradinho Dam [7.23]

Between 1976 and 1978, a total of 70 000 people were removed from the area of the São Francisco basin flooded for the Sobradinho Dam, which has an installed capacity of 1050 MW. A giant artificial lake was formed, measuring 350 km long and 10–40 km wide, and covering 4214 km^2, including seven districts in the State of Bahia, in the Northeast region of Brazil. It is worth describing the Sobradinho case to reveal some social and cultural aspects that go beyond the traditional energy indicators.

The region has a typical semi-arid vegetation, called caatinga, and the area's inhabitants normally lived next to the river, where the land was suitable for agricultural activities. At the time the dam was constructed, State officials tried to convince the local population to move to a new colony project 700 km from the proposed site. However, because of the high costs involved, the planning team had decided not to include an irrigation alternative for the new land, which would have been essential for the families being relocated away from their homes along the river.

The dialogue that took place between the officials and the local peasants was difficult. The former could not understand why the latter did not want to move to the colony, where, in the officials' view, they would find better living conditions, with electricity, running water and sewage systems.

The peasants' position was based on their traditional way of life, which is highly dependent on the natural and cyclical river floods. Therefore, they simply wanted to stay along the lake's borders. Moreover, they could not believe the water would actually reach the projected limits, because they had never before seen the river flood to that extent. They also believed that the utility's representatives were trying to mislead them so their lands could be taken over by others once the waters had receded. At the last minute, many people had to escape from the rapid, artificial flood. Of the 8619 families that had originally lived in the area, 62% stayed in the region, at the lake's borders.

TABLE 7.9. ARGUMENTS REGARDING NUCLEAR ENERGY ACCORDING TO THREE STAKEHOLDER GROUPS [7.25]

	Entrepreneurs (nuclear and construction)	Researchers/scientists	Environmentalists
Safety	Angra I does not have a good operational record; Angra II is much more reliable in operational terms. The probability of an accident is remote.	The Angra complex must improve its safety measures. Historically there has been a lack of transparency with respect to relevant information regarding operational problems at the plants.	The Angra nuclear complex is not safe; it is mainly the Angra I plant that has presented several technical problems. The emergency plan is not reliable and has never proved workable.
Fuel cycle knowledge	Brazil has the sixth largest uranium reserves in the world and has the capacity to enrich uranium domestically.	Mutual inspections between Brazil and Argentina of radioactive material and of compliance with Non-Proliferation Treaty procedures are important.	There are problems concerning overburdening in the retired Poços de Caldas region and operational and safety problems in the new uranium mine in Lagoa Real, in Bahia State.
Technological issues	Technical skills should be stimulated.	It is important to develop technological nuclear capacity for sovereignty reasons; however, military use must be prevented.	Technological capacity should be applied for proven safe industrial and medical uses, besides monitoring and safety.
Importance to electricity supply	Nuclear plants are important for the national electric system.	The contribution of the Angra nuclear plants is relatively small.	Other options exist.
Completion of Angra III	Angra III should be built.	Additional studies are necessary. There is no ‘for’ or ‘against’ position.	Construction should not proceed in any way.
Waste	A solution to the problem of waste storage will be found, but nobody knows when.	Solutions to the problem of waste storage are not yet sufficient.	There is no satisfactory solution to the problem of waste storage. We should not transfer environmental liabilities to future generations.
Costs	Angra III should be built because US $750 million has already been spent on equipment. Angra III is important to the financial health of Eletronuclear, Brazil’s State owned nuclear electric generation utility. US $20 million is spent annually just to store the equipment already bought.	Costs and investment projections are not reliable. Costs for finalizing the construction of the plant may be much higher than projected (currently an additional US $1.8 billion).	Nuclear plants are too expensive. Other, cheaper options are available. There is no reason to subsidize nuclear plants.
Decommissioning	Funding still has to be defined.	Decommissioning should be funded by tariffs.	There are serious flaws concerning decommissioning funding. No reasonable structure exists. Liabilities will be transferred to future consumers.
Environmental impacts	Nuclear energy is ‘clean’ because there are no emissions of acids or greenhouse gases.	There are positive aspects regarding atmospheric gases and negatives aspects relative to radioactive waste.	Radioactive waste represents extremely serious impacts and should be considered unacceptable.

and the security of the local population and the workers;

- Increased unemployment resulting from the cessation of coking coal production;
- Adverse competition with fuel oil and natural gas for industrial consumption, in particular in the cement and ceramics sectors;
- Mining health impacts and safety.

In Santa Catarina State, coal mining has led to contamination of surface and underground water sources through the solubilization of metallic compounds. There are strong conflicts among economic, social and environmental interests, mainly linked to the future availability of good quality water and coal extraction activities.

The recent strong opposition to coal fired plants scheduled to be built in Paraná, São Paulo and Rio de Janeiro States demonstrates awareness concerning unsustainable energy paths based on coal. In Rio de Janeiro, for instance, local authorities authorized the construction of a 1250 MW imported coal thermal power plant. After a complex decision process that included politicians, industry lobbies and social and environmental movements, in which it was proved that emissions from the plant, together with other sources, would exceed regional limits for nitrogen oxides, the initial licence was revoked and the project suspended.

In summary, some urgent measures with important social benefits are needed, such as regeneration of the South region's underground water supply, reuse of the water used in the processing of coal, establishment of territorial limits to mining activities in order to preserve mountains and forests that allow the refilling of the aquifer, and improvements in the quality of underground water in that region.

7.3.3.4. Charcoal production

In Brazil, charcoal is mostly used as an input for pig iron smelters that supply the steel industry. Charcoal production involves hazardous working conditions and extremely precarious living conditions [7.26]. Charcoal workers face physical risks of chronic fatigue due to lifting and stacking heavy logs, with up to 12 hours of work a day, including shifts during nights and weekends, which increases the risk of accidents on the job and the loss of emotional control. They are also subjected to fine dust and smoke inhalation, causing skin irritations, conjunctivitis and serious respiratory problems such as silicosis [7.27].

More than a century after slavery was abolished in Brazil, forced labour remains widespread. Even with efforts by the Federal Government and social movements during the past decade, violations of labour laws are still common, including the use of unregistered workers, low wages and lack of freedom for workers. In some regions, mainly Pará, Maranhão, Piauí, Tocantins and Mato Grosso States, people are recruited by labour contractors called gatos (Portuguese for 'cats') to work in remote areas. Increasingly smaller production areas are rented to subcontractors to avoid regulation and union organizing. Children work alongside their parents in remote areas far from towns, schools and medical facilities, and workers are often prevented from leaving the work premises by armed guards. They are often forced to buy food and supplies at inflated prices at company stores and thus constantly find themselves in debt, which represents a perverse indebtedness slavery system [7.28]. In recent years, however, modern industrial scale charcoal producers have made some improvements in order to comply with social and environmental laws.

Unfortunately, indebtedness slavery still occurs in several economic activities that often lead to deforestation, such as charcoal, sugar cane and other agricultural production. The case of charcoal presented here is just one example of how poor workers are forced to submit to this system. In 1995, a Special Mobile Enforcement Group was created, associated with the Ministry of Labour and Employment, to fight against labour irregularities and abuses. Between 1995 and 2001, the group inspected 770 labour units employing some 160 000 people and found 2232 workers in conditions of slavery [7.29]. In 2003, the group, with the support of the Federal police, managed to free almost 5000 workers. Despite some improvements — such as the increase of inspections that allow the imprisonment of workforce subcontractors and gradual improvement in the compliance with social and environmental laws — much more has to be done to abolish indebtedness slavery in Brazil and to improve working conditions in some economic activities in Brazil.

7.4. ENERGY PRODUCTION AND JOB CREATION

A fundamental driver for sustainable energy policies is the opportunity for job creation in the energy sector itself. The creation and maintenance of jobs make the energy chain from biomass highly relevant from a social perspective. This is crucial for a developing country like Brazil, where income inequalities contrast with major achievements in agriculture and livestock production. In Brazil, the main employment related features of energy production and use are as follows:

- Power plants (fossil fuel power plants and hydropower plants, for instance) create many jobs (1000–5000) during the construction phase (normally lasting 2–5 years and possibly creating subsequent social problems in the region) and fewer jobs (50–200) during the long term operation.
- The oil and gas sector requires workers with higher education levels and higher salaries than does agribusiness.
- Some recent studies suggest that it is possible to create jobs and income while reducing energy use and greenhouse gas emissions by shifting Brazil's production from energy and import intensive activities towards value adding and labour intensive commodities (see, e.g., Refs [7.12, 7.30]). In particular, a recent study concludes that the potential for job creation is higher for energy conservation than for energy production (see Ref. [7.31]).
- There is a trend towards mechanical harvesting in the sugar cane sector, implying a net loss of jobs in the sector.

7.4.1. Ethanol (sugar cane) production

The production of ethanol from sugar cane is the most labour intensive energy activity in Brazil, but new renewable energy sources can also play an important role in the creation of new jobs, including in rural areas.

Social considerations are strong determinants of PROALCOOL, the Brazilian Alcohol Programme.[13] Ethanol production (including the agriculture and industry segments) supports some 1.5 million jobs in Brazil, with a relatively low index of seasonal work [7.32]. The number of harvest workers was reduced in the past decade owing to the increase in mechanization.[14]

Job creation per unit of energy is three times higher for hydropower and 150 times higher for ethanol production than for oil production [7.34]. This reflects the large number of workers and the low labour cost per employee in the ethanol chain, mainly at the harvesting step of production. The ethanol chain of production, including both the agricultural and the industrial phases, provides the least cost for job creation among the different industrial sectors, although there are variations among regions. Estimated investment costs range from US $11 000 per job in the Northeast region to US $23 000 per job in São Paulo State, excluding the land costs [7.35].

PROALCOOL also has social benefits at the end use stage in the form of reduced health impacts. Atmospheric emissions of sulphur oxides (SO_x), carbon monoxide (CO), particulates and volatile organic compounds (VOCs) from vehicles have been reduced by the programme. Zero net emissions of carbon dioxide (CO_2) from ethanol production also substantially reduce the total CO_2 emissions from the transport sector [7.36].

7.4.2. Biodiesel production

Another proposed option for energy production combined with job creation is biodiesel. In July 2003, the Ministry of Mines and Energy (MME) launched a biodiesel programme to gradually blend biodiesel, made from various indigenous vegetable species — mamona and palm oil, among others — with regular diesel fuel and increase its use in the transport sector. The principal objectives of the programme are environmental advantages and job creation. Among the products that can be obtained are B2, with 2% biodiesel content, B5, with 5% biodiesel content, and so on up to B100.

In December 2004, the Federal Government authorized the commercial use of B2. Using the 2002 Brazilian diesel consumption of 38 billion L as a reference, the equivalent use of B2 would require the production of 800 000 L of biodiesel, which would avoid US $160 million per year in diesel imports [7.37]. Under the biodiesel programme, biodiesel producers that buy mamona and palm oil

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[13] For a better understanding of PROALCOOL in Brazil, see Chapter 9.

[14] In 1991, harvest workers made up 60% of the total workers in the sugar cane industry [7.33].

from small rural producers in the North and Northeast regions can apply for tax breaks.

It is estimated that in the first phase an area of 1.5 million ha can be cultivated for B2 production. Each family producing 5 ha of mamona, with an average of 700–1200 kg/ha, can earn 2500–3500 Brazilian reals per year just selling the seeds (primary production with no additional aggregated value), which gives a range of 160–275 reals per month [7.38]. The upper value is slightly higher than the national minimum wage per month as of December 2004.

In the North region, palm oil is one of the best options for meeting biodiesel demand, with a potential of 3.2 Mt of production on 720 000 ha, sufficient for 140 000 families. The net income of a 5 ha family unit can reach six times the minimum wage. For soybeans, a well established agro-industrial sector in the country, the potential for B5 is around 1.8 billion L of oil, requiring the cultivation of an additional 3 million ha [7.39]. However, as there are environmental and economic arguments against the uncontrolled expansion of soybeans in Amazonia, biodiesel production from soybeans should be compared with the cultivation of other species that perhaps create more jobs with less impact on the environment.

If Brazil is to be successful in its biodiesel programme, appropriate plant species need to be cultivated in different regions in the coming years. Rough estimates indicate that for a demand level of 1.85 billion L of B5 produced from mamona, dendê and soybeans, around 260 000 jobs can be created [7.40]. The figures are much higher for B20; even in this case, the cultivated area, almost 20 million ha, is some 25% of the estimated area for energy crops in the country (see Chapter 6). From the supply side, it is reasonable to point out that, considering the potential for mamona production in the Northeast region, some two million new jobs could be created. In summary, biodiesel production presents many environmental and social benefits and can be a unique alternative for increasing the number and quality of rural jobs in Brazil.

7.5. MAIN ISSUES

This chapter is a first step towards a full quantitative description of the social dimensions of Brazil's current energy situation in the context of sustainable development. The selected data also provide a qualitative summary picture of the social dimension of Brazil's energy situation as it stands today.

A general summary of the social goals discussed in this chapter is presented in Table 7.10. Accessibility, affordability and acceptability are taken in a broader sense than described in the text, in order to include some features from each energy source. The main issues are the following:

- Social inequalities in Brazil regarding energy use are substantial and important. Energy use differences among income groups reflect typical and unacceptable Brazilian income disparity levels. There are also strong differences both among the regions of Brazil and between urban and rural areas. HDI differences occur within urban centres and between the cities and peripheries. Thus, the social differences between income groups can be greater than those between urban and rural populations. Access to modern energy services will be important for improving Brazil's HDI, both by promoting economic activities and by providing safe water, better cooking systems and electrification.
- As demonstrated by comparing the energy and the income Gini indices, national energy inequalities are lower than income inequalities owing to energy cross-subsidies for lower income groups.
- Recent decades have seen improvements in energy accessibility, but much more needs to be done. Universalizing electricity services is a major Government priority, with Government established targets for distribution companies. LPG is relatively well distributed throughout most of the country, but distribution companies could be stimulated to supply some remote areas still lacking modern energy services.
- There are many opportunities throughout the country for biomass energy projects to promote employment, particularly in the Northeast and North regions, where palm oil and mamona could be used for sustainable biodiesel production, resulting in positive environmental impacts.
- There is still a huge potential for hydropower expansion in Brazil. There is also some tragic history in connection with past projects. Even with the more democratic decision processes adopted in recent years, care must be taken to ensure that social demands are respected, that

TABLE 7.10. BRAZILIAN SOCIAL ISSUES RELATED TO ENERGY SOURCES

Primary and secondary energy sources	Past record	Accessibility	Affordability	Acceptability	Sustainable energy development	Present policies and goals for the future
Fuelwood	Main energy source in Brazil until the 1960s.	Largely available in native forests and becoming scarce in other areas.	Mainly collected for free in rural areas.	Public opposes present high levels of deforestation.	Reduction of deforestation in general and of consumption of wood from native forests by industrial sectors.	Replacement by LPG for cooking purposes.
Charcoal	Production incentives from the Government and international banks for the iron and steel industry.	Production from planted forests has increased in recent years, but production from native forests continues.	Limited consumption in the residential sector. Charcoal industry has very low labour costs.	Poor working conditions (including indebtedness slavery) together with environmental disruption. Production from native forests using child labour is absolutely unacceptable in the country today.	No charcoal production from native forests. Energy efficiency and technological improvements; social security for employees.	Some improvements in recent years in social and environmental issues but much more to be done. Control working conditions and eliminate slavery. Labour incentives for other economic activities.
Coal	Small share in the energy matrix. Mining led to high environmental disruption and liabilities.	Relatively large reserves of low quality coal in the South region.	Coal production is subsidized. Coal is mainly consumed by coal power and cement plants.	Strong conflicts between economic, social and environmental interests, mainly linked to the future availability of good quality water and coal extraction activities.	Recovery of degraded mined areas.	Highly efficient and clean technologies (fluidized bed) for small thermal plants must be developed if coal is to have a place in the electricity sector.
Diesel	High consumption in the transport sector.	In 2001, 16% was imported. Filling stations spread across the country. Consumed in isolated areas for electricity generation.	Not subsidized but is taxed at lower rates; is mainly consumed in the transport sector for transport of freight and passengers, with a positive economic effect for low income groups.	High atmospheric emissions affect the population.	Fuel efficiency in power generators and trucks. Increasing substitution of biodiesel for diesel.	Present Government programme for fuel conservation in trucks. Substitution of biodiesel for diesel.

TABLE 7.10. BRAZILIAN SOCIAL ISSUES RELATED TO ENERGY SOURCES (cont.)

Primary and secondary energy sources	Past record	Accessibility	Affordability	Acceptability	Sustainable energy development	Present policies and goals for the future
Biodiesel	Technology has been known for a long time. No significant production.	Plenty of options in Brazil from mamona, palm oil, soybeans and other plants.	Increasing scales can promote cost reduction.	Substitution for diesel sounds environmentally friendly. Potential problems concerning working conditions.	Large scale biodiesel production can foster economic growth and job creation.	Government incentives recently offered for biodiesel production from mamona. Diesel with 20% biodiesel content (B20) by 2020.
Natural gas	Historically a small share in the energy matrix.	Recent growth in national production and imports. Increasing gas pipelines and grid systems in cities.	Higher prices for residential use due to the competition with LPG.	Environmental advantages compared with oil, city gas, diesel and other fuels.	Substitution for other fuels.	Incentives for broader use.
Vehicle natural gas	High and growing rates since the 1990s.	Growing number of filling stations.	Lower prices than gasoline and alcohol because of subsidies. Mainly consumed by taxis, benefiting only the fraction of the population that uses this kind of transport.	Environmental advantages compared with gasoline and diesel.	Use in buses and cars, mainly in cities, because of safety and environmental issues.	Market oriented prices for private transport.
LPG	Used mostly for cooking in the residential sector.	A good national distribution system is in place.	In 2000, prices were twice as high as in 1992.	Environmental advantages compared with fuelwood.	Modern energy services for the whole country, rural areas in particular.	Opening markets for LPG distribution companies.
Ethanol (sugar cane)	Historically one of the most important economic activities. High export levels.	Sugar cane is planted in several regions in the country.	Production costs have seen strong reductions over the years.	Difficult working conditions.	Large scale ethanol production and job creation. Potential problems concerning working conditions.	Improving working conditions, social security rights for workers.
Hydropower plants	Construction of large dams in the country has removed thousands of people from their original land over time. Resettled people have not received fair compensation.	Large reserves, mostly in Amazonia.	Among the power plants, hydropower plants present the lowest costs per MW·h.	Large environmental and social impacts are no longer widely accepted. Projects need to be exhaustively discussed in order to be approved.	To be a viable sustainable option, hydropower requires the minimization of environmental and social impacts.	Still the main power option in Brazil. Democratic decision processes needed.

TABLE 7.10. BRAZILIAN SOCIAL ISSUES RELATED TO ENERGY SOURCES (cont.)

Primary and secondary energy sources	Past record	Accessibility	Affordability	Acceptability	Sustainable energy development	Present policies and goals for the future
Small hydropower plants	Represents a tiny fraction of the Brazilian energy matrix.	Large potential in Brazil, between 7 and 14 GW.	Smaller investment requirements can allow new players to invest in the energy sector. Lower costs for regional supply due to the reduction in transmission costs.	Fewer social and environmental impacts than with large dams.	Possible problems concerning particular regional conditions and the impact of many plants. Democratic decision process needed.	Increase the share in the energy matrix.
Nuclear power plants	Operational problems at the Angra I plant.	Brazil has large uranium reserves and has developed technological and industrial capacity for producing nuclear fuel, from mining to uranium enrichment.	Among the power plants, it presents one of the highest costs per MW·h.	Public fears; emergency plan under critical scrutiny; radioactive waste stored at the plants.	Trade-off between nuclear waste problems and reduction of greenhouse gases (compared with fossil fuels).	Future role of nuclear power under discussion.
Vegetable oil power plants	Pilot plants in research projects in isolated areas.	Several species can be used, such as andiroba, matauá, uricuri and copaiba.	Suitable plants can be collected from the forests by isolated communities.	Such plants can promote economic activities in isolated communities.	Local employment generation; reduction of external vulnerability and dependence on oil imports; reduction of greenhouse gas emissions.	Should have technical and financial support during the implementation phase.
Electricity	High and growing rates since the 1970s.	Universal access by 2008 is targeted.	Tariff structures allow the low income (and low use level) population to pay less.	Related to electricity sources.	Universal access by 2008 is targeted.	Universal access by 2008 is targeted.
Energy efficiency	Government programme for electricity conservation established in the 1980s.	Many technological options are available for the residential sector.	Cheapest option for energy supply.	After electricity shortage in 2001, people became aware of efficiency issues in residences.	Best option for minimizing environmental impacts.	Establishing clear targets for energy efficiency improvement.

affected people receive fair compensation and that unjustifiable projects are halted early in the process.

- Ethanol production presents huge opportunities for job creation and environmental benefits, although if biomass is to play a major role in sustainable development in Brazil, improving the quality of employment should be a major task. Rural workers in the sugar cane sector should receive the same kinds of social rights received by urban workers, such as acceptable health and safety conditions, social security, salaries above specified minimum levels, vacations and profit bonuses.

- Coal mining and power generation in the South region have created conflicts between social demands for jobs and pollution problems. Unless these environmental liabilities are solved, the coal industry's future is limited.
- Incentives should be given for electricity generation in isolated systems to help it gain in scale, particularly for some energy options like PVs and vegetable oils. There are some institutional, technical and economic barriers to the development of these options. Finally, emerging technologies still have to find a place on the basis of their future costs resulting from technological advances and organizational learning.

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Chapter 8
ENERGY SECURITY

J.R. MOREIRA, R. ESPARTA

8.1. INTRODUCTION

Energy security aims at minimizing economic and other risks associated with different energy supply options. It has been variably defined to imply:

- A reliable, affordable and environmentally sound energy system [8.1];
- The continuous availability of energy in varied forms, in sufficient quantities and at reasonable prices [8.2];
- Security of energy supply, competitiveness and protection of the environment [8.3].

The risks that might compromise or threaten the reliable distribution of energy services include supply constraints, transport or transmission constraints, cost and financial limitations, natural disasters, poor planning and logistics, poor management or maintenance, market shifts, technological changes, acts of nature, sabotage or international market fluctuations.

Brazil's energy markets have experienced many of these risks. This chapter begins by highlighting some general points about the dimensions of energy security and then describes some of the more salient energy system security problems in Brazil's recent history. It next explores present and continuing systemic vulnerabilities and finally reviews policies being considered to mitigate some of these risks.

8.1.1. General considerations and dimensions of security

The traditional approach to energy security has been to diversify energy supplies — both internally, by maximizing the use of domestic resources, preferably based on domestic technologies, and externally, by selecting a variety of products from a diversity of supplies from different geographical regions. However, there is no universal consensus on the level of energy import dependence considered acceptable or sustainable, and this level varies from country to country.

Although predominantly viewed as a supply issue, an important measure to enhance energy security may well be using less energy to accomplish the same tasks or supply the same energy services — in short, using energy more effectively and efficiently. The European Commission, in a 2000 Green Paper on energy security, stated that "only a policy that is also geared to control demand can lay the foundation for sound energy supply security policy" [8.4]. In addition, security encompasses the notions of vulnerability and reliability, that is, the idea of deriving more energy services from options that are inherently less vulnerable, being more diverse, dispersed or renewable.

An analysis of energy security requires a thorough systems approach, examining the complete chains from primary energy sources to the provision of energy services to the final consumer. Existing energy systems are inherently vulnerable, especially given their centralization and complexity.

Energy security also encompasses different timescales, ranging from the immediate — a power station breakdown causing a nationwide blackout — to the very long term — the risk that world oil production will peak within the next 10 years (a pessimistic and narrow scenario of oil occurrences [8.5]) or 40 years (an optimistic and broader oil occurrence scenario [8.6]), and extreme oil market price volatility. Then there is the risk of climate change, which may force the premature retirement of previous investments. A low carbon economy could also have long term security benefits compared with the current fossil fuel dependent system. Such an economy would be associated with a combination of end use technologies with high energy efficiencies (thus using fewer MJ per unit of service), the use of resources that are either renewable (and often local) or plentiful and the use of nuclear power.

But a low carbon economy does not protect against all risks. While energy efficiency and the use of renewable energy and nuclear power hedge against dependence on fossil fuels, they are not an effective response to a sudden supply crisis. For one, these options are usually fully utilized and leave little margin for additional output. For another, their incremental expansion is a time consuming process requiring many years until new capacities become operational. Transmission networks, pipelines, distribution systems, etc., continue to present risks of failure and disruption, irrespective of a low carbon economy. Therefore, it is necessary to consider possible policy responses to a wide range of security issues.

8.1.2. Energy security highlights

The following events, among others, have acted as driving forces that have made energy security a global issue in the past 30 years:

- The first oil crisis in the 1970s;
- The war between Iraq and the Islamic Republic of Iran (Iran) in the 1980s, Iraq's invasion of Kuwait in the 1990s, the war in Iraq in 2003 and the political instabilities in the Middle East, the region with the largest oil reserves in the world;
- Studies of global climate change and the United Nations Framework Convention on Climate Change in the 1990s [8.7];
- Worldwide electricity supply uncertainties resulting from the liberalization of the energy markets at the turn of the 21st century.

8.1.3. Security measures and policies

Security of the energy system includes two perspectives:

- *Physical security*: vulnerability to accidents, disruptions and attacks;
- *Strategic security*: the flexibility to react to fluctuations in national and international energy markets (availability and prices).

A system can be made more inherently secure if policies are applied to reduce its operational complexity, to make the subsystems as independent as possible and to diversify the system's demands on fuels, equipment and suppliers.

8.1.4. Economics

For most developing countries, security of supply means security of expanding supply in line with their economic development [8.8]. In most developing countries, the main energy security risk is rooted in economics, that is, uneconomical pricing or the lack of access to capital for energy infrastructure investments or funds for energy imports, especially for oil and oil products. Capital and funds often are not forthcoming because of low expected returns or the high risk when revenues from energy product sales are insufficient to cover costs.

8.1.5. Physical security

Energy vulnerability in its widest sense — the potential for interruptions of any form of energy supply, by deliberate means, on any scale, at any time and place — has serious political implications. The threat of terrorism can fundamentally alter the political balance between large and small groups in society. This may in turn erode the trust and the civil liberties that underpin democratic governments.

As Lovins and Lovins [8.9] have pointed out, modern energy supplies depend on technicians with specialized skills. Strikes that involve oil and gas workers have in the past disrupted electric power generation and have helped to unseat governments in States. Similarly, power strikes, or threats of them, have been used as political instruments. Coordinated attacks on electric power systems hastened the fall of the Allende Government in Chile in 1972.

8.1.6. EISD related to security

Energy import dependence (Energy Indicator for Sustainable Development (EISD) ECO15; see Table 1.1 in Chapter 1) is one gauge of energy supply vulnerability. Brazil's import dependence has decreased over the past two decades, mostly due to Government programmes targeted at fuel switching away from oil products and the expansion of national oil production. Oil import dependence decreased from 81% in 1980 to around 10% in 2002. Coal imports moved in the opposite direction, increasing mainly in response to the needs of the metallurgical industry. Since the Itaipu binational hydropower plant started operation in 1984,[1] a small fraction of electricity has been imported every year. Natural gas imports started in 1999 with the entry into operation of the Bolivia–Brazil natural gas pipeline (see Fig. 8.1).

ECO16 (stocks of critical fuel) is the second EISD for monitoring energy security. To date, no policy induced strategic oil reserve or any other stockpile of imported fuels exists in Brazil. However, there has been some natural stockpiling of ethanol at the production units (around 300 sugar mills). Until the liberalization of the alcohol market at the end of the 1990s, Brazil's national oil company, Petrobras, was responsible for keeping a stock that was financed by a fuel tax called the Parcela de Preço Específica (PPE). This tax was abolished with the liberalization of the alcohol market [8.12]. Stockpiling is a costly proposition: the costs of maintaining one tenth of Brazil's annual alcohol production, about 1 billion L, amounts to approximately US $30 million annually.[2] Until recently, no organization was willing to assume the costs of protecting the country from fluctuations in the alcohol market. On 1 September 2003, the Federal Government announced the allocation of around US $166 million (500 million Brazilian reals) to cover infrastructure and financial costs related to the storage of fuel alcohol in the sugar cane processing industry [8.13].

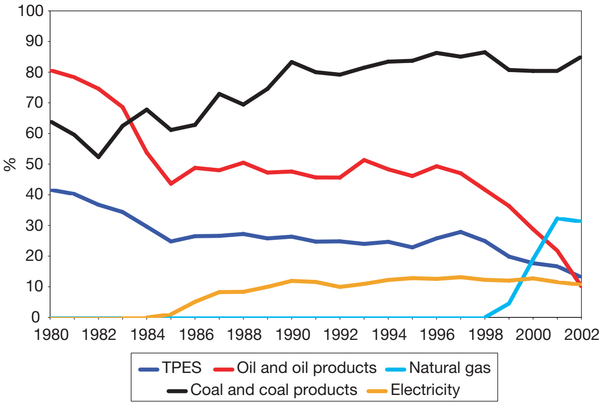

FIG. 8.1. Net energy import dependence (EISD ECO15) [8.10].
Note: *The net imports of oil used to calculate Brazil's dependence on oil include imported crude and oil products over the period [8.11].*

8.2. ENERGY SECURITY IN A BRAZILIAN CONTEXT

8.2.1. Oil crisis in the 1970s

The 1973 oil embargo by the Organization of Petroleum Exporting Countries (OPEC) caused oil prices to soar from US $3/bbl to US $12/bbl in 1973–1974, an increase that was chiefly responsible for the global economic recession that followed in its wake. This price rise represented a significant increase in import expenses — from around US $500 million in 1972 to US $2.8 billion in 1974.[3] In 1979, the events in Iran led to a second surge in oil prices to US $40/bbl, pushing Brazilian expenditures for oil imports to over US $10 billion (see Fig. 8.2) and causing another global recession [8.15].

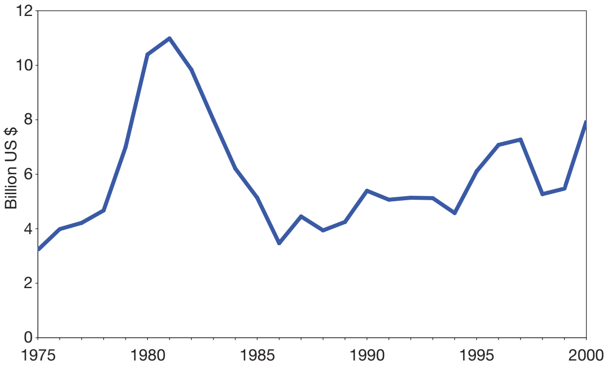

FIG. 8.2. Net fuel expenses in billion current US dollars [8.14].
Note: *Net fuel expenses represent the yearly total hard currency cost for energy imports minus exports.*

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[1] In 1975, construction began on the binational Itaipu hydropower plant, located on the border between Brazil and Paraguay in Brazil's South region. The reservoir was filled in 1982 and the plant was inaugurated in October 1984; the final installation of 12 600 MW was completed in 1991 (the water intake of a single 715 MW Francis turbine is 700 m^3/s, its weighted efficiency is 93.8%). The frequencies in Brazil and Paraguay are different; Paraguay consumes less than 4% of the electricity generated by Itaipu and delivers most of the power generated to Brazil at 50 Hz. Thus, it was decided to build a composite transmission system, including an extra high voltage system (alternating current (AC)) for 6300 MW (the Brazilian part at 60 Hz, transmitted 891 km at 750 kV) and a high voltage system (direct current (DC)) for about 6000 MW of the 50 Hz part (imported from Paraguay, at ± 500 kV, and converted back into AC).

[2] Based on US $200/$m^3$, a total value of US $200 million and a 15% interest rate per year.

[3] All economic values given here are in current US dollars.

To pay these import bills and to develop domestic energy alternatives, Brazil, like many other countries in Latin America, absorbed excessive liquidity from US, European and Japanese banks in the form of loans at favourable conditions. Huge capital inflows were directed to infrastructure investments, and State enterprises were formed in areas that were not attractive for private investment. In the case of Brazil, this occurred mostly in the energy sector (refineries and large scale hydropower plants).

In the early 1980s, however, the significant rise in US interest rates began to affect international capital markets, ending the favourable conditions to foreign debtors. A substantial increase in interest rates worldwide forced Brazil, along with other Latin American countries, to implement strict economic adjustments that led to negative growth rates. The suspension of capital inflows reduced Brazil's capacity to invest. The debt burden affected public finances and contributed to an acceleration of inflation.

8.2.2. Alcohol fuel crisis at the end of the 1980s

In 1975, the Federal Government decided to implement a national programme to produce ethanol from sugar cane as a gasoline substitute. This decision was motivated by the extreme burden placed on the country's external trade balance by the high price of imported oil and was aimed at the reduction of petroleum imports despite the fact that the programme required substantial additional investments and high subsidies.

In Brazil, ethanol is used in two ways: as gasohol, a mixture of gasoline and 20–26% anhydrous ethanol,[4] or as neat ethanol in the form of hydrated ethanol.[5] The use of alcohol as a fuel was an extraordinary success until 1990. In 1985, neat ethanol automobiles represented 96% of new sales, and by the end of the decade 4.5 million of these automobiles had been sold. In the next decade, a precipitous sales drop resulted from a shortage of ethanol supply in 1989, triggered mainly by the increase in the production and export of sugar in lieu of alcohol production, together with the following developments:

- The price at the pump for neat alcohol fuel per unit of volume, set in 1979 at 59% (in energy units: 74%)[6] of the price of gasoline, gradually increased to 80% (100% on an energy equivalent basis).
- Taxes on industrial products were initially set lower for alcohol fuelled automobiles than for the same models fuelled by gasoline. This advantage was eliminated in 1990 when the Government launched a programme of inexpensive 'popular' automobiles (motors with a cylinder volume up to 1 litre), for which the taxes on industrial products were reduced to 0.1% regardless of the fuel used. Triggered by the large tax reduction, the demand for 'popular' automobiles exploded and, because of a lack of domestic production capacity for engines fuelled by neat ethanol, manufacturers resorted to gasoline fuelled engines readily available abroad.
- A lack of confidence in the steady supply of alcohol and the need to import ethanol/methanol to compensate for decreased domestic production caused by sudden surges in the world market price of sugar became apparent.

As a result of this combination of factors, the sales of neat ethanol automobiles dropped to almost zero by 1996, and their production was almost abandoned. The blending of ethanol into gasoline was not affected, because a Federal regulation required the addition of ethanol to all gasoline marketed in the country. The situation started to reverse by 2000 owing, first, to an increase in international oil prices combined with a continuous reduction in the price of ethanol produced in Brazil and, later, to the manufacture of dual fuel vehicles.

The International Energy Agency has estimated that Brazil could produce over 20 billion L of ethanol annually in the next 10 years (from today's level of around 15 billion L/year). Exports of ethanol would be the main driver for such an increase in production. Trade is constrained, however, by tariffs and other import restrictions in

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[4] At 99.6 Gay-Lussac and 0.4% water. As a side effect, ethanol functions as an effective octane enhancer.

[5] At 95.5 Gay-Lussac.

[6] In reality, the best index is price per kilometre travelled. Considering the higher compression rate used in neat ethanol automobiles, fuel consumption was only 20–25% higher for ethanol than for gasoline. Thus a price cap for ethanol of 59% of the price of gasoline translates into a cost per kilometre for ethanol equal to, at least, 71% of the cost for gasoline.

many countries. Brazil is currently negotiating with a number of countries — including China, Japan, Mexico, the Republic of Korea and the United States of America — that have expressed interest in buying Brazilian ethanol. While the United States of America is one of the nearest and largest short term markets, agricultural subsidies and import restrictions frustrate export efforts [8.16].

8.2.3. National electricity rationing in 2001

The 2001 electricity supply shortage, which prompted rationing, had a significant direct impact on more than 100 million people in the Southeast, Midwest and Northeast regions of the country. It also had an indirect impact on all Brazilian citizens as a result of the severe reductions in gross domestic product (GDP) growth between May 2001 and July 2003.

Brazil's current electricity generation mix is dominated by its vast hydropower resources, despite the country's large geographical area and the long distances between the generating sites and demand centres. Heavy dependence on hydropower with long transmission lines in itself presents multiple supply security risks, ranging from fluctuations in annual precipitation patterns to physical security of the electricity transmission infrastructure. In Brazil, a compounding risk factor was the privatization of the energy sector. Until the beginning of the 1990s, the energy sector was State owned. A lack of public funds for infrastructure investments led the Brazilian Government to follow the examples of many other countries and initiate a shift of the investment burden to the private sector by way of liberalizing the energy markets (see Section 2.3.1 in Chapter 2).

However, by early 2001, five years into the privatization process, the high expectations of private sector investment in electricity generation and transmission capacities had not materialized and investments in new generation were not keeping pace with demand (see Fig. 8.3). Demand grew faster than GDP, a phenomenon often observed in developing countries, especially with the electrification of previously unserviced areas and accelerated industrialization. If growth in generating capacity begins to fall behind demand, measures must be taken to prevent bottlenecks in supply, such as higher capacity utilization — that is, squeezing more kilowatt-hours out of existing plants — or determined demand-side management including accelerated investments in energy efficiency. Regarding the latter, the Government established the National Electricity Conservation Programme (PROCEL) in 1985. Although the qualitative objectives of the programme were worthy, the results were limited, largely because of small investments and poorly managed implementation strategies.

Increasing the capacity factor of existing plants is feasible as long as fuel availability is adequate (and capacities are not fully utilized). For hydropower, this means adequate water supply, including storage capacity. While fuel availability posed no obstacle, an expansion of the storage capacity required additional investment, which was not made. Figure 8.4 depicts the levels of 'stored energy' in the reservoirs in the Southeast and Midwest regions for the period from January 1998 to December 2002. These reservoirs represent 68% of the total water storage in the country and generate 66% of the total electricity supply. Although designed to buffer three consecutive years of below average precipitation, the reservoirs almost collapsed after a single season of low precipitation in 2000–2001, with 72% of the historical average [8.20]. The rapid decline in water storage in the years that preceded the electricity shortage is being investigated and is not yet fully understood, because the precipitation level that regulates the water flow into the rivers was reasonably high during the period.

Explanations for the shortage include the following:

- Not all hydropower dams have water storage capacity; some dams are of the run-of-river type.

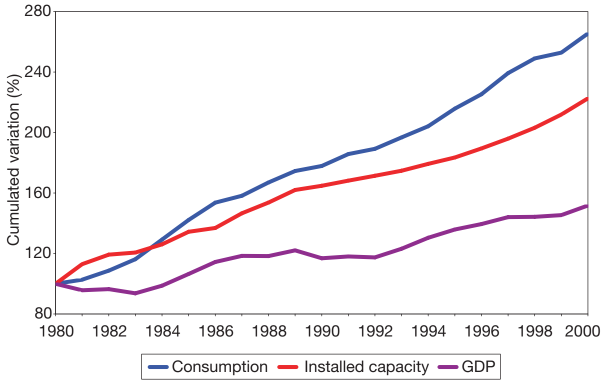

FIG. 8.3. Indices of cumulated variation of GDP, electricity supply (installed capacity) and demand (consumption) (1980 = 100) [8.17, 8.18].

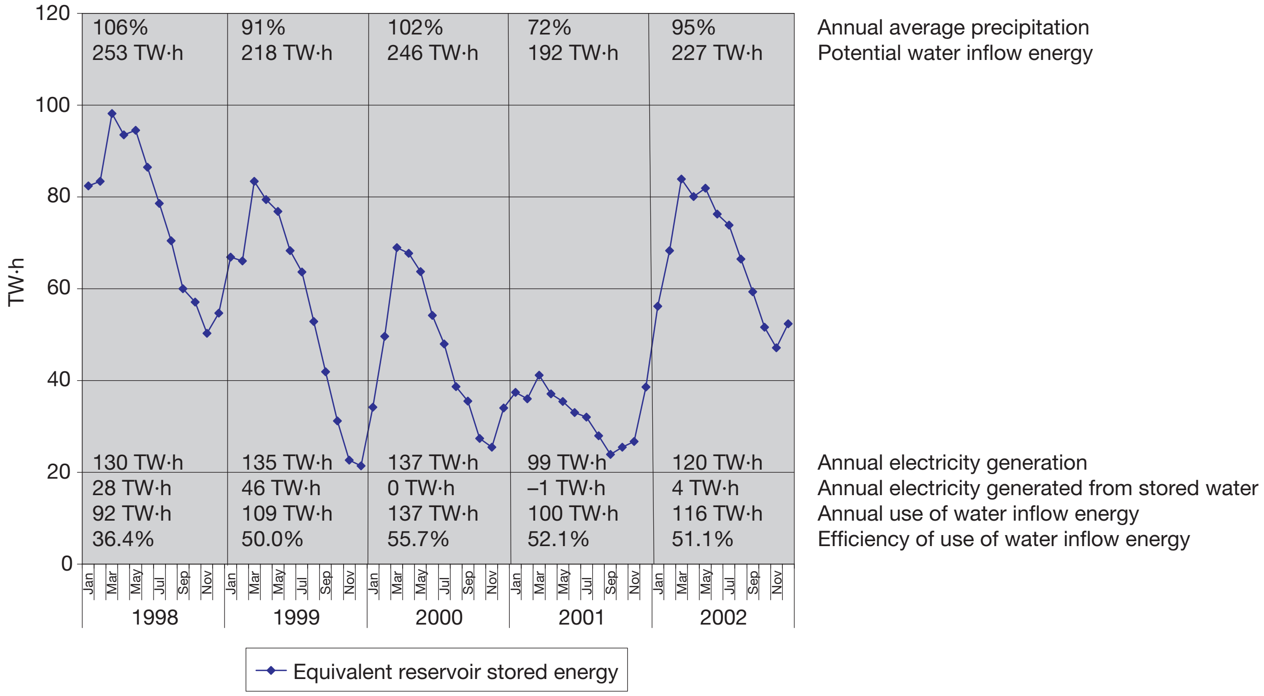

FIG. 8.4. Stored energy, water inflow energy, electricity generation and energy efficiency of use of water inflow for the electric system of Brazil's Southeast and Midwest regions, 1998–2002 (based on authors' calculations using data from Ref. [8.19]).
Note: *Numbers at the top are potential energy in the inflow water on a yearly basis; numbers at the bottom are the amount of electricity effectively generated in the respective years. Note that the electricity generated was approximately half the amount of potential water inflow energy in each of the periods. For the five-year period from 1998 to 2002, the water inflow energy was 1136 TW·h and the amount of electricity generated was 621 TW·h.*

- Not all hydropower facilities have enough installed capacity to use the high water flow that may occur a few times during the rainy season.
- Water flow throughout a cascade of facilities in the same river was not optimized.
- Lack of transmission capacity imposed limits on the maximum amount of generation from some plants.
- There was a need to maintain a minimum amount of water flow for reasons other than electricity generation, for example, to guarantee river navigation.

Hydropower availability, low efficiency in part of the hydropower system and fluctuations in rainfall contributed to, but do not fully explain, the electricity supply shortage in 2001. While the cause is still under investigation, several measures are being implemented to mitigate the risk of future electricity shortages, including (a) a substantial increase in thermoelectric power generation using natural gas, (b) an increase in the Government budget for improving the country's electricity infrastructure, (c) a revision of tariff policies with fewer subsidies and better correlation of costs and prices and (d) the implementation of policies supporting renewable energy (Alternative Energy Sources Incentive Programme (PROINFA), included in electricity reform law No. 10 438, signed on 26 April 2002).[7]

An analysis of the present short term supply situation shows a modest risk of another shortage like that of 2001. Utility owners claim that demand growth has been held back by two to three years

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[7] PROINFA foresees a growing share of renewable energy in power generation [8.21]. This expansion should add around 3300 MW of capacity from various alternative sources besides hydropower. Furthermore, long term contracts with special conditions will be offered, as well as lower transmission charges and lower interest rates from the local development banks. While both programmes and the long term contracts are clearly indicative of a positive approach by the Federal Government, the 'special conditions' were only precisely defined at the end of December 2002. The call for project qualification started in June 2004.

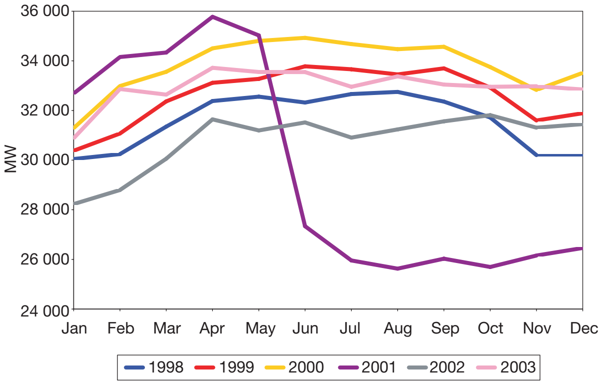

FIG. 8.5. Electricity delivery in Brazil's Southeast–Midwest region, 1998–2003 [8.22].

since the rationing imposed in 2001. In 2003 the demand was around 4% below the level of early 2001, just before the crisis (see Fig. 8.5). This drop in demand creates a time buffer during which the industry can review and develop longer term solutions. From January 2002 to October 2004, new power plants were added to the system: natural gas thermoelectric units (~6100 MW), hydropower plants (~5800 MW) and standby units, mainly based on diesel oil (~2000 MW).

8.2.4. Electricity supply constraints imposed by transmission

Since 1999, Brazil has experienced two large scale blackouts.[8] In both cases the most probable cause was poor maintenance and the high complexity of the transmission system. Also, during the 2001 electricity crisis, bottlenecks in the transmission network exacerbated the shortages. The South and North regions had an abundance of hydropower that could have been transferred to the regions experiencing shortages, had transmission capacity been available.

The Brazilian electric system has interconnections between the extreme north and the most populated areas in the south, as well as between the cities along the coast and those in the west, including a small share of the Amazon jungle (see Fig. 8.6). In principle, such a huge interconnected system should allow the transfer of electricity among the South, Southeast–Midwest, Northeast and North regions, and over the 3000 km distances in a straight line. In practice there are constraints imposed by the maximum amount of electricity that can be transferred by the existing transmission network (see Table 8.1). The strongest link connects the South and the Southeast–Midwest subsystems. The weakest link connects the Southeast–Midwest region with the North–Northeast subsystem. A transfer of up to 1962 MW on average was performed between the South and Southeast–Midwest subsystems (see Table 8.1) in an effort to mitigate the electricity shortage.

Table 8.2 lists transmission capacities available to feed the Southeast–Midwest electrical subsystem in periods of electricity shortage. In 2001, transmission capacity from the South to the Southeast–Midwest region was limited to 3200 MW. The maximum transference for the Southeast–Midwest region was limited to 6600 MW, including the electricity delivered by the Itaipu binational plant, which shares the same line used to bring electricity from the South region. Itaipu is assumed by the National System Operator (NSO) to be able to produce 10 000 MW, of which 4500 MW were transferred using the line shared by electricity transmitted from the South region. Thus, it is possible to infer that maximum transmission from the South region to the Southeast–Midwest region was limited to 2100 (6600 – 4500) MW, very near the maximum value observed in Table 8.1.

As noted in Table 8.2, Government plans presented at the end of 2001 [8.23] foresaw the necessity of improving transmission capacities for the period starting in April 2003 (total transmission from the South to the Southeast–Midwest increased from 3200 to 4800 MW).[9]

The South region's hydrological system is completely different from the Southeast–Midwest region's hydrological system (which also rules hydropower generation in the Northeast, since the main river that feeds hydropower plants in the Northeast region flows from the Southeast–Midwest to the Northeast). During the electricity crisis of 2001–2002, rainfall levels in the South region were normal and storage levels were satisfactory. In the period from May 2001 to July 2002, 62.5 TW·h were produced, with 2.6 TW·h of equivalent reservoir storage energy depletion. Total energy flow in the reservoir was 96.8 TW·h in the period, and efficient utilization of the surplus energy

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[8] Both blackouts occurred in the South, Southeast and Midwest regions. The first occurred on 11 March 1999, affecting 12 States; the second took place on 21 January 2002, affecting 10 States.

[9] In reality, by 2004 the total maximum transfer from the South to the Southeast–Midwest region was increased from 3200 to 3500 MW, and it is expected to reach 5400 MW only in 2006 [8.22].

FIG. 8.6. Brazil's interconnected electricity transmission system [8.19].

— amounting to 34.3 (96.8 – 62.5) TW·h — would have allowed the generation of approximately 32 TW·h. This energy could have been transmitted to the Southeast–Midwest region at a monthly rate of 2.13 TW·h, requiring a transmission capacity of 2.92 MW. This additional energy would have increased energy availability in the Southeast–Midwest region during 2001 from 99 to 116 TW·h (a 17% increase), reducing the total rationing effort from 25% to only 8%.

Even more important, in June 2000, water availability in the South region started to rise from the minimum equivalent reservoir storage level of 25%. From June 2000 to April 2001, total energy flow in the reservoir was 58.5 TW·h, while generation was only 39.3 TW·h.[10] If the water available had been used efficiently, it would have been possible to generate around 57 TW·h, or a surplus of around 18 (57 – 39.3) TW·h. The transfer of this energy to the Southeast–Midwest region from June 2000 to April 2001 would have brought the storage capacity of the Southeast–Midwest region's reservoir from 37.4 to 55.4 TW·h by April 2001 (see Fig. 8.4), a value that probably would have postponed the decision to apply electricity rationing. Starting with a 55.4 TW·h storage level in

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[10] The information included here is from a plot of the South region's electric subsystem similar to the one shown in Fig. 8.4 [8.24].

TABLE 8.1. AVERAGE POWER TRANSFER BETWEEN REGIONS IN THE INTERCONNECTED SYSTEM (MW) [8.22]

1999	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tr S–SE/MW	–2183	–1726	–1479	–1147	–1444	–1738	–726	–713	–1177	–813	–818	–1371
Tr international	0	0	0	–13	–44	–37	–46	–41	–40	–42	–47	–48
Tr N–NE	174	433	656	660	645	652	679	741	787	758	613	0
Tr N–SE	0	21	42	14	18	40	–112	–604	–561	–536	–490	530
2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tr S–SE/MW	–2157	–1767	–2198	–2022	–1945	–2304	–1904	–1907	–1150	62	–581	–862
Tr international	–43	–42	–40	–60	–214	–597	–971	–1058	–477	–133	–379	–925
Tr N–NE	243	166	122	217	305	339	296	243	305	–13	–50	103
Tr N–SE	666	581	509	510	501	589	356	483	302	276	187	345
2001	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tr S–SE/MW	325	266	774	883	1569	872	1274	1962	1648	1517	1144	577
Tr international	–286	–51	–339	–498	–1038	–1027	–148	–622	–1003	–51	–556	–221
Export N	870	1006	909	1021	1198	1185	613	734	700	823	755	947
Tr N–NE	420	507	493	922	1063	1177	613	734	700	823	755	947
Tr N–SE	450	499	416	99	135	8	0	0	0	0	0	0
Tr S–SE/MW–NE	0	0	0	0	0	0	690	588	590	493	584	342
Import NE	420	507	493	922	1063	1177	1302	1322	1290	1316	1339	1289
2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tr S–SE/MW	–1669	–939	–931	–1246	–1217	481	47	–16	80	903	1425	1155
Tr international	–512	–46	–46	–63	–53	–96	–53	–45	–41	–41	–41	–40
Export N	937	641	796	785	649	855	858	506	226	–140	–517	–773
Tr N–NE	921	641	796	785	649	845	858	506	226	0	0	0
Tr N–SE	16	0	0	0	0	10	0	0	0	–140	–517	–773
Tr SE–NE	0	667	412	504	198	0	62	383	241	778	640	418
Import NE	921	1308	1208	1289	846	845	919	889	467	778	640	418

Note: TR = transfer; S = South region; SE/MW = Southeast–Midwest region; N = North region; NE = Northeast region.

the period that rationing was imposed would have allowed the generation of an extra 1.5 TW·h during the full period using the extra water stored in the Southeast–Midwest reservoir. With the extra 2.13 TW·h/month of electricity delivered by the South region (discussed in the previous paragraph), it would have been possible to increase electricity availability in the Southeast–Midwest region by 3.63 TW·h/month during all 12 months of the electricity shortage. In this scenario, electricity availability would have been increased by 29 TW·h during the last 8 months of 2001 and by 14 TW·h during the first 4 months of 2002. Such figures are equivalent to an annual generation of 128 (99 + 29) TW·h in 2001 and 134 (120 + 14) TW·h in 2002 (see Fig. 8.4). Considering that electricity generation in the Southeast–Midwest region in 2000 was 137 TW·h (enough to meet demand), with a 3% annual growth rate the expected demand would be around 141 TW·h in 2001 and 145 TW·h in 2002. Potential electricity shortages of 13 and 11 TW·h in each year, respectively, could have been managed more easily or even avoided, since the Southeast–Midwest reservoir storage level never declined below 21 TW·h in the most critical year of the period (see Fig. 8.4).

It is possible to conclude that an extra transmission capacity of 1.8 TW·h/month (2460 MW) in 2000–2001 and 2.13 TW·h/month (2920 MW) in 2001–2002 would have been enough to mitigate or even eliminate electricity rationing in the Southeast–Midwest region of Brazil. The conclusion is that a transmission capacity shortage prevented the transfer

TABLE 8.2. ELECTRICITY GENERATION AND TRANSMISSION CAPACITIES: SITUATION DURING ELECTRICITY CRISES OF 2001–2002 AND ALTERNATIVE MITIGATION SCENARIO

Region	Jan–Apr 2001	May–Dec 2001	Jan–Apr 2002	Apr–Dec 2002	Apr 2003–Feb 2004
	Business as usual scenario				
	Average electricity generated (TW·h/month)[a]				
SE/MW	10.67	7.09	10.10	9.92	
Itaipu	6.88	5.66	6.47	6.37	
S	4.73	4.55	3.42	4.71	
Total	22.28	17.30	19.99	21.00	
	Maximum average transmission capacity (MW)[b]				
S–SE/MW	3 200	3 200	3 200	3 200	4 800
Itaipu–SE/MW	10 000	10 000	10 000	10 000	10 000
Total	13 200	13 200	13 200	13 200	14 800
	Maximum average transmission capacity used (MW)[c]				
S–SE/MW	883	1 962	0	1 425	
Itaipu–SE/MW	9 424	7 753	8 863	8 726	
Total	10 307	9 715	8 863	10 151	
	Higher transmission capacity scenario				
	Average electricity generated (TW·h/month)[d]				
SE/MW	8.87 (10.67 – 1.8)	8.89 (7.09 + 1.8)	11.9 (10.1 + 1.8)	9.92	
Itaipu	6.88	5.66	6.47	6.37	
S	6.53 (4.73 + 1.8)	6.68 (4.55 + 2.13)	5.55 (3.42 + 2.13)	4.71	
Total	22.28	21.23	23.92	21	
SE/MW available	10.67 (8.87 + 1.8)	11.02 (8.89 + 2.13)	14.03 (11.9 + 2.13)	9.92	
SE/MW demand	11.41	11.76	12.10		
	Average transmission capacity required (MW)[e]				
S–SE/MW	4 420 (1 960 + 2 460)	4 880 (1 960 + 2 920)	2 920	1 962	
Itaipu–SE/MW	9 424	7 753	8 863	8 726	
Total	13 844	12 633	11 783	10 688	
	Average additional transmission capacity required (MW)				
S–SE/MW	1 220	1 680	–280	–1 238	
Itaipu–SE/MW	–576	–2 247	–1 137	–1 274	
Total	644	–567	–1 417	–2 512	

Note: SE/MW = Southeast–Midwest region; S = South region.

[a] Values from Ref. [8.19].

[b] Values from Ref. [8.23].

[c] Values from Table 8.1.

[d] Model discussed in Ref. [8.24].

[e] Values discussed in Section 8.2.4.

of an extra 1.8 TW·h/month (2460 MW) in 2000–2001 and 2.13 TW·h/month (2920 MW) in 2001–2002. In reality, the shortage in transmission capacity was lower, as indicated in Table 8.2 (an average of only 1220 MW in 2000–2001 and 1680 MW in 2001–2002). In practice, some surplus must be available in the transmission line and some extra 2000 MW of capacity probably would have been enough to mitigate or even avoid the electricity crisis.

8.2.5. Raising capital and external debt

The annual cost of servicing Brazil's total external debt is currently very high. It was around US $60 billion in 2000, having escalated very quickly from around US $20 billion in the early 1990s [8.25], as has been the case with most indebted countries (see Fig. 8.7). Debt service now amounts to 10% of GDP, of which interest alone represents US $17 billion (2.83% of GDP), twice the amount of average annual investment in the electricity sector. Considering the heavy penalties for debt escalation, debt mitigation is one of the country's top priorities. The required austerity measures drain resources from investments, including those in the electricity sector.

Investments in electricity infrastructure and payments for oil imports have been the main contributors to Brazil's external indebtedness. Between 1970 and 1997, Brazil invested US $192 billion to increase installed generation capacity and associated infrastructure (transmission, distribution and management facilities) from 8.7 to 59.2 GW — an average cost of US $3802/kW. This high cost is explained by the fact that hydropower plants provide around 90% of the country's electricity supply. Not only are they more expensive to build than thermal plants, but given the distances in Brazil between hydropower sites and the consumption centres, this choice has required significant investment in transmission capacities.

Despite a relatively high average domestic saving rate of 22% of GDP, capital demands from other sectors required that a significant share of the investments in the power sector be financed from international sources. The precise amount of external investment is not available, but it is reasonable to assume that 40% of the total investment came from abroad [8.26]. Considering the long history of this debt and the perverse mechanism of debt increase due to the high interest charged to heavily indebted countries and their limited capacity to amortize hard currency, it is possible to evaluate the huge burden caused to Brazil's economy today. The oil import bill is another external debt burden. In some years, net fuel trade used up more than 50% of the country's export revenues. Even in recent years, when most of the oil supply was obtained from indigenous resources (see Table 2.1 in Chapter 2), the amount of hard currency expended was still significant because of the increase in domestic oil demand, the high cost of oil and the net economic losses in trade of oil and oil products owing to a mismatch of the production structure of the domestic refining industry and oil product demand.

Figure 8.8 shows the actual evolution of Brazil's debt plus scenarios of lower oil imports

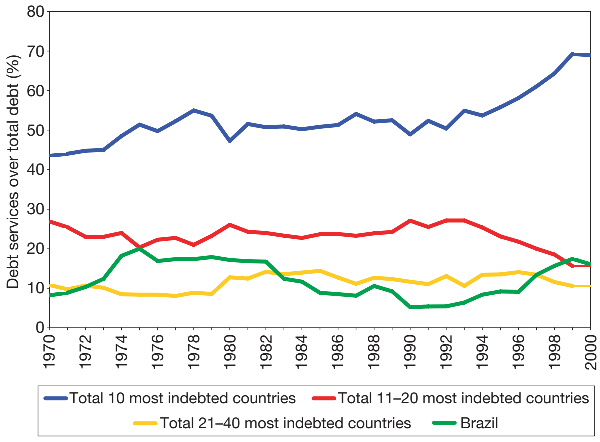

FIG. 8.7. Relative share of external debt service for some of the most indebted countries compared with total external debt service of 137 countries [8.25].

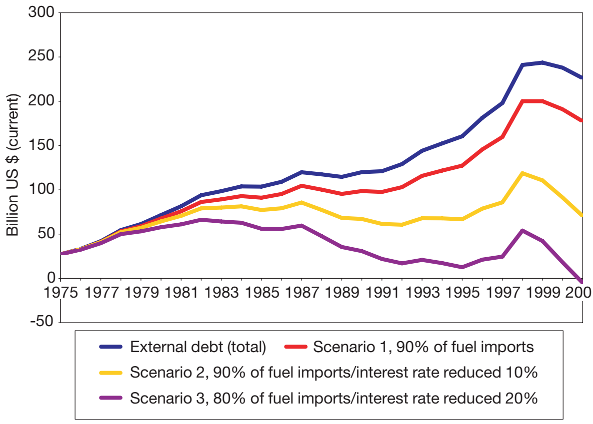

FIG. 8.8. Brazil's external debt, actual and under three alternative scenarios [8.25].

Note: *Results were obtained assuming (a) that PROALCOOL had no impact on the external debt, since it was essentially financed with national currency, and (b) that all extra revenue generated as a result of the reduction in oil imports is used to pay off the debt.*

and/or lower interest rates (the average interest rate paid by Brazil between 1975 and 2003 was around 7% per year), illustrating the impacts on the country's external debt. A reduction of 10% in fuel imports in the 1975–2000 period would have reduced the 2001 debt from US $225 billion to US $175 billion (Scenario 1). As in the case of investments, lower indebtedness could induce lower interest rates. With a 10% reduction in fuel imports and interest rates at 90% of the charged value, the debt could have been only US $65 billion (Scenario 2). With fuel imports at 80% of the historic value and with 20% lower interest rates, the 2001 debt could have become a small surplus (Scenario 3).

In summary, external debt is sensitive to small changes in the annual deficit because of the long time span over which debt is accumulated and the high cost of external money for most indebted countries. Investments in electricity and fuel imports are largely responsible for the external debt, and since energy is the subject of this study, it is essential to understand how actions directly concerning the energy market can have an impact on the country's economy as a whole.

Regarding energy exports, trade barriers imposed by developed countries are a serious constraint. One possible source of further revenue through exports is ethanol produced from sugar cane. As shown by Moreira and Goldemberg [8.27], ethanol production and use in Brazil since 1975 has avoided the accumulation of US $100 billion (in 2000 US dollars) on the external debt of the year 2000. Under a more liberalized international market regime, Brazil could be producing more ethanol to meet international demand. Building a scenario where ethanol production increased by 50% during the 1980–2000 period, it is possible to show impacts on the national external debt similar to those shown in Fig. 8.8. This scenario is a simplified approach for the intended analysis that does not take into account the origin of investments for further ethanol production. Still, a national resource and associated conversion chain like sugar cane requires funding only in the national currency and thus carries a modest cost compared with international oil market prices.

8.3. SECURITY RISKS

8.3.1. Uncertainties

8.3.1.1. Future energy demand

Projections of long term energy demand vary considerably with assumptions about the growth of per capita income and population, and with assumptions about relative prices, future progress in technology performance and gains in energy efficiency. Considering that per capita use of commercial energy and electricity in developing countries is barely one tenth of that in Organisation for Economic Co-operation and Development (OECD) countries, while the populations in these countries are over five times as large, most energy scenarios point to an increase in the world's demand for commercial energy over this century of roughly 2.5–5 times the current levels [8.2].

To date, no empirically based study has shown that developing countries can achieve prosperity without large increases in demand for energy, even with strong assumptions about improvements in technology, including energy efficiency. What has been observed, however, is that developing countries may well experience lower peaks in energy intensities than the now industrialized countries experienced when they underwent their respective industrialization processes. The reason is the availability of much improved current technology compared with the state-of-the-art technology of 50 years ago. Moreover, a number of engineering and economic studies have shown that the possibilities for further gains in technology performance and energy efficiency are far from being exhausted, so a continual lowering of the peak intensity can be expected as more countries become developed countries [8.28]. Therefore, developing countries are likely to require less energy to produce a unit of GDP and to meet consumer needs per unit of income than was the case for the industrialized countries at the same point in their development paths. How much less is uncertain, because of ambiguities in the evidence and oversimplifications in both the engineering and economic models of energy use.

Nonetheless, Chapter 5 shows that energy intensity in Brazil has been quite stable since 1970 and even increased from the early 1980s up to 1999. This result conflicts with the leapfrogging theory [8.29], but reflects Brazil's increased industrialization, urbanization, economic development and rising standard of living, as well as the limited investment available for technological innovation. To the extent that energy efficiency falls more dramatically because of technical inefficiencies or becomes disproportionate to available resources, and to the extent that incentives (such as cost based energy pricing) are inappropriate, this trend could pose a supply security risk requiring ever increasing quantities of energy for limited incremental productive gain.

8.3.1.2. Hydropower

As explained in Section 8.2.3, Brazil is highly dependent on hydropower and on its complex transmission system to bring electricity across vast geographical areas from generating sites to demand centres. Although the share of hydropower in electricity generation has decreased from over 90% in 1980 to less than 85% in 2002, the still high reliance on hydropower represents a security issue.

Regarding further development of hydropower, most of the technical capacity not yet in use is located in the Amazon region (Amazonia), far from the large demand centres in the Southeast, South and Midwest regions of Brazil. Moreover, new hydropower plants in Amazonia are quite controversial, especially in the view of environmentalists, making it difficult to raise funds outside the country. Even if financing were not a barrier, all the projects in the region are required to undertake very careful, time-consuming and burdensome management of all possible environmental and social impacts. Shortages of external financing and high investments to mitigate environmental and social impacts pose serious restrictions on the practical utilization of these technical reserves.

The most extensively studied hydropower project in Amazonia, Belo Monte, is a 6000 MW plant. It enjoys what probably is one of the most favourable geographical characteristics for a hydropower plant, with a head of up to 100 m. This project has been in the planning stages for around 20 years, and it may be decisive for the exploitation of the hydropower potential of Amazonia. If Belo Monte is not environmentally, economically and socially feasible, probably no other large projects in Amazonia will be either.

8.3.1.3. Nuclear power

Nuclear energy is often considered an option for electricity generation. Despite several barriers imposed by its high cost, the risks associated with nuclear proliferation and its potentially dangerous waste, it has advantages regarding supply security and greenhouse gas (GHG) mitigation. Most of the new nuclear installations currently under construction are located in Asia, and diversification of primary energy sources yielding improvement in security of supply has been the primary driver. With the growing concern about global atmospheric pollution, nuclear energy may have a more promising future in other regions as well.

Nuclear energy provides an interesting chapter in Brazil's energy policy. In the early 1970s, nuclear energy was considered to have great potential, but it never really developed. The nuclear programme historically came under the jurisdiction of the Ministry of Defence rather than the Ministry of Mines and Energy. Decreasing funding for the military then delayed the development of the nuclear power programme and the construction of nuclear power plants. The agreement with the Federal Republic of Germany in 1975 to supply eight nuclear power reactors, including technology transfer of the complete nuclear fuel cycle, did not materialize, primarily for economic and political reasons.

Today, Brazil has two operational nuclear plants, Angra I, with 657 MW capacity, and Angra II, with 1350 MW capacity. The nuclear capacity represents less than 3% of Brazil's total electric generating capacity. Angra I was ordered from Westinghouse in 1969, construction started in 1971 and commercial operation commenced in 1984. The Angra II plant came into operation in 2000, 24 years after its construction began, at a cost of US $10 billion. Several factors contributed to the extremely long construction period and the devastating cost escalation, including the several fiscal crises in the 1980s and 1990s, the adverse reaction of the United States of America to the agreement between Brazil and the Federal Republic of Germany, and growing environmental activism in Brazil.

The construction of a third reactor, Angra III, has been the subject of considerable technical and political debate. The 2001 electricity shortage put the construction of the partially built plant back on the Government's agenda, with estimated costs of US $1.7 billion [8.30]. However, as soon as the shortage receded, the appeal of this large domestic supply option declined.

Brazil's uranium reserves are plentiful (see Chapter 3, Table 3.1), and the country is among the top 10 uranium producers worldwide. A yellow cake factory, an enrichment plant and a plant to produce nuclear fuel elements have been completed, and additional processing facilities are under construction or planned. Nuclear power, therefore, could fully rely on domestic fuel supply and thus contribute to national supply security. In the short to medium term, the prospects for additional nuclear power capacities are hampered by the high costs, the presence of competitive alternatives and the general lack of public acceptance of the technology.

8.3.2. Pollution and energy security

Energy security also means that a national energy system must not be a threat to its neighbours or pose a threat to international political stability. Pollution and wastes from energy production and use not only can cause domestic conflicts, but can also be a source of regional and global transboundary disputes.

Growing public concern about damage to the environment caused by the energy supply system, whether such damage is of accidental origin (oil slicks, nuclear accidents, methane leaks) or is connected to emissions of pollutants and wastes, has highlighted environmental weaknesses in the use of fossil fuels, nuclear energy and renewables.

Energy production is always associated with at least some pollution at the local, regional or global level, as well as with risks. Except for GHG emissions, societies with higher per capita incomes historically have adopted measures that increasingly reduce pollution and risk (see Fig. 8.9). Local environmental protection is thus a matter of affordability: additional protection will require more disposable income. Reducing the risk of climate change by reducing the emissions of carbon dioxide and other GHGs will incur costs. Estimates of these costs vary significantly depending on the degree of reduction, the location and time frame of the reductions, technology learning, etc.

Since the 1980s, a growing body of literature has dealt with the relationship between environmental problems and conflict prevention [8.32]. More specifically, evidence is mounting that the adverse effects of climate change can contribute to an increasing potential for conflict, particularly by interacting with a number of other factors, such as scarcity of natural resources.

Brazil uses only small amounts of coal in its energy system and enjoys a large share of renewables in its energy mix. Pollution is not a serious security issue. Nevertheless, oil represents a significant share of the primary energy supply, and any new investment in the energy sector should take into consideration its potential impacts in an environmentally compromised future world. There are risks associated with the unlimited future use of oil in developing countries, which could be managed

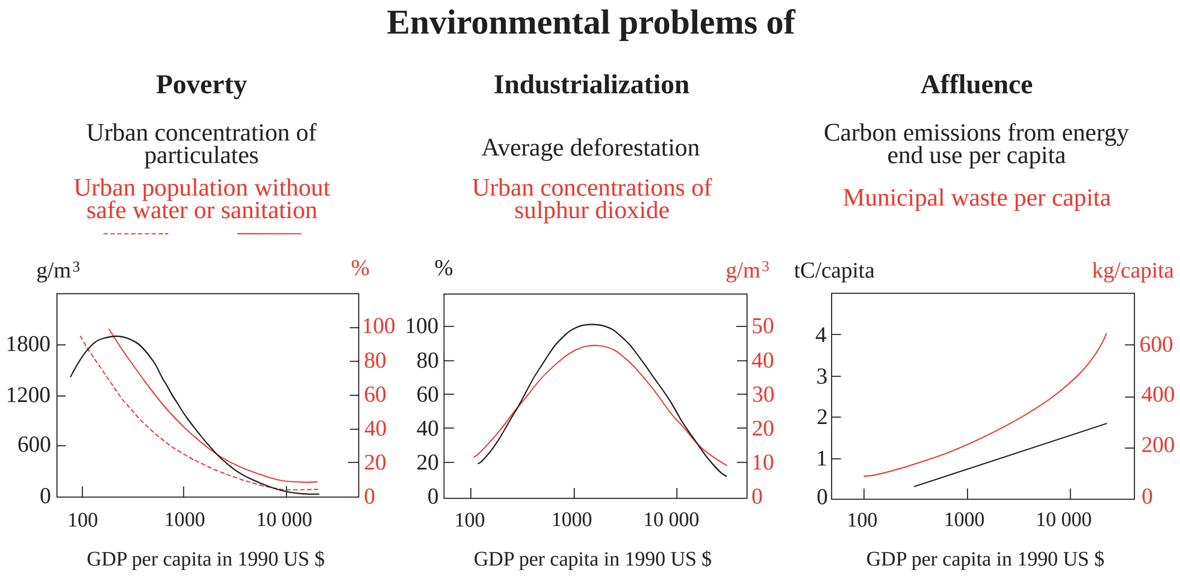

FIG. 8.9. *Environmental indicators at different levels of per capita GDP in 1980 [8.31].*

by a future, post–Kyoto Protocol climate change agreement.

Even the potential for more intensive use of renewable energy sources must take climate change into account, either because their increased use may have negative impacts or because their availability may be affected by climate change. For example, hydropower can release substantial amounts of methane from inundated biomass decomposition and could also be susceptible to potential changes in rainfall intensity. Since hydropower plants are designed for 50 or more years of operation, the future behaviour of weather conditions can have important economic consequences.

8.3.3. Domestic supplies versus imports

Brazil imports energy, mostly oil but also coal, gas and electricity (see Fig. 8.1). Oil import volumes have decreased in recent years owing to a considerable increase in domestic oil production (Fig. 8.10). The present situation shows a decline in oil imports and an increase in electricity imports.

Current Brazilian domestic consumption of oil products exceeds installed refining capacity. Moreover, refining capabilities do not match the oil product demand mix. Three alternatives are being considered to solve this mismatch. First is the construction of a new unit with a refining capacity of around 200 000 bbl/d. Second is the possibility of processing domestic oil outside the country and repatriating the oil products. Third is a combination of the first two alternatives. In parallel with any of the above measures, Petrobras plans to modernize and expand the existing refineries. Construction of the new unit would be capital intensive, and returns are expected to be low. The global refining market is very competitive, and refineries are forced to work with small profit margins. Such returns are usually unattractive to the private sector. Not surprisingly, Petrobras is not interested in new refining capacity, but it may be forced to reconsider its position for strategic reasons defined by the Government. The real question here is the trade-off between economic risks and dependence on foreign refining capacities to meet domestic demand for oil products.

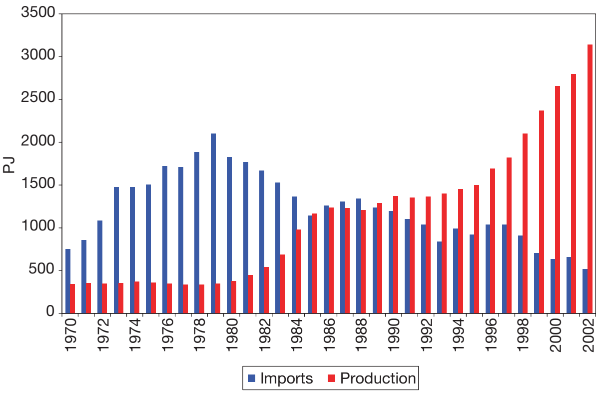

FIG. 8.10. Brazil's domestic production and imports of oil [8.15].

Natural gas is being imported in greater quantities from Bolivia (30 million m^3/d, or 1.2 PJ/d, authorized capacity) and Argentina (12 million m^3/d, or 0.48 PJ/d, authorized capacity). Moreover, the possibility of connecting the Camisea natural gas deposit in Peru to the Brazilian gas network is being examined. However, the substantial devaluation of the national currency in 1999 raised gas import prices (denominated in US dollars), which curbed demand. Growth in domestic gas demand has fallen below expectations, and earlier plans for a second pipeline from Bolivia have been shelved, in part also because in 2003 Petrobras announced the discovery of 419 billion m^3 (around 17 EJ) of new natural gas reserves in the Santos Basin in the Southeast region. Petrobras intends to invest around US $1 billion by 2007 to further develop the natural gas distribution network and pipelines from the Santos Basin to the southwest market with a possible link between the Southeast–Midwest and Northeast regions. All these investments must be coupled with a market pull demanding more natural gas, and this has been a main concern for Petrobras.

8.3.4. Domestic oil sector

The Brazilian oil sector has a reasonably well distributed infrastructure for oil production and import terminals. Oil refining takes place in 11 refineries, where oil and oil derivatives are usually stored on-site. Each processing unit can operate independently, but some units are quite large, and a complete disruption at one of them could cause significant supply shortages. A possibly even more serious risk component is the pipeline system that transports oil and oil products to and from the refineries. The same network often serves two or more refineries. Alternate delivery by rail or truck represents only a partial solution for shortages, given the large volume of oil and oil products handled on a daily basis.

Another source of risk is associated with the explosive character of liquid fuels. As explained by Lovins [8.33], these fuels are handled in large amounts, often in or near cities, with the potential to cause large explosions. A standard fuel oil delivery truck carries fuel equivalent to 0.3 kt, while a medium sized airplane carries fuel equivalent to 0.8 kt. This must be carefully considered with respect to risks of terrorist acts.

8.3.5. Electric power system

The function of the electric power system is to provide electricity as economically as possible and with an acceptable degree of security and quality. The economics of electric power security (reliability) involve striking a reasonable balance between cost and quality of service.

Despite some structural weaknesses (see discussion in Section 8.2.4), for a developing country, the Brazilian electric system is reasonably adequate regarding the existing number of generating facilities and the capacity of the transmission and distribution systems. Electricity generation is dispersed over more than 1000 units, but only a few of them are responsible for most of the production or storage of the primary energy input. The Itaipu hydropower plant generates 20% of the total national electricity supply and provides almost half the needs of the Southeast–Midwest system. Water is stored in a few reservoirs (Table 8.3). More than 40% of the South region's water is stored at Foz do Areia, while more than 20% of the Southeast–Midwest region's water is stored at Furnas. Consequently, any serious disruption at Itaipu, Foz do Areia or Furnas could result in significant electricity supply shortages. However, even with large investments, interruptions are almost inevitable, and the costs of improving the continuity of supply can become very high where a high degree of reliability is desired.

The transmission system is technically very complex and at times spins out of control. Tight capacity constraints, lack of adequate maintenance, technical faults within the control system, synchronism and reliance on vulnerable telecommunications and information technologies constitute serious vulnerabilities (see Section 8.2.4). Another risk is frequent lightning. Critical transmission lines subject to lightning strikes include the direct current lines connecting Itaipu to the Southeast–Midwest system and the city of São Paulo, and the alternating current lines connecting the Tucuruí plant to the city of São Luis in the North region's system. In the case of transmission failures, hydropower plants can easily change their generation level, and some turbines are kept in operation without load (spinning reserve) for emergency situations. Also, a provision for fast load disconnect exists to avoid a general system overload.

8.3.6. Labour force

The relatively small number of skilled workers in Brazil is seen as a risk by Petrobras, which directly employs about 50 000 workers well organized in labour unions. The electric system overall has around 100 000 organized workers. Thus, unions can easily rely on strikes as a bargaining tool. To date there have been almost no supply shortages caused by strikes.

8.4. ENERGY SECURITY POLICIES

The first requirement for achieving energy security is to ensure global energy adequacy, that is, the existence of enough energy resources, or other prospects, to meet long term world energy needs (see Ref. [8.2]; see also Chapter 4 of this report). Local or national energy security can be ensured by local adequacy — abundant and varied forms of indigenous energy resources — or by flexible and robust energy markets. Where local shortages do occur, energy security can be enhanced through (a) the flexibility and ability of governments and market agents to import needed supplies (which implies an adequate transport infrastructure); (b) national (or regional) strategic reserves to address transient interruptions, shortages or unexpected surges in demand in the short term; and (c) technological and financial resources and know-how to develop indigenous renewable sources and power generating facilities with adequate attention to environmental challenges in the long term. Energy security can also be enhanced through measures targeted at the improvement of energy efficiencies, adequate energy pricing, rational energy use and the use of nuclear power. Reducing energy intensities will reduce the economy's dependence on energy supplies, including imports.

TABLE 8.3. MAJOR RESERVOIRS OF THE INTERCONNECTED ELECTRIC SYSTEM [8.34]

Hydropower plant	Utility	Region	Capacity of regulation (months)	Classification	Share capacity (MW-month)	Share of storage capacity of the region (%)
Furnas	Furnas	SE	21	Multi-year	36 246	21
Emborcação	Cemig	SE	31	Multi-year	22 741	13.2
Nova Ponte	Cemig	SE	41	Multi-year	20 069	11.7
Serra da Mesa	Furnas	SE	61	Multi-year	16 979	9.9
Itumbiara	Furnas	SE	9.5	Multi-year	16 414	9.5
I. Solteira–Três Irmãos	Cesp	SE	1.7	Interannual	6 344	3.7
Marimbondo	Furnas	SE	3.2	Interannual	5 377	3.1
São Simão	Cemig	SE	2.7	Interannual	5 259	3.1
Paraibuna	Cesp	SE	44	Multi-year	4 637	2.7
A. Vermelha	AES	SE	2.9	Interannual	4 588	2.7
M. de Moraes	Furnas	SE	2.8	Interannual	4 519	2.6
Capivara	Duke	SE	6.2	Interannual	4 090	2.4
Jurumirim	Duke	SE	17	Multi-year	3 913	2.3
Chavantes	Duke	SE	11	Multi-year	3 412	2
Barra Bonita	AES	SE	7.2	Interannual	2 841	1.7
Foz do Areia	Copel	S	6.9	Interannual	6 325	41
Salto Santiago	Eletrosul	S	5	Interannual	3 372	21.8
Passo Real	CEEE	S	19	Multi-year	3 152	20.4
Passo Fundo	Eletrosul	S	30	Multi-year	1 217	7.9
Sobradinho	Chesf	NE	12	Multi-year	30 290	60.4
Três Marias	Cemig	NE	25	Multi-year	16 142	32.2
Itaparica	Chesf	NE	1.4	Interannual	3 416	6.8
Serra da Mesa	Furnas	N	61	Multi-year	888	57.4
Tucuruí	Eletronorte	N	3.3	Interannual	6 579	42.5

8.4.1. Energy security policies in Brazil

8.4.1.1. Short term energy security

8.4.1.1.1. Energy efficiency

Energy efficiency improvements are one option to reduce energy supply risks, as lower demand levels can be more easily met. Federal policies regarding energy efficiency have been in place since 1985, but even today their application is not widespread (see Chapter 9). During the 2001 electricity shortage, Brazilian consumers indicated a large potential for making significant energy efficiency improvements (see Fig. 8.5). Although the reduction in electricity use was mainly achieved through changes in habits and decreases in the quality of life — since it is impossible to obtain instantaneous energy efficiency improvements of 15–20% — a sizable and lasting drop in demand was attributable to the replacement of incandescent light bulbs with compact fluorescent tubes (replacing between 1000 and 2000 MW of supply [8.35]).

8.4.1.1.2. Managing stocks

Strategic oil reserves exist, but for financial reasons current reserves are only sufficient to support demand for two or three weeks. Natural gas is more difficult to stock, and essentially the only existing storage is provided by the pipeline system. Even considering that one of the pipelines is 2600 km long, the buffer is only good for a few days.

Anhydrous alcohol, which is blended into gasoline, and hydrated alcohol used as neat ethanol fuel are produced during seven months of each year, with stocks maintained to supply annual demand. Currently, there are no contracts or supply guarantees between alcohol producers and the Government. The producers have primarily managed storage. For instance, at the beginning of 2003 there was a potential supply shortage due to a temporary increase in international sugar prices. Given the high flexibility of sugar–alcohol refinery production, better prices for sugar meant less alcohol was produced in the 2002 season. Advancing the sugar cane harvest by one month mitigated potential alcohol shortages, although at the expense of lower total ethanol production, as the crop was harvested before it had reached its maximum sugar content.

8.4.1.1.3. Trade and technology transfer

Brazil imports oil, natural gas and electricity (because of insufficient domestic production), as well as coal (because of the poor quality of domestic reserves). With the significant increase in domestic oil production, foreign oil dependence has shrunk (see Fig. 8.10). Natural gas is imported from neighbouring countries (Bolivia and Argentina), and negotiations are under way to import natural gas from Peru. Electricity is imported from Argentina (2250 MW), Uruguay (70 MW) and Venezuela (200 MW), not to mention the significant contribution of Paraguay through the joint Itaipu Dam effort. The possibility of importing several thousand megawatts from Venezuela is frequently considered. It is clear that a trend exists towards establishing electricity exchange, with these countries handling more significant amounts in the near future.

Perhaps more important to Brazil's overall balance of energy trade is the potential for export of indigenous energy production technologies. These include ultra-deepwater drilling and seismology techniques and equipment, as well as commercialization of the entire sugar cane–alcohol industry. The technology transfer of this sugar based energy system is highly desirable for other developing countries with a heavy agricultural focus and could be included as part of the aid packages that developed countries offer as environmentally friendly development and energy system packages.

8.4.1.1.4. Indigenous renewable energy development

The ethanol programme implemented in 1975, the recent programme on electricity generation by sugar mills using sugar cane bagasse and the recently proposed programme to foster renewable energy (wind, small hydropower and biomass), called PROINFA, are examples of good practice for renewable energy development in the country. In recent years, biodiesel has been the subject of several studies, and in mid-2004 the Government finally announced that it would authorize its addition to regular diesel fuel, up to a proportion of 2% by the end of 2005 and increasing to 5% over the next few years. Through such efforts, it is possible to increase the energy supply portfolio and to produce energy at costs not quoted in hard currency — both of which increase national energy security. The issue of lower cost for indigenous technologies is quite significant, and the success of the indigenous programmes that have already been implemented is a good validation of them.

8.4.1.2. Long term energy security

Long term energy security can be enhanced in several ways. Medium and long term policies should be concerned with the following:

- *Technology transfer*. Investing in and transferring more efficient end use technologies to developing countries effectively enhances total energy supplies, increases energy efficiency and improves environmental management (see Ref. [8.2]; see also Chapter 4). Technologies are welcome in several sectors, but two of the most relevant for Brazil are the following:
  - *Distributed electricity*: These emerging technologies, such as fuel cells or small gas turbines, are being pursued in many developed countries and may become popular in the short term, mainly because of their compatibility with cogeneration.
  - *Renewable energy sources other than biomass*: The need to develop cost effective renewable sources of energy is tied to potential constraints in oil availability, as well as to social and environmental considerations. Traditional oil reserves are limited, and reliance on non-conventional oil sources is not a well

established alternative for Brazil (see Ref. [8.36]; and Chapter 3).

- *Oil resources and reserves*: Figure 8.11 shows two different scenarios for the estimated ultimately recoverable oil in Brazil (18 billion bbl as the lower estimate and 25 billion bbl as the upper estimate). Assuming consumption growth of 4% per year up to 2006 and 1.5% per year from 2007 on, oil production in Brazil will peak between 2008 and 2012. The present trend in consumption growth is much lower than 4% per year, but there is an expectation that higher economic growth will resume.
- *Self-sufficiency as a goal*: Supply security should not be measured solely by energy self-sufficiency. Increasing energy independence by fostering and developing local resources may not be economical. A well balanced supply policy that includes external energy sources can offset many of the drawbacks of dependence and be more economical than a policy that precludes energy imports.
- *Reducing the share of hydropower in the electricity generation mix*: This need has been recognized for decades, since a system based almost entirely on hydropower is too vulnerable to weather variability and is highly capital intensive [8.38]. With the privatization process of the electricity sector, the interest in lower cost thermoelectric generation has increased. Moreover, in response to publicly voiced environmental and social concerns, International Monetary Fund and World Bank policies have restricted loans to public companies that might be willing to invest in long payback projects like large hydropower, fossil fuelled thermoelectric and nuclear power plants.

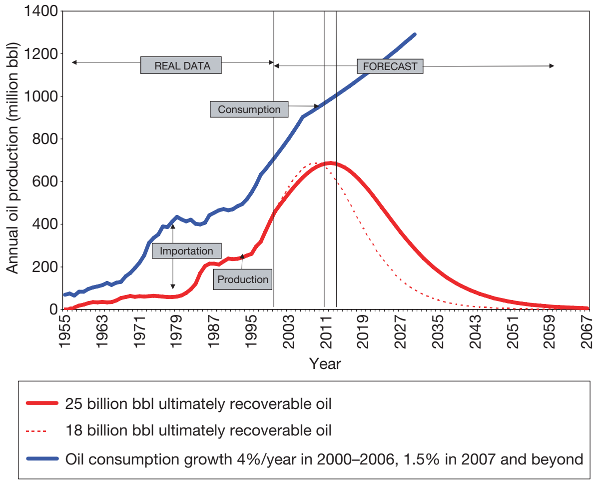

FIG. 8.11. Oil production, consumption and Hubbert peak scenarios for 18 and 25 billion bbl of estimated ultimately recoverable oil [8.37].

8.4.2. Geopolitics and regional integration

The following are points already under discussion regarding geopolitics and regional integration (see Ref. [8.39]):

- The desire of the Brazilian Government to take the lead in strengthening regional integration efforts and at the same time strengthen Brazil's bargaining position with regard to the Free Trade Area of the Americas (FTAA) and the World Trade Organization (WTO).[11]
- Construction of interconnected natural gas pipelines and liquefied natural gas infrastructure for the regional integration of reserves and major demand centres. The most relevant sites are the Potiguar and Recôncavo fields in the Northeast region, the Campos and Santos Basins in the Southeast–Midwest region, Camisea in Peru, the Argentine and Bolivian border fields, the Neuquén fields on the border of Argentina and Chile, Tierra del Fuego in southern Argentina and the Venezuelan reserves.
- Electricity integration, mainly involving Itaipu (Brazil and Paraguay) and Guri (Brazil and Venezuela), as well as Argentine exports to Brazil.
- Regional development of renewable energy potential.

8.5. MAIN ISSUES FOR BRAZIL

From the figures, strategies and policies presented above, one can draw some conclusions

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[11] This includes the creation of the Group of 21, with Brazil, China, India, South Africa and many South American countries, for the Cancún WTO ministerial meeting in September 2003; the efforts to strengthen the Mercosul trading block; the substantial trade incentives to Argentina, Bolivia, Peru and Venezuela; and the bilateral talks with Colombia, Ecuador, Mexico and Venezuela held in preparation for the Miami FTAA meeting in November 2003.

about how energy security in Brazil can be enhanced:

- Foster flexible and robust energy markets with the freedom to import needed energy supplies (which implies adequate import and cross-boundary transport infrastructure).
- Improve the ability to attract more private (national and international) financial resources and to foster technology transfer and further capacity building to develop indigenous renewable sources with adequate attention to environmental challenges.
- Develop those local energy resources that are economical or that can be made economical through technology learning, mainly with technologies likely to be in the public domain within a reasonable time frame. Among the promising options for expanding domestic energy supplies other than hydropower are the use of vegetable oils for diesel substitution, fuelwood from reforested tropical areas, and bagasse from sugar and alcohol production for electricity generation.
- Adopt an appropriate supply policy. Supply security should not be measured solely by energy independence. An intelligent supply policy that includes external energy sources can offset many of the drawbacks of dependence and be more economical than a policy that precludes energy imports.
- Diversify domestic sources of energy and maintain a balanced import portfolio. The combined impact of less oil and more natural gas and electricity imports means more security and more integration through stepped-up regional trade.
- Improve energy efficiency in the energy system. Decreasing energy intensities in the production and consumption of goods and services reduces the dependence of the economy on energy supply, including imports. Improving energy intensities may yield a wider range of benefits than focusing solely on new sources of energy.
- Encourage international cooperation and agreements concerning energy importing and exporting between both governments and companies.
- Create national (or regional) strategic reserves to address transient interruptions or unexpected surges in demand.

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Chapter 9

POLICY OPTIONS FOR SUSTAINABLE ENERGY DEVELOPMENT

A. SZKLO, H. GELLER

Energy policy in Brazil over the past 25 years has attempted to reduce the country's dependence on foreign energy supplies and stimulate the development of domestic energy sources. Policies have been devised to increase domestic oil production, expand alcohol fuel production and use, generate nuclear energy and conserve energy. The positive experience with alcohol fuel production is described in Chapters 2, 3 and 4 and discussed in Section 9.3 below. Efforts to expand domestic oil output, including developing new techniques for oil production in deep waters, have also been very successful, as noted in Chapter 4. As discussed in Chapters 2 and 4, domestic oil production increased from about 0.2 million bbl/d in 1980 to nearly 1.5 million bbl/d in 2002 [9.1]. These policies and their outcomes benefited the country's balance of trade, national security, capital goods industry and labour market.

During the 1990s, energy policy concentrated on restructuring both the petroleum and power sectors, mostly aimed at attracting private sector investments through partnerships with Petrobras, Brazil's national oil company, or by privatizing power utilities. Also, an effort was made to stimulate the development and utilization of natural gas in Brazil. These initiatives have had mixed success. Privatization and restructuring of the electricity sector, two major driving forces of the country's policies during the 1990s, were reviewed by the Brazilian Government elected in 2002. Flaws in this strategy led to relatively little investment in new generation and transmission facilities during the late 1990s, which in turn contributed to a severe electricity shortage in 2001 [9.2].

Overall, Brazil has successfully implemented several energy policies over the past 25 years. Policies for increasing modern renewable energy sources and domestic petroleum supply have been very successful. Yet, policies for increasing energy efficiency and expanding natural gas use have met with limited success. Using lessons learned from past experiences, a variety of new energy policies and initiatives could help Brazil to advance socially and economically, as well as to achieve other important objectives of sustainable energy development.

This chapter reviews major energy policies adopted by Brazil to increase natural gas use, improve energy efficiency and increase renewable energy utilization. The review illustrates that, although these policies were not necessarily motivated by an interest in sustainable energy development, their positive characteristics justify their continuation, intensification or modification. This chapter also presents and analyses a number of policy options that could be implemented to further promote sustainable energy development in Brazil.

9.1. NATURAL GAS

The Government of Brazil has implemented a number of policies to increase natural gas supply and demand in recent years. This has been done to diversify Brazil's energy matrix in order to reduce the nation's excessive dependence on only two primary energy sources: hydropower to generate electricity and oil for the fuels sector.

A major focus of this effort has been on increasing natural gas imports through the adoption of policies focused on gas pipeline capacity expansion and South American energy integration. Brazil's gas pipeline length increased from 3954 km in 1996 to 7710 km in 2001, an increase of 14% per year on average for the five years, compared with 6% on average between 1986 and 1996 [9.3]. In addition, as described in Chapters 4 and 8, a major gas pipeline was built from Bolivia to Brazil, totalling 3150 km in length. As a result, by the late 1990s, Brazil's natural gas supplies had increased appreciably. The Bolivia–Brazil gas pipeline, whose current nominal capacity is around 16 million m^3/d, will be able to transport 30 million m^3/d by 2007. Brazil was importing about 12 million m^3 of natural gas per day from Bolivia as of 2002 [9.1]. In addition, a gas pipeline from Argentina was providing some 2 million m^3/d as of 2002. This pipeline could eventually transport up to 12 million m^3/d [9.3].

The so-called Zero Burn-Off Plan also helped to expand natural gas supplies in Brazil. Petrobras introduced this plan in 1998 to reduce flaring of natural gas as much as possible on offshore rigs. The natural gas was piped to on-shore supply terminals and then marketed to consumers, mainly in Rio de Janeiro and the Amazon States. As a result, natural gas supplies from the Campos Basin in Rio de Janeiro were boosted by around 1 million m^3/d as of 1999, equivalent to one fifth of all natural gas distributed in Rio de Janeiro State [9.4]. However, 19% of Brazil's gross natural gas supplies were still burned off (not used) in 1999, dropping to 17% in 2000. This is a high figure, particularly when added to the percentage of Brazilian gas associated with oil that was reinjected to enhance oil recovery. Nonetheless, domestic gas supply (excluding imports) increased from 6895 million m^3 in 1998 to 8397 million m^3 in 2001 [9.5].

The restructuring of Brazil's electricity sector at the end of the 1990s, especially the deregulation of Brazil's electricity market through the introduction of eligible consumers and independent power producers having open access to the transmission grid,[1] boosted the use of natural gas for power generation to some degree. The amount of electricity generated from natural gas increased from none in 1995 to 19.3 TW·h as of 2004 [9.6]. As of September 2005, natural gas fired thermal power plant capacity had reached 9157 MW, with another 1868 MW under construction [9.7].

There have been, however, a number of problems related to expanding natural gas supply and demand. First, there is still considerable uncertainty regarding relative energy prices — for example, the relationship between natural gas and fuel oil prices, which impacts industrial gas demand. Second, the Brazilian gas distribution network remains incipient, meaning that development in the market is still heavily dependent on the expansion of thermal power generation fuelled by natural gas. Third, the pricing of gas supplies from Bolivia in dollar terms has made this fuel very expensive since the devaluation of the Brazilian real in recent years and the increase of international oil prices, to which the price of the imported natural gas is related. Fourth, some potential gas users have found it difficult to deal with, or have refused to accept, the take-or-pay clause in gas contracts. Thus, it is worth considering revised or additional policies to expand the use of natural gas in ways that are economical, energy efficient and environmentally beneficial.

9.1.1. Policy option: Remove barriers to NGCHP implementation

As mentioned above, the bottleneck that was caused largely by constraints on natural gas supplies was removed through the startup of the Bolivia–Brazil gas pipeline at the end of 1998. Indeed, the analysis of the energy used by Brazil's industrial sector as a whole from 1998 to 2000 indicates that sectors such as chemicals, food and beverages, pulp and paper, ceramics and textiles increased their use of natural gas and reduced their oil consumption. Natural gas has managed not only to serve new projects, but also to displace fuel oil in some existing facilities, especially in the chemical sector. However, significant potential remains for using natural gas fired combined heat and power (NGCHP) systems. This would increase overall energy efficiency,[2] reduce the consumption of other fuels such as oil, reduce the need for new conventional power plants and the associated transmission and distribution infrastructure, and enhance the reliability of the electricity grid. However, some long standing barriers have inhibited NGCHP systems in Brazil [9.8]:

- First, Brazil's electricity system consists primarily of centralized generation based mostly on hydropower. Many thermal power plants exist merely to supplement hydropower plants, operating only for a limited number of hours per year in most years (see Chapter 2).
- Second, Brazil's power sector has lacked clearly defined mechanisms to allow NGCHP ventures to transfer their energy through the power grid. Potential owners of combined heat and power (CHP) projects have also faced high backup power rates and other barriers related to the power sector, which has hampered the implementation of CHP projects.
- Third, low electricity prices, particularly for industries that connect to the grid at higher

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[1] See Section 2.3 in Chapter 2 of this report.

[2] As mentioned in Chapter 2, Brazil's overall first thermodynamics law efficiency is less than 40%.

voltages, have discouraged investments in CHP projects.[3]

- Fourth, among commercial businesses and industries in Brazil there is limited awareness of CHP systems and their potential advantages, and relatively few vendors actively market CHP systems.

This historical context has started to change. The 2001 electricity supply crisis highlighted the need to further diversify Brazil's electricity supply. Ten per cent of newly available gas supplies were allocated to CHP projects in 2001. In addition, at the beginning of 2003, the Government implemented a new model for the Brazilian power sector that is driven by two main principles: first, that the Ministry of Mines and Energy (MME) should ultimately be responsible for the country's energy planning,[4] and second, that the electricity market should be fully contracted over the long term, under both a deregulated arrangement (bilateral contracts between power producers and eligible consumers) and a regulated arrangement based on power supply bids. These binding commitments will necessarily include thermal power options as alternatives to the hydropower expansion, because these options:

- Allow the optimal use of hydropower reservoirs by running at maximum load during the dry season or at peak periods;
- Will be selected when the expansion should be made quickly[5] and if there is no available economic hydropower potential (e.g. in isolated systems);
- Are located close to the electricity markets, and thus are able to improve the quality of the power distributed (voltage enhancement, etc.).

However, while reform of the electricity market can remove some market barriers to NGCHP systems, particularly those involving access to the transmission grid and retailing surplus electricity, deregulation does not overcome all the barriers. For instance, if power supply bids lead to lower energy prices, NGCHP systems will be negatively affected because the incentives for conservation will decline [9.9]. There is also the possibility of anticompetitive behaviour on the part of the power utilities that may negatively affect CHP investments, such as unreasonable terms for backup power. Thus, additional policies are needed to remove barriers and stimulate NGCHP implementation. These include the following:

- Require utilities to pay full avoided costs for power surpluses provided to the local grid on a firm basis by qualified facilities (distributed cogenerators)[6] and provide backup power at regulated tariffs that reflect the real value of the emergency power required by cogeneration systems under maintenance.[7]
- Remunerate qualified cogenerators as spinning reserves for the electric system and for other services provided by these producers to the local grids (e.g. voltage enhancement, emergency power).
- Educate end users in the commercial and industrial sectors about the advantages of and potential for CHP adoption, and facilitate contacts between CHP vendors and end users.
- Give priority to CHP projects as new gas supplies become available and are allocated to commercial and industrial consumers.
- Provide financial incentives such as long term loans at attractive interest rates from the national development bank or accelerated

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[3] For more details about electricity price trends in industry, see Chapter 2.

[4] An agency of energy planning has been created, called Empresa de Pesquisa Energética (EPE), aiming at technically supporting the country's long term energy planning.

[5] Actually, the model considers two serial bids, one five years before the target expansion and the other three years before the target expansion. Thus, it allows the expansion through hydropower and complementary thermal power plants (five year bid) and through thermal power plants if the market expansion is higher than previously forecasted (three year bid).

[6] The full avoided costs include avoided generation, transmission and distribution costs via long term contracts. Power transmission and distribution costs hover between US \$5/MW·h and US \$15/MW·h in Brazil. Avoided operating costs depend on the season (dry or rainy), owing to the predominance of hydropower in the Brazilian system. Nevertheless, it is possible to estimate that the distributed cogenerator would receive at least US \$40/MW·h under this type of incentive policy. Actually, in 1998, a power utility in São Paulo State signed long term contracts with two cogenerators at US \$34/MW·h, making their investments feasible [9.10].

[7] Backup power tariffs may be three times the normal electricity tariff [9.11], compromising the economic feasibility of cogeneration plants.

depreciation for CHP systems that meet certain conditions, such as high overall efficiency and low pollutant emissions.

- Encourage third party financing and project implementation by energy service companies (ESCOs), energy suppliers such as gas or electric utilities, or equipment suppliers. One option is to use bidding programmes in which ESCOS bid for NGCHP ventures through performance based contracting. For instance, this could be done under the aegis of the new power sector model, which is based on power supply bids.
- Reduce import duties on CHP equipment such as gas turbines, but also promote the production of this equipment in Brazil.

Recent studies show that a combination of these policies could overcome current remaining barriers to CHP adoption [9.12]. It is estimated that adopting these policies could result in at least 6 GW of new NGCHP capacity by 2010 [9.13]. In fact, the long term energy plan of the Brazilian Government [9.14] calls for NGCHP systems to provide at least 5% of Brazil's total electricity supply by 2020. This is an achievable, although modest, target, provided the policies proposed here are adopted [9.15].

9.1.2. Policy option: Adopt minimum efficiency standards for thermal power plants

In the short term, new natural gas supplies are expected to be consumed mainly in thermal power plants. Therefore, it is worthwhile to establish policies to maximize the energy and economic benefits from this development. The majority of the natural gas fired power plants constructed in recent years have been open cycle plants, meaning rated efficiencies of under 35% rather than the 50–60% achieved by state-of-the-art combined cycle plants. Private investors have preferred simple cycle plants because of the lower investment costs, shorter construction times and consequent quicker returns. Nonetheless, some of these plants may be converted later to combined cycle operation.

Minimum efficiency standards could be adopted for all new natural gas fired power plants that enter into operation in Brazil. Also, plants built as open cycle gas turbines could be required to add steam turbines and operate as combined cycle plants if they are used for longer than a specified period of time. For example, the Government could require all natural gas fired power plants used for more than 4500 h/year to meet an efficiency level of 50%. This is a realistic target considering the performance of gas turbines operating in Brazil, where temperatures are often higher than 15ºC [9.11]. This type of requirement also would narrow the difference in capital cost between electricity only and CHP plants, thereby helping to stimulate investment in CHP systems.

9.1.3. Policy option: Internalize sulphur emission costs associated with fuel oil use

The use of natural gas for industrial process heat has not grown as fast as the Brazilian Government expected it to after 2001. On the contrary, since 2001 natural gas has been losing its competitiveness, mainly owing to an unfavourable ratio of natural gas to fuel oil prices in the industrial sector [9.3]. From 1997 to 2000, this ratio decreased from 1.43 to 0.92 on an energy equivalent basis [9.16], but then increased to 1.33 by November 2001 [9.17]. Therefore, some industries have reconverted equipment (boilers, furnaces, etc.) to fuel oil or even fuelwood, in spite of the fact that natural gas fuelled equipment is more efficient and residual fuel oil in Brazil has an average sulphur content of 2.5% [9.11]. In addition, in 2001, only 45% of the total natural gas supply contracted by gas distribution utilities to serve the industrial market was sold to industrial consumers [9.17]. Given the advantages of natural gas compared with fuel oil, additional policies could be adopted to promote greater natural gas use by industries.

One option would be to internalize the costs associated with sulphur emissions through fuel taxation or the use of a sulphur emission permit system. The emissions control cost associated with scrubbing equipment can be used as a proxy for determining this cost, as is done in some industrialized countries [9.18]. The sulphur dioxide (SO_2) emissions control cost in Brazil is estimated to be US $880/t [9.19]. This corresponds to a tax on residual fuel oil of US $0.74/GJ. It may be desirable to adopt a somewhat higher tax, however, as the emissions control cost may be lower than the damage caused by sulphur emissions [9.18].

This policy could have a significant impact on industrial natural gas demand. A recent study concluded that, under the current conditions of Brazil's natural gas industry, and based on an exchange rate of 3.0 Brazilian reals to the US dollar and oil price projections by the International Energy Agency, the ratio of natural gas to fuel oil prices will hover between 1.0 and 1.2 in Brazil [9.11]. In this case, it is feasible to convert more than 70% of fuel oil use in Brazil's chemical sector to natural gas with a residual fuel oil tax of just US $0.21/GJ [9.11]. This value is similar to the average sulphur emission certificate price in the United States of America as of 2001 [9.20].

9.1.4. Policy option: Expand natural gas use in buses

Converting buses from diesel fuel to natural gas will reduce emissions of nitrogen oxides (NO_x) and particulate matter and improve urban air quality [9.21]. It will also reduce consumption of oil products and marginal oil imports. In addition, natural gas fuelled buses are less noisy than diesel buses. However, they have higher initial costs, and the thermodynamic cycle of gas engines is normally less efficient than that of diesel engines. Nevertheless, adoption of natural gas fuelled buses is increasing around the world. There were around 6200 natural gas fuelled buses in use in the United States of America as of January 2002, and some US cities such as Atlanta, New York and Los Angeles are ordering only natural gas fuelled buses [9.22]. In addition, a number of cities in the developing world (e.g. Beijing and New Delhi) have begun to use natural gas fuelled buses on a large scale.

There have been a few efforts in Brazil to convert urban buses to natural gas. During the 1980s, the São Paulo State and city transport agencies, Mercedes Benz of Brazil and the Institute of Technological Research (IPT) converted 10 buses to dual fuel (diesel and natural gas) operation. This experience led the city of São Paulo, in 1991, to establish a target of converting all buses to natural gas operation by 2001 [9.23]. However, by 1996 only 133 buses had been converted to natural gas, owing to bus engine conversion delays, operational problems in some converted engines, the limited natural gas distribution network, high upfront costs for implementing natural gas fuelled buses and fuelling stations, and the high maintenance costs of natural gas fuelled buses. Therefore, the city adopted less aggressive targets in 1996, leading to a total of 224 natural gas fuelled buses in São Paulo as of 2001 [9.24].

Brazil exports gasoline and imports diesel. Nevertheless, Brazil's natural gas fuelled light vehicle fleet (mainly automobiles) increased sharply from around 50 000 vehicles in January 2000 to over 390 000 vehicles in January 2003. This had a positive impact on the construction of natural gas fuelling stations, which increased from 59 to 508 during the same period [9.25]. Therefore, it is now reasonable to promote the adoption of natural gas fuelled buses on a large scale. The following policies could be used to expand the fleet of natural gas fuelled buses in Brazil:

- The Federal Government could gradually implement higher taxes on diesel fuel to reflect its environmental and socioeconomic costs (i.e. its adverse impact on Brazil's trade balance), thereby improving the economic feasibility of natural gas fuelled buses.
- The Federal Government could provide low cost financing and/or fiscal incentives to bus companies that purchase natural gas fuelled buses. This is in line with the financing and incentives used to stimulate the purchase of ethanol fuelled automobiles in the 1980s as well as renewable energy technologies today.
- Municipalities could favour companies that deploy natural gas fuelled buses in the licensing and concession process.
- Research institutes could monitor the performance of natural gas fuelled engines and buses and, if necessary, conduct research and development (R&D) to improve reliability and increase engine lifetime.
- The Government, along with bus manufacturers, engine manufacturers and bus companies, could develop and implement a training programme for bus drivers and technicians.
- In the short term, the Federal Government could promote the adoption of natural gas fuelled buses in those metropolitan areas with the most severe urban air quality problems, highlighting the benefits of shifting to natural gas.
- In the short to medium term, the Government could develop fuelling infrastructure and promote the adoption of natural gas fuelled buses in some small and medium sized cities. This is important because these cities represent a secondary market for buses first used in larger cities.

Studies are needed to precisely estimate the impact of these policies. As a rough estimate of their potential, it has been estimated that for the city of São Paulo, replacement of diesel with natural gas in the total fleet of public buses — about 10 000 buses

— could save about 1.1 million L of diesel per day, or about 6% of the volume of diesel imported by Brazil in 2001.

9.2. RENEWABLE ELECTRICITY SOURCES

Brazil has experience with policies to stimulate both centralized (on-grid) renewable energy facilities other than large scale hydropower and decentralized (off-grid), smaller scale renewable energy systems. These policies have had a limited impact on energy supplies so far, but some recent policy initiatives could change this situation. For certain regions of Brazil where the potential for alternative renewable electricity supply is appreciable, expanding renewables could help to diversify energy supply and reduce the fraction of consumers not connected to the power grid.

With regard to major policies that apply to all new renewable energy sources in Brazil, the first milestone was the definition of independent power producers and self-producers under Brazilian law in 1996. This was an institutional milestone in the reform of Brazil's electricity sector, opening up opportunities for new agents to enter the electricity retailing and generation markets. However, this definition per se proved insufficient to boost investments in alternative renewable energy sources.

Within this context, the benefits of the so-called cross-subsidy Fuel Consumption Account were extended to alternative energy sources, provided that they replace, partly or totally, oil based thermal power generation in Brazil's isolated power systems, which are mainly located in the Amazon region (Amazonia).[8] This measure addressed a historical barrier to the use of alternative energy sources in stand-alone systems created by the cross-subsidy awarded to thermal power generation. Yet this measure was not sufficient to make alternative energy sources economically feasible, except for certain small scale hydropower (SSH) plants and wind farms under very favourable conditions [9.27], and for diesel–photovoltaic (PV) hybrid systems up to 50 kWp in isolated systems [9.26]. In other words, additional types of incentives were required to stimulate the adoption of alternative renewable energy sources. This situation led to the introduction of the PROINFA programme, discussed below.

9.2.1. Centralized renewable electricity sources

Several specific policies to stimulate the adoption of SSH projects were introduced in 1998. These policies included the following:

- Modification of the size limit on SSH plants. Until 1998, these plants were limited to an installed capacity of up to 10 MW. The new law allowed SSH plants up to 30 MW, with a reservoir area of up to 3 km^2.
- Simplification of the licensing process and exemption of SSH plants from payment of the water resources usage fee — equivalent to 6% of the value of the electricity generated in 1998.
- Allowing direct electricity sales from SSH plants to consumers with loads equal to or greater than 500 kW and discounts of at least 50% on the power transmission and distribution system usage rates.

Additional financial incentives were adopted in February 2001 to further stimulate the development of SSH systems. These incentives include low interest financing from the Brazilian National Development Bank (BNDES) as well as payments for the electricity produced by SSH plants at 80% of the average tariffs paid by final consumers throughout Brazil. These incentives were offered for to up to 1.2 GW of SSH capacity installed from 2001 to 2003, as part of the Small Scale Hydro Programme (PCH-COM). However, despite the advantages offered by this programme and the other policies that were adopted, and by the institutional changes that took place during the late 1990s, the adoption of SSH systems has been relatively limited. Only 100 MW have been submitted under this programme so far, equivalent to one quarter of the level initially planned, and as of 2002 no SSH plants had been licensed or built under the PCH-COM financing portfolio [9.28]. The main barriers — relatively low electricity purchase prices

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[8] Subsidies to utilities purchasing fossil fuel to operate power plants, the so-called Fuel Consumption Account, are about US $350 million per year, coming from a contribution contained in electricity tariffs [9.26]. The Fuel Consumption Account, known in Brazil as the CCC (Conta de Consumo de Combustível), traditionally was used to subsidize the cost of power in isolated and/or fossil fuel based power systems. The subsidies correspond to the excess costs of the fossil fuel over a reference hydropower tariff.

set by the Brazilian Government and high perceived risk on the part of potential project developers — remain in place.

There is significant wind power potential in certain regions of Brazil, such as the Northeast coastal region and parts of the South and Southeast.[9] However, there has been relatively limited development of wind power in Brazil, with only about 21 MW of installed capacity as of June 2003 [9.7]. A wind power development programme known as PROEOLICA was launched during the electricity supply crisis in 2001. The two main objectives of this programme were to implement 1050 MW of wind power by December 2003 and to promote the seasonal complementarity of hydropower and wind power resources in the national grid system. The programme featured fixed 'feed-in' payments for a specified amount of wind power capacity, but the payment levels were not adequate to stimulate the development of any new wind farms. In addition, the short term focus of PROEOLICA created an incentive for wind turbine imports and did not support the establishment of a viable wind industry in Brazil [9.30].

In this context, the Alternative Energy Sources Incentive Programme (PROINFA) was adopted in 2002. This programme is designed to stimulate renewable electricity generation and sales to the grid. It is aimed at increasing electricity generation by three new renewable energy sources (wind, biomass and SSH), preferably through projects implemented by independent power producers that are not directly or indirectly controlled by a power utility. The programme is divided into two phases, one aimed at stimulating renewable energy development in the short term and the other, over the long term.

In the first phase through April 2004, Eletrobras was directed to sign long term power purchase contracts with wind power, biomass based power and SSH power producers, to total 1100 MW of installed capacity from each of these three alternative energy sources. The deadline for the startup of these projects is December 2006. They will receive 15-year long term contracts guaranteeing the purchase of their electricity at an 'economic value' up to 80% of the average retail electricity rate in Brazil. However, the definition of the 'economic value' of each energy source is controversial and imprecise, and constitutes a major barrier to the success of PROINFA.[10]

The second phase of PROINFA establishes an impressive target: alternative renewable energy sources should supply 10% of Brazil's electricity consumption in 20 years (i.e. by 2022). Once again, 15-year long term contracts will be signed between Eletrobras and independent renewable power producers. However, in this second phase, the price paid for the electricity provided by the alternative energy source ventures will be based on the average cost of new competitive power generation plants, considering hydropower plants larger than 30 MW and natural gas fired thermal power plants, along with a complementary credit from a fund known as the Energy Development Fund. This credit will be set in principle so that the renewable energy sources on average are cost effective, but again the total payment for electricity supplied will be limited to 80% of the average retail electricity price. In addition, the alternative energy sources under PROINFA will be considered baseload plants, and their dispatch will be prioritized by the National System Operator (NSO), provided that this does not adversely affect the power quality of the grid.

It remains to be seen how successful PROINFA will be. Many substantial wind power projects were proposed and authorized before 2005. But whether or not these (and other) renewable energy projects are implemented will depend in large part on the still to be determined rules regarding the Energy Development Fund. This fund is supposed to support not only PROINFA but also universal electricity service (i.e. electrification of homes not yet connected to the grid), natural gas grid expansion and new 'clean coal' thermal power plants. However, if carefully implemented, PROINFA could significantly expand the contribution of alternative renewable energy sources to the Brazilian power system.

Incentive policies such as PROINFA not only should guarantee minimum market shares for renewable energy sources, but should also take advantage of competitive market forces to stimulate cost reductions. Thus, the procedure for establishing the electricity rates (or the reference values for electricity generated by the alternative energy

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[9] CEPEL, the Eletrobras Research Centre, has estimated a wind power potential of over 140 GW in Brazil [9.29]; see also Chapter 3.

[10] According to Decree 4541/2002, the 'economic value' is the value that, for a specific period of time and a specific efficiency level, guarantees the economic feasibility of a typical project based on a specific alternative energy source.

sources) is crucial. As the cost of renewable energy sources has been declining steadily over the past 20 years, some nations have revised their incentive payments in order to develop renewable energy markets in an orderly, cost effective manner, that is, to avoid both inadequate and excessive incentives [9.31]. The revision of incentives over time should be balanced with the need to provide renewable energy developers with some degree of certainty for planning purposes. In particular, the Government could utilize market oriented mechanisms, such as tradable permits or competitive bidding for licences, to establish payment levels for alternative energy sources. This could simplify the price setting process and reduce the subsidies provided, thereby saving consumers money in the long run. However, it may not lead to technological or geographic diversity with respect to alternative energy development.

9.2.1.1. Policy option: Adopt renewable energy portfolio standards

If the PROINFA policy fails to result in a significant and orderly expansion of new renewable electricity sources, an alternative approach known as renewable portfolio standards (RPSs) could be enacted. An RPS obligates utilities to supply or purchase a specified amount of electricity from renewable sources, expressed as a percentage of either capacity or electricity sales. An RPS provides certainty that renewable energy sources will be implemented, stimulates competition among renewable energy providers and encourages cost reductions. Generally, utilities are allowed to achieve the renewable energy targets through their own installations and/or the purchase of tradable renewable energy credits from other utilities or independent project developers. In addition, the selection of targets can involve trade-offs between environmental improvements, long term technological developments and cost. For instance, if Brazil is interested not only in environmental improvements but also in newly emerging, but still expensive renewable sources, it should have two or more classes of standards, ensuring a more diverse mix of renewable sources. The RPS policy has been successfully implemented by a number of States in the United States of America as well as by some European countries [9.31, 9.32].

An RPS policy could apply to electricity generators or distributors in Brazil. Distribution utilities, for example, could be required to purchase a percentage of their power from new renewable sources (i.e. excluding larger hydropower plants) or purchase credits from renewable projects serving the grid but outside their region. Issues that must be addressed in designing an RPS include quantity, timing, which resources to include, whether or not to include a cost cap and whether or not to include minimum or maximum amounts for particular types of technology [9.31].

9.2.2. Decentralized renewable energy development

Currently, nearly 1000 small scale power plants, mostly diesel generators but also charged automotive batteries and dry cells, supply electricity to isolated cities and villages in Amazonia [9.26, 9.33]. Also, as discussed in Chapter 2, nearly 4% of all households in Brazil (or less than 7% of the total population) do not have access to electricity; this share is about 25% in rural areas and even higher in the North and Northeast regions.

Smaller scale renewable energy (PV, bioenergy or very small hydropower) systems are relatively expensive, but they can be a viable alternative for households without access to electricity. The real cost of electricity is quite high in these communities because they are far from the power grid, they comprise a limited number of widely scattered consumers and they require fuel imports to power stand-alone generators.[11] In addition, stand-alone power generators are very inefficient owing to partial load operation and difficulties regarding maintenance and repair. Thus, electricity generation costs in isolated systems range between US $300/MW·h in the case of diesel generators and US $25 000/MW·h in the case of dry cells [9.26].

The sheer size of the country and the rural electrification programmes implemented over the past few years indicate that the marginal costs of expanding the grid are rising, thereby making the use of decentralized power generation alternatives more feasible. The modularity, simplicity, versatility, low maintenance requirements and freedom from fuel supply requirements offer additional advantages for the PV alternative in remote rural locations. Additionally, widely dispersed consumers and the low level of power demand are key factors in defining the lowest cost alternative for meeting

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[11] The cost of diesel oil to generate electricity in stand-alone systems can increase up to 2.5-fold when shipping is added [9.13, 9.26].

the energy demands of remote communities. Yet, some type of policy intervention is required if alternative renewable energy systems are to achieve their potential in rural applications.

The Government of Brazil has taken a number of steps to encourage PV adoption. First, it has eliminated sales taxes on solar cells and modules. Second, it now permits renewable electricity systems to benefit from the subsidy provided by the Fuel Consumption Account (known in Brazil as the Conta de Consumo de Combustível (CCC)). Three renewable energy systems totalling about 14 MW in capacity were developed in remote communities after this policy was adopted [9.33].

Third, the Energy Programme for Small Communities (PRODEEM), launched in 1994, has promoted the installation of PV systems in rural communities in Brazil. PRODEEM purchases PV systems in bulk and provides them at no cost to schools, medical centres, community centres and water pumps via State and local agencies. By 2002, this programme had installed 5914 systems, or 3850 kWp [9.34]. However, the total cost of installing a PV system under this programme hovers around US $20/Wp, resulting in a generation cost of some US $370/MW·h, including taxes and replacement costs [9.35]. Also, surveys have indicated that many systems installed under PRODEEM were inoperative or operated improperly as a result of technical problems, a lack of a local servicing infrastructure and carelessness resulting from the fact that the systems were provided to the communities at no cost [9.36]. Actually, PRODEEM's decentralized structure, which was thought to be one of its main advantages, has partially undermined its performance, because regional agents have failed to properly service and maintain PV systems installed under the programme [9.35]. Nevertheless, PV systems can still be an attractive source of electricity in remote homes and communities in Brazil, assuming that costs can be reduced and the technical and infrastructure problems can be solved.

Fourth, in addition to PRODEEM, the partnership between the National Renewable Energy Laboratory (NREL) in the United States of America and the Eletrobras Research Centre (CEPEL) is noteworthy. This partnership installed some 1200 PV systems donated by the US Government in various States in the mid-1990s. However, according to Ribeiro [9.35], a sampling of 180 systems found that 35% were inoperative, mainly due to the lack of technical support. This confirmed that it is critical to develop a PV support infrastructure to service and maintain PV systems in those regions where they are provided.

Fifth, in December 1999, the Brazilian Government launched its 'Light in Rural Areas' Programme, designed to provide electrification for one million homes in rural areas by 2002. This programme finances up to 75% of the total costs of proposed rural electrification projects, with an interest rate of 5% per year. In 2000, the overall amount assigned to this programme reached some 2 billion Brazilian reals, connecting about 106 800 consumers to the grid. Of this total, around 62 800 are in northeastern Brazil [9.37]. However, this electrification programme has focused mainly on extending the grid or installing groups of diesel powered generators [9.35], instead of considering the use of local renewable energy alternatives.

Finally, Law 10 438 (which also created PROINFA, discussed earlier in this chapter) directs the National Electricity Regulatory Agency (ANEEL) to establish targets for increasing access to electricity service in remote communities. Local power utilities are supposed to then meet these targets without any additional fee to the new customers. In addition, to promote universal electrification, ANEEL may grant concessions, through a bidding process, for provision of public electricity service in areas already under concession where concession contracts do not have an exclusivity clause [9.33]. Before this law was enacted, these customers had the right to be served, as the contracts of Brazil's power utilities prohibit any discriminatory practice against low income consumers; however, they had to, first, demand to be served, and, second, pay for any additional cost incurred in the electricity service expansion. Therefore, the new obligation to serve remote areas, which removed the historical disincentive to expand electricity service access, could force utilities to develop local technological options and exploit decentralized renewable energy sources.

9.2.2.1. *Policy option: Stimulate PV use in remote, off-grid areas*

In combination with some of the policies discussed above, it would be helpful to develop a private sector PV supply infrastructure by supporting solar energy entrepreneurs as well as providing attractive microfinancing and subsidies to households that are not yet connected to the power grid.[12] This policy also could include low interest loans and technical support for rural PV dealers who market, install and service PV systems. Subsidies could be reduced over time as PV technology improves and its costs drop.

This type of integrated strategy that addresses both supply and demand has proven successful in PV programmes in other countries, such as India and Japan. Japan, which led the world with around 50 000 household PV systems installed as of 2000, used carefully designed incentives and economies of scale to drive down the cost of PV systems [9.31]. Furthermore, the focus of a revamped PV programme in Brazil could be on providing electricity for both domestic services (lighting, communications, entertainment, etc.) and productive purposes (home businesses and cottage industries) so as to foster both social and local development in poorer regions.

Considering that electric utilities are now obligated to serve isolated areas of the country, another interesting policy option would be a mechanism similar to the RPS previously discussed. In this case, a 'rural electrification portfolio standard' involving renewable energy quotas in rural electrification programmes could be adopted. Utilities could utilize a bidding process to select the least cost providers of renewable energy systems. As part of this policy, utilities could be allowed to trade renewable energy obligations. In other words, all retail electricity suppliers could be required to serve a fraction of the total rural market (or a fraction of the low income groups not served by the electricity grid) with new renewable energy sources, with suppliers allowed to sell these obligations to one another [9.38].

The progressive replacement of diesel generators with PV and PV–diesel hybrid systems in northern Brazil is applicable to diesel generators supplying stand-alone systems run by utilities or private actors. For instance, a programme for converting all diesel generators up to 100 kW run by utilities (86 stand-alone systems) to hybrid systems with a solar fraction of 75% involves a cost of about US $40 million, allows fuel savings of 8.5 million L per year and results in an installed PV capacity of 7.1 MW [9.26].

9.2.2.2. *Policy option: Stimulate the adoption of solar water heaters*

Almost 30 million Brazilian households use point-of-use electric resistance water heaters. These high powered devices greatly contribute to peak electricity demand, especially in the South and Southeast regions [9.39]. Use of solar water heating is a feasible alternative to these undesirable electric water heaters in some situations. There are now approximately 100 manufacturers of solar water heaters in Brazil, and sales grew rapidly to about 600 000 m^2 in 2001, due mainly to the electricity crisis [9.33].

The Government has promoted the use of solar water heaters by implementing sales tax exemptions and providing low interest financing through banks such as the Caixa Económica Federal and Banco do Brasil. A few electric utilities in Brazil (e.g. CEMIG, CPFL and Light-Rio) have undertaken initiatives to develop and promote low cost solar water heaters. Also, the Federal Government has begun to test and certify solar water heaters. However, the widespread dissemination of solar water heaters requires further cost reductions, attractive financing for consumers and incentives such as cost buydowns until economies of scale and learning effects drive down their cost.

It would be logical for distribution utilities to offer financial incentives and/or low interest loans to expand the adoption of solar water heaters, given the peak load benefits from replacing point-of-use electric water heaters. The utility in metropolitan Rio de Janeiro, Light-Rio, announced in January 2004 that it will give away 1000 solar water heaters to low income households with electric resistance shower water heaters. However, considering that consumers will benefit from lower electricity use and lower electricity bills, utilities should be able to share the cost of solar water heaters with end users rather than paying the full cost.

9.3. ETHANOL FUEL, OTHER BIOENERGY SOURCES AND HYDROGEN

As discussed in Chapters 2, 4 and 8, production of ethanol fuel from sugar cane began in 1975 as a way to reduce oil imports and provide an additional market for Brazil's sugar producers. The Brazilian Alcohol Programme, PROALCOOL, stimulated ethanol production and demand through a combination of policies including (a) low interest

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[12] This policy proposal emphasizes PV systems and markets, but it could support other off-grid renewable energy technologies such as small scale wind and bioenergy systems, where appropriate.

loans for the construction of ethanol distilleries, (b) guaranteed purchase of ethanol by the State owned petroleum company at a price considered adequate to provide a reasonable profit to ethanol producers, (c) pricing of neat ethanol to be competitive with, if not slightly more favourable than, the gasoline–ethanol blend and (d) sales tax incentives provided during the 1980s to stimulate the purchase of neat ethanol vehicles. Price regulation ended in the late 1990s with relatively positive results.

During the first phase of PROALCOOL (1975–1979), the main target was to produce anhydrous ethanol for blending with gasoline, using existing distilleries and annexes to existing sugar mills. Ethanol producers received heavily subsidized loans to finance their capital investments [9.40]. The goal of achieving 20% ethanol in the gasoline blend by 1980 was nearly reached.

The Government decided to greatly expand ethanol fuel use in the wake of the second oil price shock in 1979. R&D at a Government supported laboratory proved that ethanol fuelled automobiles were feasible.[13] The Government and automobile manufacturers signed an agreement that led to large scale production of neat ethanol automobiles starting in 1981. With strong Government support, a large number of autonomous distilleries were built and large scale production of hydrated ethanol began. Annual production of ethanol fuel quadrupled during the second phase of the programme (1979–1989).

Between 1983 and 1989, the large majority of automobiles and light trucks sold in Brazil consumed neat ethanol. Demand for these vehicles was created by lowering the sales tax on ethanol fuelled vehicles compared with the tax on vehicles that operated on the gasoline–ethanol blend and by pricing neat ethanol so that it cost drivers slightly less to drive ethanol fuelled vehicles. The Government essentially subsidized ethanol fuel by recycling a portion of the substantial tax it collected on gasoline [9.41].

The Brazilian Government cut the price it paid to ethanol producers throughout the 1980s, particularly after the world oil price collapse in 1986. In addition, the price of sugar spiked in the international market. Consequently, fuel producers stopped increasing ethanol production by the late 1980s. This, in turn, resulted in ethanol shortages and the need to import ethanol and methanol starting in 1990. Economic incentives for ethanol vehicles were then cut, leading to relatively low levels of production of automobiles operating on neat ethanol during most of the 1990s. Alcohol fuel imports were no longer needed after 1996.

Following a period of political and economic turmoil in the early 1990s, the Government emphasized reducing inflation and cutting Government expenditures. The Government continued to reduce the price paid to ethanol producers, which put pressure on them to cut costs and improve productivity. The price paid to ethanol producers as of 1996–1997 was still about twice the price of gasoline, in spite of reductions in the cost of ethanol production of nearly 67% during the period from 1980 to 1996. Moreover, ethanol production started to increase again in 1996, mainly owing to growing fuel demand, continuing cost reductions and favourable market conditions.

In addition to these policies, ethanol producers in São Paulo State established a high calibre R&D and technology transfer centre. The centre has been very effective in improving sugar cane and ethanol yields and reducing production costs. Sugar cane yields and sucrose levels increased with the introduction of improved sugar cane varieties and better field management. Ethanol yields increased owing to better process control, development of continuous fermentation techniques, improved yeast cultures and distillation equipment, and other advances. Also, a benchmark programme in São Paulo State proved to be very effective for technology transfer and rapid diffusion of these agricultural and processing improvements [9.42].

In the late 1990s, the Federal Government deregulated the price of ethanol, allowing it to be determined by the market. This led to a further decline in the retail price of ethanol, which reached US $0.39/L (US $0.46/L of gasoline equivalent) as of October 1999 [9.43]. In addition, this reinforced the pricing pattern whereby neat ethanol fuel was more attractive than the gasoline–ethanol blend (see Fig. 9.1) [9.16].[14] This in turn led to renewed interest in neat ethanol vehicles on the part of manufacturers and consumers. Sales of ethanol vehicles expanded from 1224 vehicles in 1998 to 56 068 vehicles in 2002. The latter value

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[13] See Chapter 4 for more details about ethanol production and the development of neat ethanol vehicles.

[14] The favourable price for neat ethanol is due in large part to the tax structure in Brazil, which taxes gasoline more than ethanol.

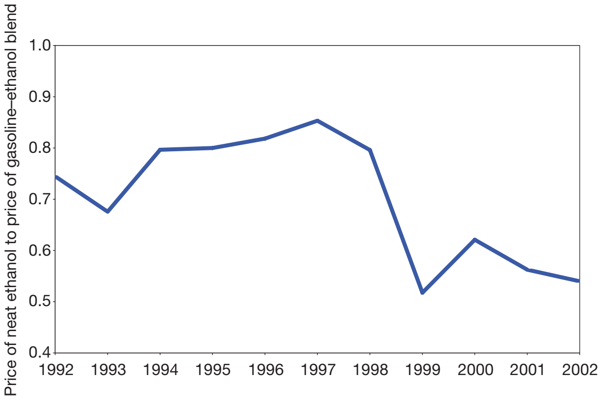

FIG. 9.1. Relative end user prices (ratio of price of neat ethanol to price of gasoline–ethanol blend) [9.1, 9.44].
***Note:** Prices quoted are from São Paulo; relative price under volumetric terms. Average prices of 1994 are based on the July–December period.*

corresponded to 4.3% of total light vehicle sales in 2002 [9.45].

Currently, PROALCOOL faces some challenges despite its long existence and significant macroeconomic, social and environmental benefits. Sales of 'flex-fuel' vehicles — vehicles designed to operate on either gasoline (i.e. the gasoline–ethanol blend) or neat ethanol fuel — are currently increasing, and some Brazilian manufacturers have announced their intention to make most of their new vehicles flex-fuel in the near term [9.14, 9.46]. The share of flex-fuel automobiles in light vehicle sales reached 17% in 2004 [9.47], and this proportion is expected to rise to 70% by 2010 [9.47–9.49].

Also, PROALCOOL's economic performance could be progressively improved, if possible, so that it is competitive in times of low as well as high oil prices. This is especially important now that ethanol fuel prices have been deregulated. Another challenge is to cut pollutant emissions by the sugar cane–ethanol industries by shifting to mechanical harvesting, and to do so without greatly reducing the number of workers employed in sugar cane and ethanol production (e.g. by increasing ethanol production and demand as mechanical harvesting is gradually phased in).

9.3.1. Policy option: Expand production, use and export of ethanol fuel

To prevent the ethanol industry and programme from declining, the Government could adopt a number of policies to increase ethanol supply and demand. It is critical to address both areas so that there is not a significant imbalance between the two.

First, low interest loans could be offered to stimulate the construction of new ethanol distilleries and the expansion of existing distilleries, if and when ethanol demand grows. This could be particularly helpful since some distilleries are now over 20 years old and their capital equipment is ageing. Investments could be made to expand output at the same time that older equipment is replaced. The BNDES is the logical source for these loans, but other sources could also be considered, such as private banks. In fact, the BNDES launched a financing programme for investments in bagasse cogeneration facilities in sugar mills in 2001. The interest rate is attractive, and the loan term is up to 12 years [9.33].

Second, the Government could create a 'strategic ethanol reserve' of, say, 5–10 billion L [9.15]. The reserve would be tapped in case of a shortfall between supply and demand. The national ethanol programme suffered a setback in 1989–1990 when demand exceeded supply and shortages occurred. Purchase of ethanol for the reserve could be paid for through a small tax increase on gasoline, or through a tax increase on both gasoline and ethanol fuel. For example, an additional gasoline tax of US $0.005/L would provide enough revenue to purchase about 1 billion L of ethanol for the reserve each year. Actually, as discussed in Chapter 8, at the end of 2003 the Federal Government announced an allocation of around US $166 million to cover infrastructure and financial costs related to the storage of fuel alcohol in the sugar cane processing industry. However, the implementation of a suitable ethanol strategic reserve is still needed, and is one of the main conditions for expanding ethanol fuel exports from Brazil [9.47], as is discussed below.

Barriers to dissemination of flex-fuel vehicles in Brazil are a lack of knowledge about the new technology, high transaction and information costs, lock-in to traditional technologies and perceived high investment risks by the vehicle producers. However, at this point, vehicle producers are embracing the flex-fuel technology, raising expectations for increased use of ethanol fuel in Brazil. Because flex-fuel vehicles are designed to operate on either the gasoline–ethanol blend or neat ethanol fuel, they are attractive to consumers in Brazil, given the fluctuating prices of gasoline and ethanol (see Fig. 9.1).

Production and sales of flex-fuel vehicles in Brazil began in early 2003. Widespread adoption of flex-fuel vehicles could lead to supply–demand imbalances and problems for ethanol suppliers if, for example, gasoline prices decline significantly for an extended period. Problems might arise for refiners too, since Brazil already exports gasoline, and the widespread dissemination of flex-fuel automobiles could increase gasoline surpluses at times when ethanol presents a substantial cost advantage compared with the gasoline–ethanol blend. Therefore, care should be taken in promoting and developing a large fleet of flex-fuel vehicles. In particular, gasoline taxes and retail prices should be adjusted periodically so as not to 'strand' a large amount of ethanol production and to optimize automotive fuel production in Brazil.

Fourth, ethanol could be blended with diesel fuel. Tests show that the use of a blend of 3% ethanol and 97% diesel not only can be adopted without any engine problems, but in fact yields a substantial reduction in particulate emissions [9.43]. The ethanol blend can be increased above this level (up to 12%) with the use of a fuel additive to enhance the quality of the blend. This strategy has been adopted in Sweden [9.43]. Blending ethanol with diesel fuel would be particularly advantageous in Brazil, since diesel demand (along with demand for liquefied petroleum gas) forces Brazil to import oil 'on the margin'. However, R&D is still needed to address the reduction of the heating value (33%), viscosity (lubricity), flash point, chemical and thermal stability, and Cetane number of the blend.[15]

Adopting these four main policies in combination with the vehicle fuel efficiency or carbon dioxide (CO_2) standards discussed in Section 9.5.1 could lead to a 24% increase in ethanol use by 2010 [9.15].

Finally, a fifth policy option could be the promotion of ethanol fuel exports (see also Chapter 8). In fact, between 2001 and 2002, Brazil's ethanol exports almost doubled (from 342 125 to 632 819 m^3), reaching 25% of the international market for this commodity [9.50].[16] The exported ethanol fuel went mainly to large distributors on the West Coast of the United States of America, such as Chevron, Shell, BP and ConocoPhillips [9.51]. Given the recent US regulation concerning blending oxygenates in gasoline and the progressive ban on adding methyl tertiary-butyl ether (MTBE) to gasoline, the use of ethanol as an automotive fuel is expected to increase in the United States of America. This opens up opportunities for Brazil's ethanol production, provided that the country's less costly ethanol production can overcome the current commercial barriers and reach the US market.[17] In the case of the European Union, recent forecasts show an impressive market of around 14 billion L/year by 2010, provided that ethanol is blended with gasoline (5.75% by volume) [9.52]. Finally, another important market could be Southeast Asia, especially Japan. This country is now studying the importation of ethanol automotive fuel from Brazil, which could reach 5.5 billion L/year if blended with gasoline at 10% ethanol in the blend.

The application of this export oriented strategy would necessitate expanding ethanol production capacity in Brazil by about 5 billion L/year, meaning around 60 new autonomous distilleries and a total investment of US $2.4 billion [9.53]. However, this strategy can only be implemented if the additional ethanol supply is reliable and long term contracts are negotiated. Given that sugar cane yields, and hence ethanol production, vary from year to year, an ethanol storage system would be needed in conjunction with ethanol exportation under long term contracts. This is the reason why some specialists argue that Petrobras should participate in this programme, both through its fuel storage system and through its fuel trade divisions [9.53]. For instance, Petrobras oil pipelines already transport ethanol from the major areas of sugar cane production (São Paulo State) to possible locations of ethanol shipping (Rio de Janeiro and Santos harbours), and Petrobras exports petroleum or petrol products to several markets, including Africa, Southeast Asia and the United States of America.

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[15] The E-10 blend reduces the Cetane number of the blend by 7.1 points; also, this blend does not match the lubricity specifications of automotive diesel.

[16] In 2004, ethanol exports reached 2.5 billion L [9.47].

[17] As of 2003, Brazil's anhydrous ethanol production cost about US $0.16/L (or US $0.63/gallon) on average. In 2003, the average world price of gasoline was about US $0.90/gallon. Moreover, the anhydrous ethanol produced from maize in the United States of America costs about US $1.05/gallon [9.52]. This means that a Brazilian strategy for exporting ethanol to the United States of America is inhibited by an import tax of US $0.54/gallon plus the ad valorem tax of 2.5% [9.52].

9.3.2. Policy option: Promote more efficient CHP systems using bagasse and other sugar cane products

As noted in Chapter 4, there is considerable potential to generate excess electricity using more efficient power generation technologies for bagasse fired CHP systems, such as higher pressure boilers with condensation and extraction cycle steam turbines, and gasification and combined cycle technologies [9.43].

The PROINFA law is designed in part to promote more efficient bagasse CHP systems. Also, adopting renewable energy portfolio standards could stimulate higher efficiency biomass based CHP systems in the ethanol and possibly other industries. In addition, there are other policies that could facilitate higher efficiency bagasse cogeneration and encourage the use of sugar cane leaves and tops for energy production, where appropriate. Some of these policies are similar to those that could be used to stimulate natural gas based CHP systems in Brazil:

- After the first phase of the PROINFA programme terminates (i.e. after the maximum capacity or deadline is reached), utilities could be required to purchase excess power from sugar mills at avoided generation, transmission and distribution costs via long term contracts.
- Utilities could be required to interconnect CHP systems to the power grid without excessive delay or unreasonable technical requirements.
- The Government could continue to develop and demonstrate more efficient technologies, such as bagasse gasification and combined cycle power generation in sugar mills.
- The Government could provide long term loans at attractive interest rates to sugar mills that adopt more efficient CHP technologies.
- The Government could finance and support the adoption of mechanical harvesting systems in a gradual manner.

Mechanical harvesting of sugar cane would enable recovery and use of leaves and tops for energy production, but it would reduce the number of workers employed in sugar cane production. Recovery of leaves and tops could take place where mechanical harvesting is already employed, or where air pollution from burning sugar cane fields is a serious problem and thus mechanical harvesting is desired for air quality reasons. As long as the shift to mechanical harvesting occurs gradually and at the same time that sugar cane and ethanol production are expanding, many of the displaced workers should be able to find new jobs within the industry.

One study estimates that implementing these policies could lead to over 6 GW of bagasse CHP capacity by 2010 [9.15].

9.3.3. Policy option: Develop and stimulate adoption of new bioenergy sources

The use of vegetable oils as an energy source started in 1975, just after the first oil crisis and in parallel with PROALCOOL. The PROÓLEO programme, under the coordination of the Ministry of Agriculture, was aimed at producing surplus vegetable oils that could compete with and substitute for ‘mineral diesel oil’ [9.54].[18] The short term goal was to replace 30% of the total diesel supply with vegetable oil, and the long term goal was total substitution [9.55]. PROÓLEO sponsored R&D in the fields of bioenergy production and conversion, and tests of biodiesel use in buses, trucks and tractors. However, the PROÓLEO programme did not succeed in stimulating industrial scale biodiesel production or use, in part because of the world oil price collapse in 1986.

There has been renewed interest in the use of vegetable oils as an energy source in recent years. R&D and testing of fuel production, conversion and utilization technologies has continued, and the environmental benefits of using biodiesel have been demonstrated [9.55].

In 2002, a new biofuel programme was created, aimed at developing an innovation chain under the coordination of the Brazilian Government. In December 2003, the Government announced the details regarding the biodiesel programme, although this effort is still waiting for funding. The programme will support the development and utilization of the ethanol route to biodiesel, as well as the production and use of vegetable oils. Law 11 097 of January 2005 also identified as a national priority the diversification of vegetable oil sources to produce biodiesel according to the agricultural area of the country (e.g. palm in the North; castor beans and palm in the Northeast; soy, cotton and sunflower in the South and Southeast). In accordance with this

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[18] The term ‘mineral diesel oil’ is used to distinguish it from biodiesel.

law, the programme set mandatory targets of 2% biodiesel added to mineral diesel by 2008, and 5% by 2013. This blend will be produced either in refineries or in fuel distribution stations. Law 11 116 of May 2005 also set fiscal incentives for biodiesel production, according to the type of vegetable oil used to produce biodiesel. Finally, the BNDES also established a financing programme to cover up to 80% of upfront costs of expanding biodiesel production in both the agricultural and industrial stages of production.

Although the diversification of vegetable oil sources to produce biodiesel has several advantages, such as job creation, regional development and income creation in the poorest areas of the country, it poses technical problems since biodiesel blends from different sources do not have the same physicochemical properties. In particular, chemical additives used to increase the stability of biodiesel derived from a particular source are not suitable for biodiesel from other sources. This poses logistical problems and requires R&D to develop additives in the short term, in order to guarantee the feasibility of the B5 (5% biodiesel) blend in 2013.[19]

Therefore, the following policies could be adopted to promote the production and use of vegetable oils and biodiesel fuel in Brazil:

- Continue to develop the ethanol route to biodiesel, which is of special interest in Brazil given its enormous ethanol infrastructure and know-how.
- Continue R&D on vegetable oil productivity, fostering multiple fuel sources and avoiding high dependence on a single biodiesel vegetable oil source, such as soy oil. In fact, soy production seems to be the main agricultural activity that benefits from biodiesel promotion in Brazil today, although it is not always the best input in terms of ester productivity or dispersed benefits for the entire country [9.55]. R&D should proceed on a variety of potential fuel oil sources, including palm oil, castor oil, sunflower oil and peanut oil.
- Similar to what has occurred in European countries [9.56], promote voluntary agreements with diesel engine manufacturers to allow the use of biodiesel and the maintenance of the modified engines.
- Develop and promote markets for biodiesel as well as the by-products of vegetable oil and biodiesel production.
- Adopt time bound (or quantity bound) fiscal incentives to establish a viable biodiesel industry. These incentives could be paid for through increased taxes on petroleum supplies [9.55]. Taxes also could be tied to the sulphur content of oil products, which favours biodiesel production.
- Stimulate vegetable oil production and biodiesel use for electricity production in remote regions of the country. Financial incentives could be provided based on the social benefits of this electricity supply option. In addition, rural energy cooperatives could be set up to produce vegetable oils and/or make use of biodiesel in rural communities.
- Engage in R&D on chemical additives added to increase stability for different blends of diesel and biodiesel (from several sources).

9.3.4. Policy option: Expand R&D and capacity building for hydrogen and fuel cell technology

There is tremendous interest worldwide in hydrogen as a future energy carrier and in fuel cells as a major conversion technology. In Brazil, natural gas still is the lowest cost source of hydrogen. In addition, because of the predominance of hydropower in the Brazilian power generation mix (see Chapter 2), which results in surplus power at very low costs during the rainy season of the year (from November to March), hydrogen produced from electrolysis using excess hydropower might be a viable source of hydrogen in the future.

Nevertheless, several barriers inhibit the development of hydrogen as an energy carrier and of fuel cells in Brazil. First, hydrogen and fuel cell costs are still not competitive with the costs of conventional technologies. Second, fuel cells are still under development. Only the phosphoric acid (PAFC) type, which is less efficient and more costly than other fuel cell types, can be considered to be available on the market. Moreover, hydrogen storage and transport/distribution is costly and requires a new network, with high upfront costs.

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[19] While stability is the critical property, because it affects the blend quality in a way that is difficult to control, other properties such as viscosity and Cetane number also vary according to the source of the biodiesel. For instance, mamona derived biodiesel has a kinematics viscosity around four times that of mineral diesel and a Cetane number of 39 (the most suitable range for diesel is 45–60).

Considering that hydrogen and fuel cells could be important technologies in the future, some policy options can be proposed, mainly focusing on R&D and product development:

- Provide public funding for fuel cell R&D and technological development, including funding for demonstration units.
- Use Government procurement of early fuel cell prototypes designed either for the building sector or for transport applications in order to help establish initial markets for fuel cells in Brazil.
- Define technical standards and provide certification of fuel cells once they reach the commercialization stage.
- Promote joint ventures and licensing so that fuel cell developments around the world are introduced in Brazil in a timely manner.

As of 2003, Brazil had an installed capacity of 0.8 MW in PAFC demonstration units. Brazilian specialists are considering the targets of 50 MW of fuel cells of all types by 2012, and of 250 MW by 2020 [9.57, 9.58].

9.4. ELECTRICITY CONSERVATION

As discussed in Chapter 4, in 1985 the Government of Brazil established its National Electricity Conservation Programme, known as PROCEL. PROCEL is based at Eletrobras, Brazil's national utility holding and coordinating company. PROCEL promotes end use electricity conservation as well as transmission and distribution system loss reduction. PROCEL operates by funding or co-funding a wide range of energy efficiency projects carried out by distribution utilities, State agencies, private companies, industry associations, municipalities, universities and research institutes.

These projects pertain to research, development and demonstration (RD&D); education and training; testing, labelling and standards; marketing and promotion; private sector support (e.g. ESCO support); utility demand-side management programmes; and direct implementation of efficiency measures. PROCEL also helps utilities obtain low interest loans for major energy efficiency implementation projects from the Reserva Global de Reversão (RGR) loan fund within the electricity sector. The programme's annual budget, including grants and low interest loans, but excluding staff salaries and overhead, reached about US $50 million in 1998. However, funding was cut in 1999–2000 following a change in programme management. As of 2002, PROCEL's budget was around US $15 million [9.59].

Some of the key initiatives PROCEL has undertaken are listed in Table 9.1. Many of these initiatives, such as testing and labelling of appliances, motors and lamps, were conducted in collaboration with the manufacturers of these products. Others were conducted through co-funded projects with distribution utilities.

PROCEL's cumulative efforts reduced electricity use and supply-side losses in Brazil by about 4.3 TW·h/year as of 1997 and 10.4 TW·h/year as of 2000. The latter value is equivalent to about 3% of the electricity consumption that year. Electricity savings resulted mainly from (a) increasing the energy efficiency of refrigerators and freezers through testing, labelling and voluntary agreements with manufacturers; (b) increasing the efficiency of motors through testing, labelling and R&D projects; (c) increasing the market for energy efficient lighting technologies such as high pressure sodium and compact fluorescent lamps (CFLs); (d) reducing electricity waste in industry through audits, workshops and information dissemination; and (e) installing meters in previously unmetered households [9.60].

Table 9.2 shows the avoided generating capacity due to PROCEL's efforts during the 1995–1999 period. For instance, it is estimated that the electricity savings due to activities in 1998 enabled utilities in Brazil to avoid constructing about 440 MW of new generating capacity. For activities during the entire 1995–2000 period, the estimated avoided capacity is 2370 MW. Assuming an average avoided cost of US $1500/kW, utilities in Brazil avoided about US $3.6 billion in investments in new power plants and associated transmission and distribution infrastructure.[20] For comparison, PROCEL and its utility partners spent about US $300 million on energy efficiency and power supply improvement projects between 1986 and 1998. Thus, from the utility sector perspective, PROCEL has achieved an overall benefit–cost ratio of around 12:1 [9.60].

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[20] This average cost assumes that a mix of hydropower capacity and gas fired turbines would be avoided. It includes the avoided investment in transmission and distribution, as well as generation.

TABLE 9.1. MAJOR ACTIONS TO IMPROVE EQUIPMENT EFFICIENCY IN BRAZIL [9.60]

Refrigerators and freezers	Lighting	Motors and motor systems
● National efficiency testing and labelling programme ● Voluntary energy efficiency targets specifying the maximum electricity use of different types of products as a function of volume ● Recognition and awards for top rated models ● Pilot rebate programmes for top rated models ● Revisions of the test procedure and labelling programme	● Replacement of over one million inefficient incandescent or 'self-ballasted' type street lights with high pressure sodium lamps or mercury vapour lamps ● Demonstrations, utility incentives and free distribution, labelling and education to promote use of compact fluorescent lamps ● RD & D programmes, audits and educational activities to promote use of high efficiency fluorescent tube lamps, electronic ballasts and specular reflectors in fluorescent lighting ● Minimum efficiency standards for electromagnetic ballasts	● Efficiency testing and labelling programme for all three-phase induction motors ● Recognition and awards for top rated motors ● Development and advocacy of minimum efficiency standards

TABLE 9.2. RESULTS OF PROCEL ACTIVITIES [9.61]

Year	Energy savings (GW·h/year)	Avoided capacity* (MW)
1995	572	135
1996	1970	430
1997	1758	415
1998	1909	440
1999	1862	420

* Corresponds to a hydropower plant with a capacity factor of 56% and includes losses of transmission and distribution of 15%.

PROCEL has had other positive impacts besides these direct economic savings. PROCEL contributed to the development of a number of new technologies now manufactured in Brazil, including demand limiters, lighting controls, electronic ballasts for fluorescent lamps and solar water heaters. It supported the development of an ESCO industry in Brazil and has trained large numbers of energy managers and other professionals. PROCEL also has reduced the risk of power shortages, although not enough to prevent the shortages that occurred in 2001.

At the urging of PROCEL and others, in 1998 ANEEL adopted a requirement stating that distribution utilities must spend at least 1% of their revenues (representing about US $160 million per year) on energy efficiency — both for distribution system loss reduction and for end use efficiency projects. At least one quarter of this 1% must be spent on end use efficiency. In the initial phase (1998–1999), utilities allocated most of these funds to distribution system loss reduction and street lighting efficiency improvements, areas in which the utilities realize clear financial benefits [9.62]. PROCEL has been assisting utilities with the preparation of energy efficiency plans, monitoring implementation and evaluating results on behalf of ANEEL.

This policy was modified by the Brazilian Congress in 2000, with a portion of the 1% allocated to R&D [9.62]. The revised policy still requires distribution utilities to spend at least 0.25% of their revenues on end use energy efficiency programmes. However, most distribution utilities have done relatively little to promote electricity conservation except in the area of street lighting [9.63]. Moreover, electric utilities became even less interested in promoting end use energy conservation after the deep reduction in electricity use prompted by the 2001–2002 electricity crisis.

Promotion and distribution of CFLs was one area where utilities expanded their efforts in 2001, contributing to rapid growth in CFL sales. It is estimated that around 60 million CFLs were sold in Brazil in 2001 and 50 million were sold in 2002, compared with only about 14 million in 2000. Likewise, sales of incandescent lamps in Brazil decreased from around 450 million in 2000 to 250–300 million in 2001 and 2002 [9.64]. It appears that Brazil now has one of the highest ratios of CFL to incandescent lamp sales in the world.

Energy efficiency and conservation were widely practised during the electricity rationing period that began in mid-2001, thereby enabling nearly all households in Brazil to comply with the requirement of a 20% reduction in electricity use. Surveys show that, in addition to purchasing more efficient lamps and appliances (i.e. those with the PROCEL seal), large numbers of consumers also reduced their usage of discretionary devices such as air conditioners, freezers and microwave ovens. Also, many consumers learned to unplug televisions and other electronic products that consume power in standby mode when not in use [9.65]. PROCEL, local utilities and other partners, such as appliance manufacturers and vendors, assisted in public education to support this overall effort.[21]

To increase its funding base and range of activities, PROCEL applied for and received a US $43 million energy efficiency loan from the World Bank and a complementary US $15 million grant from the Global Environment Facility (GEF) in 2000. These funds were to be matched by an equal or greater amount of Brazilian funding. The loan was meant to be used for large scale implementation of proven energy efficiency measures. The grant supports pilot projects featuring new technologies or delivery mechanisms as well as core activities and capacity building. But PROCEL's activities were curtailed during the 1999–2001 period, when leadership of the programme changed, staff size was reduced and the budget provided by Eletrobras was cut. This was particularly unfortunate given that Brazil faced a severe power shortage in 2001. In addition, it was very difficult for PROCEL to utilize either the World Bank loan or the GEF grant. Because of these problems, the World Bank loan to PROCEL was cancelled, although the GEF grant was maintained.

In 2000, PROCEL launched the so-called RELUZ programme aimed at converting 8 million streetlights to higher efficiency equipment by the end of 2002. It also aimed to make 1 million new streetlights energy efficient. These investments were financed through low interest loans from the RGR fund to municipalities. In addition, another regulation, adopted in January 2000, required Federal agencies to reduce their electricity use in buildings by 20% over a two-year period. PROCEL was given responsibility for assisting Federal agencies and overseeing this regulation. Considering that there were over 30 000 Federal buildings at the time, this was a relatively ambitious policy. Implementation of this policy proceeded slowly prior to the electricity crisis in 2001. However, Federal agencies (along with the private sector) dramatically reduced their electricity use in response to the crisis.

Appliance efficiency standards have been a very effective policy for saving energy and saving consumers and businesses money in Japan, North America and elsewhere [9.66]. In September 2001, the Brazilian Congress adopted legislation that authorizes and directs the Federal Government to establish mandatory minimum efficiency standards for major types of energy using products. The standards are based on an analysis of technical and economic feasibility, with assistance and input from PROCEL. The first set of standards, pertaining to electric motors, was issued in late 2002. This law also directs the Federal Government to develop mechanisms to improve the energy efficiency of new buildings constructed in Brazil.

In terms of electricity conservation potential, it is worth noting that Brazil's current marginal cost of supplying electricity from different power generation technologies ranges from US $20/MW·h for some hydropower plants to US $40/MW·h or more for natural gas fired thermal power plants. However, a recent survey of electricity conservation measures implemented by Brazilian distribution utilities shows an average of some US $20–30/MW·h saved for many projects [9.67]. This shows that saving electricity is, on average, less costly than supplying it, with a wide range of benefits, from reduced chances of power shortages to providing a competitive edge for Brazilian industries and products in global markets to the fact that conserving electricity has far more favourable environmental and social impacts than supplying it. Some recent studies have shown economic electricity conservation potential in the range of 20–30%, depending on the sector considered [9.13, 9.68].

9.4.1. Policy option: Establish a new national energy efficiency agency

From the discussion above, it is obvious that the PROCEL programme, although relatively successful, has experienced problems over the years. This is due in large part to the fact that the programme (based in Eletrobras) has been subject

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[21] For more details about the electricity rationing, see Chapter 8.

to political manoeuvres and to the hiring and contracting rules of the public sector. A similar situation exists with respect to the CONPET fuels conservation programme housed in Petrobras (see Section 9.5). In addition, requiring distribution utilities to invest a minimum amount of their revenues in energy efficiency programmes has not been a very effective policy [9.67, 9.69].

A new approach would be to replace the PROCEL and CONPET programmes with a new national energy conservation agency. The agency could be responsible for promoting conservation of both electricity and fuel, thereby taking a holistic approach and assisting consumers and businesses in saving all forms of energy. The agency could be funded through a small surcharge on major forms of energy use (electricity and fossil fuels), replacing the current surcharge on electricity for distribution utility programmes and providing funding stability. The agency could be established as a non-profit foundation, providing flexibility and agility in hiring and contracting. Oversight could be provided by a board of directors including representatives from both the public and private sectors.

If a new energy conservation agency is established, it should have a significant budget, of the order of US $50–100 million per year. This will enable it to engage in a wide range of activities, including R&D, demonstrations, grants to facilitate project implementation, training and public education. For example, the agency could be funded through a 0.25% surcharge on electricity and fossil fuel sales in Brazil (exclusive of other taxes). A surcharge at this level would generate approximately US $100 million annually.

A new energy conservation agency could have branches throughout the country as well as a national office. It could engage in cooperative projects with electric and gas utilities, universities, research institutes, industry associations, consumer organizations and the like, copying the best features of previous conservation programmes. Effective programmes currently operated by PROCEL and CONPET could be transferred to the new agency. However, the agency could be set up strictly for the purpose of promoting energy savings and could be evaluated based on its energy savings results and the cost effectiveness of its activities.

There are precedents for establishing an independent energy conservation agency in other countries as well as precedents for adopting small surcharges on energy prices to fund the agency. For example, independent energy conservation agencies have been effective in a number of countries, including France, Japan, the Republic of Korea and New Zealand. In the United States of America, many states have adopted electricity bill surcharges of 1–2% to fund energy efficiency programmes [9.70]. In some states, the programmes are implemented by an independent agency; in other states, by utilities.

9.4.2. Policy option: Incorporate demand-side bidding and energy planning

As mentioned above, the new institutional model for the electricity sector developed by the Central Government in 2003 emphasizes resource planning and bidding to identify the lowest cost new sources of electricity generation [9.71]. However, the new model does not include bidding for ‘saved energy’ on the demand side. In fact, the model virtually ignores the potential for electricity conservation to help meet future energy service needs in Brazil. This shortcoming could be corrected by incorporating electricity conservation strategies into the model, including conducting demand-side bidding.

Demand-side bidding involves bidding for energy efficiency projects that are proposed and implemented by commercial or industrial customers, in some cases through an ESCO. Demand-side bidding could be carried out by a central agency such as the MME, ANEEL or PROCEL, or by a new agency set up to promote energy efficiency in Brazil (see Section 9.4.1). This organization could issue requests for energy savings projects, evaluate proposals and select those for possible implementation.

Proposals should include the measures that would be implemented, location, estimated project cost, estimated energy and peak demand savings, estimated measure lifetime and a requested incentive level. Proposals would be evaluated and those deemed reasonable would be selected for possible implementation, with projects ranked based on requested incentive level. Those with the lowest requested incentive per unit of energy savings would be at the top of the list, thereby encouraging bidders to reduce the requested incentive.

Once efficiency projects are selected for implementation, a central energy agency (e.g. PROCEL or a new energy efficiency agency) could pay the incentives, monitor implementation and verify energy savings. The total amount of incentives available during each round of bidding could be announced in advance, and projects selected for implementation could be given a time limit to complete installation. The central agency could inspect the work and confirm the estimated energy savings before paying the incentives. Funding for these incentives could be provided either by the utilities receiving the energy savings or through a small fee on all electricity sales.

Demand-side bidding could be an important mechanism for promoting more efficient energy use under the new institutional model for the electricity sector. However, it should not be the only mechanism for promoting efficiency. Demand-side bidding is not likely to have an impact in the residential sector, for example. Therefore, PROCEL as well as individual utilities (or a new energy efficiency agency) should maintain energy efficiency programmes focused on residential consumers, RD&D of new technologies, product labelling and standards, and consumer education in all sectors.

The energy planning called for in the new sector model also could incorporate electricity conservation as a potential ‘energy resource’. Energy planners could be directed to evaluate the potential for cost effective end use efficiency improvement and electricity conservation in all sectors of the economy, to establish goals for achievable levels of conservation and to incorporate these goals into the proposed energy plans. Doing so would provide guidance and targets to energy efficiency programmes in Brazil, including any demand-side bidding efforts.

9.4.3. Policy option: Fully implement the appliance efficiency standards law

As noted above, a law was enacted in 2001 directing the Federal Government to adopt minimum efficiency standards for energy using products and devices. Efficiency standards for motors were issued in 2002. Standards could be adopted for all new major household appliances (refrigerators, freezers, clothes washers, stoves and air conditioners), lighting products (lamps and fluorescent lighting ballasts) and commercial sector air conditioning equipment sold in Brazil, as has been done in numerous other countries [9.66]. Standards could also limit the standby power consumption of electronic devices such as television sets, video recorders, microwave ovens, personal computers, printers and fax machines.[22] The standards should be set at the maximum efficiency levels that are technically and economically feasible. For example, a study indicates that is it is technically and economically feasible to cut the average electricity use of new refrigerators produced and sold in Brazil by 43% [9.73].

PROCEL, together with the National Testing and Standards Agency (INMETRO), has already established energy efficiency test procedures and an efficiency labelling programme for many (but not all) of these products. Also, PROCEL provides recognition and promotion of top rated energy efficient products. These valuable ongoing activities will facilitate the adoption of minimum efficiency standards in Brazil.

9.4.4. Policy option: Adopt energy codes for new commercial buildings

Commercial sector energy demand in Brazil grew nearly 8% per year on average during the 1995–2000 period [9.74]. Commercial sector electricity demand is projected to increase 6% per year in the future if energy codes and other policies to promote more efficient electricity use are not adopted [9.61].

Building energy codes are common around the world, but no city or State in Brazil has adopted energy efficiency requirements for new commercial buildings. However, the 2001 energy efficiency law calls for policy mechanisms to improve energy efficiency in new buildings. A group of experts could be convened to develop and publish a national model energy code that would include requirements for different climate zones in Brazil. The Federal Government could then give all municipalities over a certain size (say, those with over 100 000 residents) a deadline for adopting the model energy code. This is a strong policy, but it is precisely what has been done in a number of industrialized countries.

Experience in other countries has shown that thorough training of architects and builders is critical to the success of building energy codes, as are concerted monitoring and enforcement [9.31]. Therefore, a key part of this policy would be to train builders, architects, building inspectors and code enforcement officials from municipalities.

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[22] This standby power is a growing source of energy waste in Brazil and other countries. A standby power limit of 1 W for most electronic products has been proposed and is being pursued in some countries [9.72].

PROCEL (or a new energy efficiency agency) could carry out this effort, with energy experts from universities and technical institutes hired to conduct the training.

Adopting energy codes (i.e. energy efficiency requirements for new commercial buildings) could eliminate of the order of 10–15% of the future growth in electricity demand in commercial buildings [9.15].

9.5. FUEL CONSERVATION AND SUBSTITUTION

After the second world oil price shock in 1979–1980, the Government of Brazil launched a petroleum fuel conservation programme known as CONSERVE. The programme promoted more efficient fuel use and fuel substitution in industries through a range of mechanisms, including sectoral protocols, industrial audits, low interest loans, technological demonstration and promotion, and education and training. This programme was relatively successful, in part owing to the high fuel prices that were prevalent during the early 1980s. By 1985, the industrial sector as a whole cut its use of fuel oil to 59% of the level in 1979. The reduction in fuel oil use was especially large in the cement, steel, and pulp and paper industries, the three sectors that entered into protocols with the Government. The BNDES financed 80 projects for CONSERVE, but most of the projects were aimed at fuel substitution rather than fuel conservation or efficiency improvement [9.75].

The CONSERVE programme was not a complete success, however. Most of the funds dedicated to the programme were not utilized, and the impact on small and medium sized industries was relatively limited. In addition, the programme did not develop very systematic monitoring and evaluation procedures [9.75]. In 1991, a new programme known as CONPET was initiated to promote more efficient and rational use of petroleum products and natural gas. CONPET is housed in Petrobras and has actively promoted energy conservation within the diverse operations of the national petroleum company. Cumulative energy savings within Petrobras from 1992 to 2000 include 230 GW·h of electricity, 610 million m^3 of natural gas and over 700 million m^3 of oil products [9.61].

CONPET has had limited success in stimulating efficiency improvements and conservation outside of Petrobras, however. One initiative, known as Siga Bem, is aimed at improving the fuel efficiency of heavy trucks through simple diagnostic tests and education of truck drivers at over 100 service stations along major highways. It is estimated that fuel savings were of the order of 12–15% per vehicle attended, with 120 000 trucks serviced by the programme per year as of 2001 [9.61]. Another initiative, known as Economizar, features similar services through a mobile testing facility that visits truck and bus depots. There were 41 mobile facilities operating throughout Brazil as of 2001, resulting in approximately 114 million L of fuel savings that year [9.61].

Regarding the residential and commercial sectors, CONPET helped initiate an efficiency testing and labelling programme for residential stoves that consume liquefied petroleum gas (LPG). This initiative prompted appliance manufacturers to improve the efficiency of their products, with estimated fuel savings of 13% on average between the 1999 and 2001 stove models [9.61]. If a new national energy efficiency agency is established (see Section 9.4.1), it could take over and expand on the efforts of the CONPET programme.

A tax incentive was introduced in 1993 to encourage the production of automobiles with smaller, fuel conserving engines (up to 1 litre in capacity). This incentive was a reduction in the tax on industrialized products (known as the IPI in Brazil). The tax incentive also helped to make new automobiles more accessible to lower income sectors of the population. Consequently, by 2001, almost 70% of domestic sales of new automobiles had 1-litre engines, compared with a 16% market share for these automobiles as of 1992. It is estimated that this policy resulted in a gasoline savings of 29 billion L/year as of 2001 [9.46]. These savings are limited, however, because the incentive only requires smaller engines, not necessarily more efficient engines or vehicles.

9.5.1. Policy option: Adopt fuel economy or CO_2 emission standards for new passenger vehicles

Passenger vehicle fuel efficiency standards have been in use for decades in North America, Western Europe and Japan [9.31]. Such standards have also been adopted recently in China. However, there are no fuel efficiency standards for new automobiles or light trucks in Brazil. As noted above, vehicle manufacturers receive some tax incentives for producing vehicles with engines with a volumetric capacity of 1 litre or less. However, the fuel efficiency of Brazilian automobiles and light trucks is still relatively low. In 1998, the average fuel economy of all passenger vehicles in circulation in Brazil was about 23.5 miles per gallon (MPG), or 10 km/L, while the average fuel economy of all new passenger vehicles sold that year in the country was about 26 MPG (11 km/L) [9.76].

Passenger vehicles sold in Brazil are relatively inefficient because of the outdated technology employed in Brazilian 1-litre engines. Most of these engines are derived from 1.6-litre engines used to equip older models. However, vehicle production by multinational automobile manufacturers is growing in Brazil, and as production expands, it would be reasonable to insist that new vehicles include a variety of fuel efficient technologies. These standards could be expressed in terms of either an increase in fuel economy (the approach followed in the United States of America) or a reduction in CO_2 emissions per kilometre travelled (the approach in Europe). The advantage of a CO_2 emissions standard in Brazil is that automobile manufacturers could opt either to raise fuel efficiency or to produce and sell more ethanol and other 'cleaner' vehicles, or a combination of the two. If a CO_2 emissions standard were adopted, manufacturers most likely would comply through some combination of efficiency improvement and fuel shifting. However, if there is going to be significant adoption of flex-fuel vehicles in Brazil, implementation of this approach would be complicated by the fact that is not known in advance which fuel will be used in these vehicles (and thus the CO_2 emissions levels are not known).

The Government could, for example, require a 40% reduction in the average CO_2 emissions per kilometre for new passenger vehicles sold in Brazil by 2012, relative to the average emissions level in 2000. The standard could apply to the average emissions of domestic shipments by each manufacturer. The proposed standard is equivalent to about a 5% per year reduction in average CO_2 emissions per kilometre starting in 2005.

This policy could be implemented under the aegis of the National Vehicle Emission Control Programme (PROCONVE).[23] PROCONVE has been a very effective programme for reducing pollutant emissions from mobile sources in Brazil. From its origin until 1998, it reduced, on average, almost 90% of the pollutant emissions by new light vehicles [9.77]. PROCONVE also catalysed technological improvements in oil refineries in order to produce higher quality fuels, for example, the removal of lead from gasoline[24] and the reduction of the sulphur content of diesel fuel. Therefore, it would be worthwhile to consider potential synergies between PROCONVE and the policy proposed here.

If about 75% of this reduction were achieved through efficiency improvements and 25% through increased sales of neat ethanol vehicles, this policy would lead to new vehicles with an average fuel economy of 16 km/L by 2012 [9.15].

9.5.2. Policy option: Improve efficiency of freight transport

There are a number of technical options for increasing the efficiency of medium and heavy duty trucks, including more efficient engines, aerodynamic drag reduction, low friction drive trains and reduced energy expended for idling [9.78]. Likewise, there are various technical options for increasing the energy efficiency of trains. The policies that could stimulate these efficiency improvements in Brazil include RD&D programmes, tax incentives to encourage production and purchase of higher efficiency trucks and locomotives, and, if necessary, fuel efficiency standards for new trucks.

It is also possible to improve the energy efficiency of freight transport by shifting cargo among modes — specifically, shifting transport from less efficient trucks to more efficient trains and barges. In fact, the fraction of freight shipped by truck declined about 5% from 1996 to 2000 as rail and water transport services were expanded and improved [9.79]. By continuing to invest in railroads, waterways and intermodal freight transfer infrastructure, it might be possible to increase the fraction of freight shipped by rail from 21% in 2000 to around 29% in 2010. Likewise, the fraction shipped by water might rise from 14% to 18%. This means the fraction shipped by truck would fall from 60% in 2000 to around 48% in 2010 [9.15].

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[23] For more details about PROCONVE, see Chapter 6.

[24] Petrobras refineries have not produced leaded gasoline since 1989.

9.5.3. Policy option: Improve efficiency of passenger transport

As discussed in Chapter 6, the transport sector is one of the main sources of atmospheric emissions in Brazil. In addition, the rapid growth of the light vehicle fleet has not been accompanied by related investments in urban infrastructure. Paradoxically, the increased access to light vehicles has reduced mobility in some cities as a result of greatly increased road congestion [9.80]. Moreover, the deterioration of the public transport system has led to greater pressure for investments in more road capacity. That infrastructure is based on materials (cement, steel, etc.) embodying considerable amounts of indirect energy.

A more sustainable transport system can be realized through the coordination of urban and transport planning in order to reduce light vehicle and fuel use. Policy options for improving urban passenger transport systems include the following:

- Stimulating greater use of public transport through better intermodal integration and improving the quality of service, encouraging shifts to less energy intensive modes of transport, emphasizing public transport options and guaranteeing access for low income consumers. Specific initiatives include promoting bus and rail use (and subway use, where appropriate), expanding public transport infrastructure, improving load management actions, using urban tolls, increasing the costs of automobile parking in congested urban areas, restricting the use of automobiles to reduce air pollution and congestion in major cities and promoting telecommuting. These policies can be implemented in a synergistic manner. For instance, a fund created by an urban toll on automobiles and light trucks can finance public transport system improvements. Likewise, policies such as restrictions on driving can have broad energy, social and economic benefits.[25]
- Improving public transport infrastructure for buses. This means constructing express bus lanes, efficient transfer stations and mass transit corridors. For instance, recently the city of Rio de Janeiro integrated subway and bus lines, thereby improving the quality of public transport at a low cost. This also means rationalization of the bus system operation to guarantee a suitable match between supply and demand on an hourly basis.
- Increasing the load factor (i.e. the average occupancy level) of automobiles and light trucks. This can be done by encouraging ride sharing and giving higher occupancy vehicles access to special lanes on major urban highways. However, this policy has limited applicability in Brazil, in part because many people are employed in the underground economy and do not have fixed working hours [9.81].
- Discouraging 'urban sprawl' that results in more personal vehicle use and undermines the viability of urban and suburban centres.
- Encouraging pedestrian and bicycle trips through the construction of dedicated pedestrian walkways and bicycle lanes and prohibiting automobile use in very dense urban core areas. In this case, it is also helpful to coordinate the design of downtown pedestrian areas with the design and operation of the public transport system.

The assessment of public transport options in major Brazilian cities shows that public buses are more cost effective in the short term than are urban trains and subways [9.81]. These last two options require large capital investments[26] and, given the existing infrastructure, are not flexible. However, the quality of the service provided by subways in terms of reliability, safety and capacity justifies further expansion of subways in extremely large cities such as São Paulo and Rio de Janeiro. Buses, express bus lanes and mass transit corridors are a preferred approach in medium sized and smaller

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[25] For example, a 'car use restriction' was implemented in São Paulo city starting in the late 1990s. By banning the use of automobiles one day per week according to licence number, this policy has reduced annual automobile use by the equivalent of more than 640 000 vehicles (75% light vehicles and 4% trucks), saved almost 200 million L of fuel and increased the average speed of light vehicles by 21%, thereby reducing the frequency of congestion by 39% as of 1998 (CETESB, cited in Ref. [9.81]). However, one undesirable side effect of this kind of policy is the incentive it creates for buying a second automobile, quite often old automobiles in poor mechanical condition.

[26] In Curitiba, a bus express lane costs about 1/200th as much as a conventional subway system per kilometre and achieves comparable performance in terms of passenger numbers and travel times [9.82].

cities, as mentioned previously. In this case, efficient transfer stations are crucial, as the transfer operation requires, on average, 50–60% of the total travel time of buses in Rio de Janeiro [9.81]. Some improvement can be achieved through the ticket sale system, by offering monthly, weekly and daily tickets, and through strategies for automobile–bus integration, by locating bus transfer stations near parking garages outside of congested areas.

The city of Curitiba exemplifies the potential for providing efficient transport services through careful land use and transport planning in a medium sized city. Starting in the 1970s, Curitiba implemented urban planning and a sophisticated public transport infrastructure, through the definition of residential and industrial zones along the so-called ‘arteries’. These arteries are supplemented with a system of ring roads. Express buses using separate lanes are responsible for most of the passenger transport load on the arteries and ring roads. Separate bus lines operate in close connection with the express buses and enter the residential areas. As a result, about 75% of commuters use buses, and fuel use per capita is about one fourth less than in comparable Brazilian cities [9.83, 9.84]. These impressive results were achieved even though Curitiba has the second highest per capita automobile ownership rate in Brazil (one automobile for every three people). This well designed and comprehensive urban transport strategy has led to about 27 million L of fuel savings per year, or 0.6 GJ per capita [9.82]. In addition, the extensive and efficient bus system has improved transport services and mobility for low income households.

9.5.4. Policy option: Adopt industrial energy intensity reduction targets and protocols

There is considerable potential to increase the efficiency of fuel and electricity use in Brazil’s industrial sector by improving operating and management practices, using better equipment such as high efficiency motors and motor speed controls, and adopting innovative industrial process technologies. One study indicates that it is technically feasible to reduce energy use by 30% or more in a wide range of energy intensive industries [9.85]. Another study found that the use of better technologies could reduce energy use in the cement industry by 19%, even considering some limitations in adoption and penetration of efficiency measures [9.86]. Yet another study found a 5–12% energy savings potential in the chemicals sector through the optimization of heat exchange alone, that is, the so-called pinch optimization technique [9.11].

Industrial energy intensity reduction targets and commitments have been successfully implemented in Germany, the Netherlands and a few other European countries [9.87]. In the Netherlands, for example, more than 1200 industries representing over 90% of industrial energy use reduced their energy intensity by 20% on average from 1989 to 2000, owing in large part to formal agreements (protocols) between the Dutch Government and industries [9.31]. The Government of Brazil could establish similar energy intensity reduction targets for major industries in Brazil through voluntary agreements (protocols) with key sectors. The targets could apply to all energy use — fuels as well as electricity. This type of policy could be modelled in part on the successful sector protocols that were adopted as part of the CONSERVE programme during the 1980s.

Voluntary agreements (protocols) should be based on well defined targets and responsibilities. To facilitate compliance and help companies meet the targets, entities such as PROCEL and CONPET (or a new national energy efficiency agency) could provide technical assistance through training industrial energy managers and sponsoring or co-funding energy audits of industrial facilities. Also, the Government could provide financial assistance through tax incentives for investments in energy efficient, state-of-the-art industrial equipment. And companies or sectors that enter into agreements to improve energy efficiency by a substantial amount (say, at least 2% per year for 10 years or more) and stay on track could be protected from any increase in fuel taxes in the future, as has occurred, for instance, in the Netherlands.

It is estimated that this policy could lead to energy savings of around 12% in the industrial sector by 2010 [9.15].

9.6. ENERGY EFFICIENCY AND RENEWABLE ENERGY FINANCING

The Government of Brazil and other public sector entities continued to attempt to finance energy efficiency projects after the CONSERVE programme ended. The BNDES started an energy efficiency financing programme known as PROEN in 1986. Loans were offered at a real interest rate of 6–8% per year, much less than the market interest rate at the time. Unfortunately the programme was not well promoted, application procedures were complicated and energy prices were relatively low during the late 1980s. As a consequence, relatively few loans were made [9.88].

The programme was revised in 1990 to attempt to streamline application and loan processing procedures. However, the revised programme also had little impact. This was due in part to the incompatibility between the size of energy efficiency projects (normally less than US $500 000) and typical BNDES loans (normally over US $5 million). In addition, the BNDES processes smaller scale loans through local banks, and it is difficult to obtain their cooperation and active participation in an energy efficiency financing programme.

Regarding renewable energy, there are a number of domestic financing programmes for renewable energy technologies, including SSH systems, bioenergy systems and solar energy systems. In addition, a number of international agencies and organizations offer financing for renewable energy systems in Brazil [9.33]. However, some of these efforts are relatively new and the overall impact has been very limited so far.

9.6.1. Policy option: Provide an effective financing mechanism for energy service companies

A number of ESCOs are operating or attempting to operate in Brazil, and these companies have formed an association (ABESCO) with more than 60 members. In other countries, ESCOs provide financing as well as installation and performance guarantees to facilitate the adoption of energy efficiency and renewable energy measures and projects by private businesses and the public sector. However, ESCO projects in Brazil are usually self-financed by the client and lack performance guarantees [9.89].

Providing effective third party financing could greatly help the ESCO industry expand in Brazil. A financing fund could be established with capital from a variety of sources, such as the BNDES, electric utilities such as Eletrobras, capital markets and international sources (including sources of financing for environmentally friendly ‘green’ projects). Project financing could be provided to ESCOs and their clients, but should not include excessive, overly burdensome loan guarantee requirements. Financing could be offered for renewable energy, cogeneration and end use efficiency projects.

Excessive guarantee requirements have been one obstacle to effective third party financing for ESCO projects in the past [9.89]. One possibility for addressing this problem would be for the Government to establish an insurance fund for ESCO projects, providing a portion of the guarantee normally required of clients. In addition, regulations should be streamlined so that the public sector can contract with ESCOs, paying for their services over time based on the stream of energy cost savings. The public sector has been the primary customer for ESCOs in the United States of America, for example [9.90].

9.7. INTERNATIONAL COOPERATION

9.7.1. Technology transfer

Technology transfer between industrialized and developing countries can be an important component of clean energy development. One way this occurs is through technology implemented by multinational companies. Multinational companies represent a large part of private sector investment in Brazil. Net foreign direct investment (FDI) grew from less than US $5 billion per year in the early 1990s to US $26–34 billion per year during the 1998–2000 period [9.33].

Joint ventures and licensing are other mechanisms for technology transfer. Formation of joint ventures and licensing agreements is relatively easy and is common in Brazil. The Government could adopt policies to steer investments and technology transfer towards clean energy technologies. For example, it could adopt and enforce strong energy efficiency and environmental standards so that new infrastructure (e.g. industrial plants) and consumer products (e.g. automobiles and light trucks) are state-of-the-art rather than technologically outdated. In this regard, adopting comprehensive, stringent, yet cost effective efficiency standards for appliances, new commercial buildings and vehicles is proposed (see Sections 9.4 and 9.5). Also, new energy efficiency and environmental standards could be adopted for major energy using facilities such as steel mills, paper and pulp mills, cement plants and thermal power plants. This would facilitate the transfer of state-of-the-art environmentally friendly manufacturing technologies to Brazil.

Technology transfer, joint ventures and licensing of renewable energy and energy efficiency technologies can be encouraged by reducing taxes on these devices or key components (e.g. components of PV systems or high efficiency lighting devices). Recently, the Government of Brazil eliminated the industrial products tax (IPI) and value added tax (ICMS) on PV modules and cells, solar water heaters and wind generators. Also, both sales taxes and import duties on CFLs were reduced at the beginning of the electricity crisis in 2001. This reduced the cost to consumers and renewable energy project developers.

Significant import duties still exist, however, for solar electric and wind technologies (i.e. a 17–21% import tax) and for solar water heaters (i.e. a 30% import tax) [9.33]. This increases costs and discourages market development, especially for technologies such as PV cells and modules that are still primarily imported.[27] Reducing these import duties could have a number of benefits besides the obvious one of lowering costs. Local manufacture of some components and/or assembly as well as marketing and installation will support jobs in Brazil, even if some components (or complete devices) are imported for a period of time. Nationalization of the entire technology should occur as production and sales grow, considering the lower wage rates and reduced transport costs associated with local production.

The Government can also provide low interest financing to encourage joint ventures and licensing of appropriate energy technologies in Brazil. Publicly owned financing agents such as the BNDES, Caixa Económica Federal and Banco do Brasil support technological development and transfer in general. Also, some other financial institutions such as Banco Real and Banco do Nordeste offer low interest loans for energy efficiency and/or renewable energy project implementation, which in turn encourages technology development and transfer. For instance, three Brazilian financial institutions offer financing for the purchase of solar water heating systems: Caixa Econômica Federal, Banco Real and Banco do Brasil. However, the loan terms are relatively short (2–5 years), and the interest rate is tied to the official long term interest rate in Brazil, which has been relatively high in recent years.

Likewise, programmes that provide financial incentives as well as marketing and promotion assistance can encourage and support clean energy technology transfer. Some of the policies and programmes mentioned above, such as PROCEL, PRODEEM and PROINFA, have had or are expected to have this effect. PROCEL, for example, has contributed to the transfer and introduction of a number of new technologies now manufactured in Brazil, including demand limiters, lighting controls, energy efficient light fixtures and electronic ballasts for fluorescent lamps [9.31]. PROINFA and its predecessor, the PROEOLICA programme, encouraged one of the world's leading wind turbine manufacturers, Enercon GmbH of Germany, to set up a wind turbine manufacturing and project development subsidiary in Brazil (Wobben Windpower).

Some funds created for promoting R&D in the energy sector, such as CT-Petro (for oil and gas) and CT-ENERG (for electricity), have also stimulated the transfer, adaptation, development and testing of new energy technology options for Brazil. For instance, in 2002 CT-Petro promoted development and transfer of dual fuel (natural gas and gasoline) automotive engines.

9.7.2. International support

Many international development assistance agencies support clean energy development and implementation in developing countries, and Brazil participates in a number of these programmes. For example, the GEF has supported two significant renewable energy RD&D projects in Brazil: the Biomass Integrated Gasification/Gas Turbine (BIG/GT) project to demonstrate wood gasification and power production, and the Energy Generation from Sugar Cane Bagasse and Wastes project. Also, the GEF has provided significant funding for PROCEL and its partner utilities and other entities. However, the implementation of some of these projects has proved difficult because of both the complex rules of the international agencies and internal problems in Brazil [9.31].

Brazil also has participated in numerous bilateral assistance programmes related to sustainable energy development in the country. For example, the US Agency for International Development has supported the national electricity conservation programme, renewable energy

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[27] There is only one Brazilian PV manufacturer, Heliodinâmica, and it does not produce a competitive product, nor does it have a significant share of the PV market in Brazil [9.33].

promotion and policy development, and electricity sector regulatory reform in Brazil. The US Department of Energy has supported PV technology demonstration and installations in northeastern Brazil. Also, Canadian and European development assistance agencies have funded cooperative projects in the energy efficiency and renewable energy areas in Brazil.

In some cases, this assistance has been useful in terms of supporting local capacity building, technology advancement and transfer, or concrete policy and programme reforms. However, in other cases it has not had any of these positive outcomes. For example, it is reported that most of the imported PV systems installed in the Northeast through a US Department of Energy funded programme functioned poorly and were not well maintained, and were eventually deactivated [9.35]. This project did not help to build PV manufacturing, marketing or maintenance capacity, and possibly did more harm than good by hurting the reputation of PV technology in general.

In the future, Brazilian officials should ensure that cooperative projects funded by development assistance agencies serve local needs, foster capacity building within Brazil and support technology transfer and/or long term business and market development. Brazilian officials may want to take a more proactive role in this area, defining the types of assistance projects and support they need, as well as establishing project guidelines and conditions, rather than constantly being on the receiving end of projects proposed (and led) by donors and their contractors.

9.7.3. Energy and climate change policy

Brazil has played a prominent role in discussions of international energy and climate change policy since hosting the United Nations Conference on Environment and Development in 1992. Brazil developed and put forward proposals regarding both climate policy and clean energy policy at various international summits. For example, a Brazilian Energy Initiative was proposed at the World Summit on Sustainable Development (WSSD) in 2002. This initiative called for an increase in the use of new renewable energy sources so that they would represent at least 10% of worldwide energy supply by 2010 [9.91]. This proposal was rejected at the WSSD, but it was approved (in a slightly modified form) by the Ministers of the Environment of the Latin American and Caribbean region [9.91].

Brazil also played a seminal role in the creation of the Clean Development Mechanism (CDM), which is part of the Kyoto Protocol for controlling greenhouse gas (GHG) emissions. In 1997, Brazil proposed that if a developed country exceeded its GHG emissions limits, an economic penalty would be assessed and the money would be deposited in a clean development fund. Resources from this fund would be directed to developing countries, which then would use them for projects designed to prevent or mitigate global climate change [9.77]. During the Protocol discussions, the Brazilian proposal evolved into the CDM that was ultimately adopted.

The CDM is starting to provide additional funding for renewable energy, energy efficiency and natural gas projects in Brazil and other developing countries. In fact, the international community sees Brazil as one of the most promising countries to host CDM projects, and various projects are under way or under development. Investments in higher efficiency bagasse cogeneration systems in some sugar mills in São Paulo have already qualified for emission reduction credits under the CDM [9.92]. Moreover, Germany is considering providing financial incentives to facilitate the production and sale of 100 000 new neat ethanol vehicles in Brazil, with Germany receiving the emission reduction credits associated with these vehicles.

Climate issues in Brazil are addressed mainly through the Climate Change Programme under the auspices of the Ministry of Science and Technology. Regarding the CDM, Brazil has emphasized the importance of national strategies and institutions, and the need for a project inventory in host countries. To contribute to the CDM process, Brazil set up the Center for Integrated Studies on Climate Change and the Environment, known as Centro Clima. Centro Clima has established a set of eligibility criteria for CDM projects, in addition to the rules of the Executive Board of the CDM and compatible with the position of the United Nations Framework Convention on Climate Change and the Brazilian policy for sustainable development [9.92]. In addition, there are several private Brazilian organizations quite active in the CDM, such as ECO Invest, Negawatt and Ecoenergy, as well as international groups sharing knowledge with Brazil, such as Ecofys and EcoSecurities.

Brazil has considerable scientific and technical expertise to deal with climate change and climate change policy. However, such expertise is held by a relatively small group of Government and university officials, and by a few private companies, while high level decision makers in both the Government and the private sector normally have more limited knowledge about global climate change discussions and CDM opportunities [9.92]. Additional efforts could be made to educate policy makers and the business community concerning climate change policy and opportunities, including the potential for attracting international funding for sustainable energy development projects through the CDM.

Moreover, climate policy in Brazil and other countries should move beyond the CDM and individual CDM projects to address structural issues affecting GHG emissions. As globalization advances, international trade can be a major factor affecting a country's CO_2 emissions and emission trends. For instance, Brazil's exports embody much more energy and CO_2 emissions than do the country's imports [9.93]. So far, international climate change policy has not addressed global trade and how this affects a country's ability to reduce its emissions. This shortcoming should be addressed.

9.7.4. International trade policies

International trade is growing relative to the size of the Brazilian economy. Additional steps could be taken to ensure that international trade supports rather than hinders sustainable energy development. The primary need is to develop trade policies that foster economic and social development without degrading the country's environment or natural resource base. For example, policies could be developed to discourage or even slowly phase out the export of primary materials that are very energy intensive and environmentally damaging to produce, with complementary policies adopted to encourage export of higher value added manufactured goods. For instance, limits or fees could be placed on unsustainable natural resource extraction. In addition, policy makers could promote and support the export of renewable energy and energy efficiency technologies and products, such as Brazil's ethanol fuel and ethanol fuel production technology.

Some international agencies support capacity building in international trade and the environment. For instance, the United Nations Conference on Trade and Development (UNCTAD) has a number of programmes for developing countries, including 'Understanding the Links between Trade and Environment' and 'Capacity Building Task Force on Trade, Environment and Development'. Under the latter programme, Brazil already has a project on 'Strengthening Research and Policy-Making on Trade and Environment in Developing Countries'. In addition, the United Nations Statistical Division has developed a Manual for Environmental System Accounts that can help to guide data improvement. Brazil could make better use of these resources and programmes as it addresses the linkages between international trade and sustainable energy development [9.94].

9.8. CONCLUSION

This review of major energy policies and programmes currently in place or used in the past in Brazil to improve the country's energy system shows a wide range of results, from success to disappointment. Policies implemented to expand alcohol and domestic oil production have achieved their principal objectives, reflected in major reductions of fuel imports. Other programmes designed to encourage conservation, fuel substitution, energy efficiency and more use of renewables have had mixed results. Initiatives to increase natural gas use and to diversify sources of electric power, in general, have not been very effective.

Clearly, there is room for improvement. Thus, a number of new or modified policies are proposed in this chapter to promote more sustainable energy development in Brazil. Policies are proposed in seven major areas: (a) natural gas use; (b) electricity from renewable sources; (c) ethanol fuel, other bioenergy sources and hydrogen; (d) electricity conservation; (e) fuel conservation and substitution; (f) energy efficiency and renewable energy financing; and (g) international cooperation.

Table 9.3 lists the proposed policies and the authors' judgement regarding priority for implementation. Of all the policies proposed, the ones considered to have the highest priority for implementation are the following:

- *Natural gas*: Internalization of sulphur emission costs associated with fuel oil use and the expansion of gas use, in particular for buses;
- *Renewable electricity*: Adoption of renewable energy portfolio standards;
- *Ethanol and other biofuels*: Expansion of production and use of ethanol fuel, promotion

TABLE 9.3. ENERGY POLICY OPTIONS

Policy options	Priority
Natural gas	
Remove barriers to natural gas CHP implementation	Medium
Adopt minimum efficiency standards for thermal power plants	Low
Internalize sulphur emission costs associated with fuel oil use	High
Expand natural gas use in buses	High
Renewable electricity sources	
Adopt renewable energy portfolio standards	Low/high
Stimulate solar PV use in remote, off-grid areas	Medium
Stimulate adoption of solar water heaters	Low
Ethanol fuel, other bioenergy sources and hydrogen	
Expand the production and use of ethanol fuel	High
Promote more efficient CHP systems using bagasse and other sugar cane products	High
Develop and stimulate the adoption of new bioenergy sources	High
Expand R&D and capacity building for hydrogen and fuel cell technology	Low
Electricity conservation	
Establish a new national energy efficiency agency	High
Adopt demand-side bidding and energy planning	High
Fully implement the appliance efficiency standards law	High
Adopt energy codes for new commercial buildings	Medium
Fuel conservation and substitution	
Adopt fuel economy or CO_2 emission standards for new passenger vehicles	High
Improve the efficiency of freight transport	Medium
Improve the efficiency of passenger transport through transport planning and shifts to less energy intensive modes	Medium
Adopt industrial energy intensity reduction targets and protocols	Medium
Energy efficiency and renewable energy financing	
Provide an effective financing mechanism for energy service companies	Medium

of more efficient CHP systems using bagasse and other sugar cane products, and development and utilization of new biofuels;

- *Electricity and fuel conservation*: Creation of a national energy efficiency agency, adoption of fuel economy or CO_2 emission standards for new passenger vehicles, improvement of the efficiency of passenger transport through transport planning and shifts to less energy intensive modes, adoption of demand-side bidding and energy planning programmes, and full implementation of the appliance efficiency standards law.

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Chapter 10
SCENARIOS

I. JALAL, I. VERA, M. STRUBEGGER, A. SZKLO, G. MACHADO,
R. SCHAEFFER, A. OLÍMPIO PEREIRA, Jr.

The previous chapters provided comprehensive summaries of national energy resource endowment, technology options, economic structural change, environmental impacts, social developments and policy aspects relevant to sustainable energy development in Brazil. The Energy Indicators for Sustainable Development (EISD) set the stage by showing historical trends and assessing the current situation. Past policies were scrutinized to ascertain their effectiveness in putting the energy system on a trajectory towards sustainability, bearing in mind that sustainability is a dynamic concept. Desirable socioeconomic development paths were charted out by the Brazilian team. Natural questions at this juncture are: What does all this mean for the future of the Brazilian energy system? Which of the many options may be realized? At what costs? What will be the environmental or social impacts? Is the energy system moving closer to meeting certain sustainable energy objectives? Many such questions come to mind and need to be answered. But the future is unknowable given the numerous uncertainties surrounding each of the options. Analysts, therefore, resort to the design and use of scenarios. Scenarios provide a framework for exploring future energy perspectives, including a continuation of current dynamics and alternative paths developed based on different assumptions relevant to sustainable energy development. It is important to note that scenarios are neither forecasts nor predictions, but are images of alternative futures based on internally consistent and reproducible sets of assumptions [10.1]. Thus, scenario outputs and assumptions are inseparable parts of the overall integrated modelling process.

This chapter presents alternative scenarios developed for Brazil for the period 2000–2025. Two basic scenarios were developed: a ‘Reference’ (REF) scenario and a ‘Shift’ (SHIFT) scenario. Variants of both scenarios have also been explored based on variations of critical assumptions. This chapter summarizes the methodology, assumptions and resulting scenario characterizations.

10.1. METHODOLOGY

10.1.1. Overall methodology

The comprehensive assessment of different energy development paths in Brazil follows an integrated approach based on assumptions derived from criteria for sustainable energy development. In this integrated approach, top-down assumptions about the country’s economy, population and lifestyles are combined with bottom-up disaggregated specifications and constraints about resources, fuels and technologies to develop scenarios of energy demand and optimal energy supply. The integrated, computer aided approach is illustrated in Fig. 10.1. The assessment includes two major modelling components:

- *Energy demand*: This component provides detailed sectoral energy demand projections by applying the IAEA Model for Analysis of Energy Demand (MAED) based on numerous scenario assumptions concerning demographic developments, technological progress, behavioural changes, economic structural change and economic growth.
- *Energy supply optimization*: This component allows the formulation of optimal scenarios of energy and electricity supply mixes using the IAEA Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE), taking into consideration available resources, present energy infrastructures, current and future conversion technologies, and socioeconomic, technical and environmental (policy) constraints.

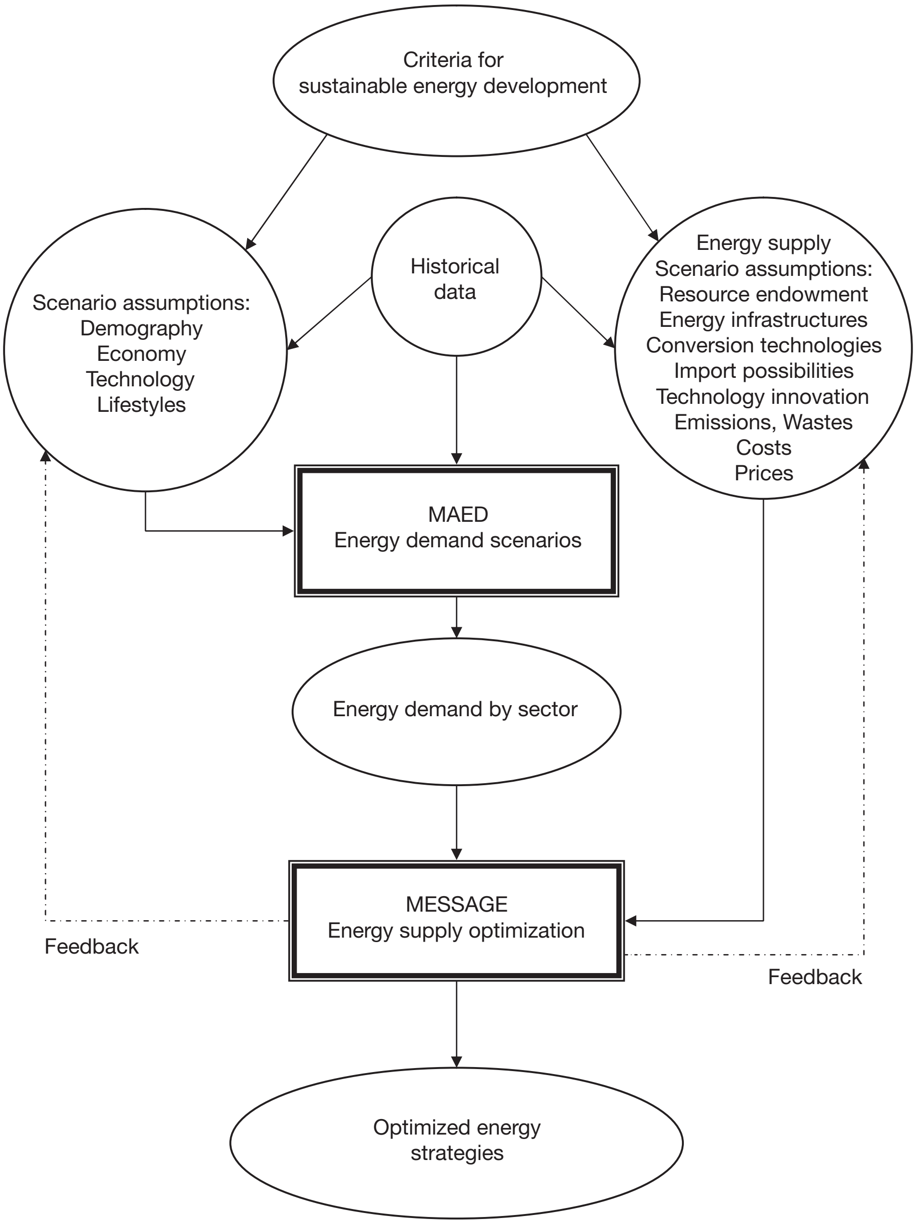

FIG. 10.1. Conceptual modelling framework.

Projected economic and demographic growth, structural economic change and the dynamics of sectoral energy intensities, as taken from previous chapters, are the key drivers of future energy demand. The energy demand projected by MAED serves as input to the energy supply system optimization based on MESSAGE. The integrated modelling system includes a feedback component that allows plausibility checks, a final demand and supply balance, and convergence of energy demand and supply with previously quantified sustainable development targets. Through this iterative process, assumptions become integral parts of the scenario results.

10.1.2. Methodology of MAED

MAED was used to project energy demand for the two scenarios. MAED evaluates future energy demand scenarios based on medium to long term socioeconomic, technological and demographic development assumptions.

The model systematically relates the specific energy demand for producing various goods and services to the corresponding social, economic and technological factors that affect this demand. Energy demand is disaggregated into a number of end use categories, each corresponding to a given service or to the production of a certain good.

The nature and level of the demand for goods and services are a function of several determining factors, including population growth, number of inhabitants per dwelling, number of electrical appliances used in households, peoples' mobility and preferences for transport modes, national priorities for the development of certain industries or economic sectors, the evolution of the efficiency of certain types of equipment, market penetration of new technologies or energy forms, etc. The expected future dynamics for these determining factors, which constitute 'scenarios', are exogenously introduced. The main inputs and outputs of MAED are depicted in Fig. 10.2.

10.1.3. Methodology of MESSAGE

MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. The underlying principle of the model is the optimization of an objective function (e.g. least cost, lowest environmental impact, maximum self-sufficiency) under a set of constraints. The backbone of MESSAGE is the techno-economic description of the modelled energy system. This includes the definition of the categories of energy forms considered (e.g. primary energy, final energy, useful energy), the fuels (commodities) and associated technologies actually used (e.g. electricity, gasoline, ethanol, coal or district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology). Technologies are defined by their inputs and outputs (main and by-products), their efficiency and the degree of variability if more than one input or output exists (e.g. the possible production patterns of a refinery or a pass-out turbine). Economic characteristics include, among other things, investment costs, fixed and variable operation and maintenance (O&M) costs, imported and domestic fuel costs and estimates of levellized costs and shadow prices.

Fuels and technologies are combined to construct so-called energy chains, where the energy flows from supply to demand. The definitional limitations on supplying fuels are that they can belong to any category except useful energy, they have to be chosen in the light of the actual problem, and limits on availability inside the region/area and on import possibilities have to be specified. The technical system provides the basic set of constraints to the model, together with demand, which is exogenous to the model. Demand must be met by the energy flowing from domestic resources and from imports through the modelled energy chain(s).

The model takes into account existing installations, their age and their retirement at the end of

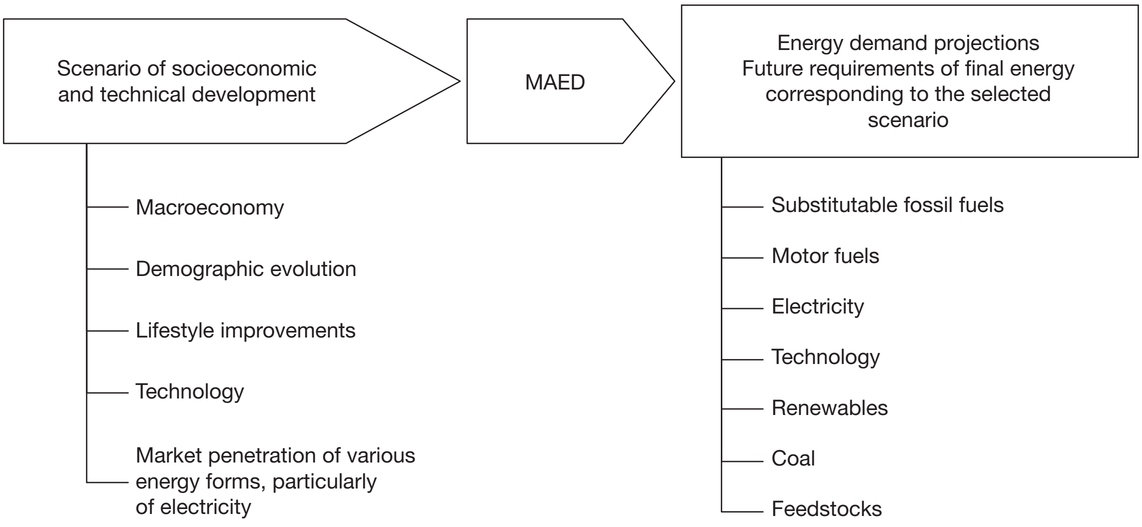

FIG. 10.2. Major inputs and outputs of MAED.

their useful lives. During the optimization process, this determines the need to construct new capacity of various technologies. Knowing new capacity requirements permits the user to assess the effects of system growth on the economy.

The investment requirements can be distributed over the construction time of the plant and can be subdivided into different categories to more accurately reflect the requirements from significant industrial and commercial sectors. The requirements for basic materials and for non-energy inputs during construction and operation of a plant can also be accounted for by tracing their flow from the relevant originating industries either in monetary terms or in physical units.

For some fuels, ensuring timely availability entails considerable cost and management efforts. Electricity has to be provided by the utility at exactly the moment it is demanded. MESSAGE simulates this situation by subdividing each year into a number of so-called load regions. The parts of the year can be aggregated into one load region according to different criteria, for example, sorted according to power requirements or aggregation of typical consumption patterns (summer/winter, day/night). The latter (semi-ordered) load representation creates the opportunity to model energy storage as the transfer of energy (e.g., from summer to winter, or from night to day).

Environmental aspects can be analysed by keeping track of, and if necessary limiting, the amounts of pollutants emitted by various technologies at each step of the energy chain. This helps to evaluate the impact of environmental regulations on energy system development. The major inputs and outputs of MESSAGE are depicted in Fig. 10.3.

MESSAGE uses the projections of useful energy demand from MAED to generate the energy supply system. MESSAGE formulates and evaluates alternative energy supply strategies consonant with the criteria and constraints specified.

The most powerful feature of MESSAGE is that it provides the opportunity to define constraints among all types of technology related variables. The user can, among other options, limit one technology in relation to some other technologies (e.g. a maximum share of wind energy that can be handled in an electricity network), give exogenous limits on sets of technologies (e.g. a common limit on all technologies for sulphur dioxide (SO_2) emissions), or define additional constraints between production and installed capacity (e.g. ensure take-or-pay clauses in international gas contracts, forcing customers to consume or pay for a minimum share of their contracted level during summer months). The model is extremely flexible and can also be used to analyse energy/electricity markets and climate change issues.

10.2. STUDY APPROACH

For energy demand analysis, the economy is disaggregated into agriculture, construction, manufacturing, mining, households, services and transport. The manufacturing sector is further disaggregated into four subsectors: basic materials, machinery, equipment and miscellaneous, and chemicals. Transport activities include freight and passenger transport.

The supply and demand analyses are performed at the national level. However, for electricity, MESSAGE categorizes electricity demand separately for three regions: North and Northeast (NNE), South and Southeast (SSE) and Remote Areas (RA). The regional division is based on demographic and industrial concentrations and transmission capacities for flow of electricity among various geographic regions. Of these three regions, only the NNE and SSE regions are interconnected.

The year 2000 has been selected as the base year for the study because of the comprehensive

FIG. 10.3. Major inputs and outputs of MESSAGE.

quality of the data set for that particular year (some data for more recent years are still under review). However, the available data for more recent years were used to guide projections for those years, making projections closer to reality. A study horizon of 25 years, from 2000 to 2025 subdivided into five-year intervals, was chosen.

10.3. GENERAL ASSUMPTIONS AND CRITERIA

10.3.1. General assumptions

Both the quantitative description and the qualitative definition of the scenarios are based on numerous assumptions and criteria concerning sustainable energy development in Brazil. These were discussed extensively among experts from Brazil and from international organizations. The Brazilian teams of experts then selected the following policy objectives:

- Demography
  - The population will grow at a declining rate.
  - The level of urbanization will continue to increase.
- Economic situation
  - Economic recovery will continue, with annual gross domestic product (GDP) growth rates of about 4% in the long term.
  - Restructuring towards competitive markets will continue to proceed smoothly.
  - The stabilization process (inflation, external accounts, public accounts, etc.) will continue.
  - A favourable atmosphere for business is assumed.
  - National (financial and non-financial) organizations will support the expansion of energy infrastructure at large.
- Economic development
  - No major structural changes in the economy are assumed in the REF scenario.
  - Structural changes in the economy are assumed in the SHIFT scenario.
  - Income per capita will continue to grow at rates slightly above recent rates.
- International environment
  - Cooperation with other countries in the region will continue in the areas of trade, technology transfer and export–import of energy currencies.
  - International financial organizations will provide some support for the expansion of energy infrastructures.
  - A favourable atmosphere for foreign investment is assumed.
- Lifestyle
  - The housing situation will improve with respect to household size and number of occupants per dwelling.
  - The number of electrical appliances per average household will increase as a result of higher incomes.
  - The number of passenger vehicles will increase.
  - Mobility will increase within the country.
- Transport
  - More modern roads will be constructed to satisfy increasing intercity and urban travel.
  - The share of public transport will increase from current levels.
  - The share of freight transport by internal navigation and rail will increase from current levels.
- Technological improvements
  - Process efficiencies will increase above historically observed rates.
  - Non-commercial fuels will continue to be replaced by commercial fuels.
  - Indigenous technology use will increase substantially.

10.3.2. Sustainable energy criteria

The sustainable energy criteria defined by the Brazilian experts as being major priorities include the following generic characteristics:

- Energy options and technologies are progressively less environmentally damaging and minimize the transfer of intergenerational environmental costs (i.e. reducing local, regional and global pollution in the short, medium and long term).
- Renewable energy options are increasingly used.
- Supply options secure long term sustainable energy supply.
- Natural resources are used more efficiently.
- Energy supply chains create jobs and income.
- Energy options promote indigenous technology development.

- Energy options minimize energy vulnerability (enhance diversity in energy supply markets).
- Energy options permit optimal universal energy services (optimal national availability of energy services).

10.4. ENERGY DEMAND ANALYSIS

To ensure the credibility of the modelling exercise, it was verified that MAED could replicate past and present trends. After calibrating and reproducing the values of energy demand for the base year, a reference (REF) scenario and an alternate (SHIFT) scenario were developed. These two scenarios were developed representing consistent sets of four groups of scenario parameters: (a) demographic evolution, (b) economic development, (c) lifestyle change and (d) technology change. Both scenarios are based on the same demographic and economic growth but have different assumptions about the future structure of the economy. The scenarios also differ in their assumptions about improvements in technology, processes, efficiencies, and changes in the preferences and behaviour of people.

10.4.1. Quantitative scenario specification

10.4.1.1. Demography and economy

The assumptions about population and GDP projections are common to both scenarios. Table 10.1 shows projections of population and GDP and the corresponding annual growth rates. The population growth rates are based on the latest demographic census conducted in Brazil [10.2]. GDP growth assumptions are based on assumptions by the Ministry of Planning [10.3] that define long term economic growth in Brazil. These assumptions are in line with those of other recent macroeconomic studies [10.4–10.7].

10.4.1.2. Economic structure

In the REF scenario, the evolution of the structure of the economy is characterized by the growth of the GDP share of the industrial sector (manufacturing, energy, construction and mining) at the expense of the services sector. The most recent dynamics include a gradual increase in aggregated investment, a gradual decrease in government expenses (as a percentage of GDP), some gains in labour productivity and continued export of energy intensive products.

The SHIFT scenario presents a particular image of how the future could unfold based on different assumptions related to the structure of the economy. In the SHIFT scenario, a gradual change in the current dynamics is assumed, so that the increase in the industrial share and the corresponding decrease in the services share of GDP in the REF scenario are avoided. A substitution process takes place, particularly in industries and subsectors of the manufacturing sector. It assumes that efforts will be made to shift away from energy intensive industries (like steel, aluminium and other basic metals) and to emphasize high value added industries. A major change in the type of exports is assumed, from the current emphasis on raw materials to an increased share of finished goods.

TABLE 10.1. POPULATION AND GDP GROWTH

	2000		2005		2010		2015		2020		2025
Population (10^6)	171.3		185.7		198.5		210.2		220.9		230.8
Annual growth rate[a] (%)		1.63		1.34		1.16		1.00		0.85	
GDP (10^9 US $ 2000-PPP)	1 151		1 365		1 682		2 057		2 509		3 060
Annual growth rate[a] (%)		3.47		4.26		4.11		4.05		4.05	
GDP per capita[b] (US $ 2000-PPP per capita)	6 719		7 351		8 475		9 788		11 360		13 261

[a] Annual growth rate for five-year periods.

[b] The per capita GDP for the year 2000 based on exchange rates was US $3513.

TABLE 10.2. ECONOMIC STRUCTURE: SECTORAL SHARES OF GDP (%)

Sector	2000	2005	2010	2015	2020	2025
			REF			
Agriculture	7.7	7.7	7.4	7.2	6.9	6.6
Construction	9.6	9.6	10.7	12.0	13.2	14.5
Mining	0.4	0.5	0.6	0.6	0.7	0.7
Manufacturing	18.6	18.9	19.7	20.3	20.7	21.1
Energy	7.2	8.0	8.1	8.1	8.1	8.0
Services	56.6	55.2	53.5	51.8	50.4	49.0
			SHIFT			
Agriculture	7.7	8.4	8.5	8.2	7.6	6.8
Construction	9.6	8.6	9.3	10.5	10.4	9.7
Mining	0.4	0.5	0.5	0.4	0.4	0.3
Manufacturing	18.6	18.1	18.4	18.6	18.5	18.3
Energy	7.2	8.1	8.3	8.4	7.9	7.0
Services	56.6	56.3	55.1	53.9	55.2	57.9
Total GDP (10^9 US $ 2000-PPP)	1151	1365	1682	2057	2509	3060

The REF and SHIFT scenarios for the structure of the Brazilian economy are presented in Table 10.2. In the REF scenario, the manufacturing share (in terms of shares of value added) increases from 18.6% in 2000 to 21.1% in 2025, while the services sector contracts from 56.6% to 49.0%. There are also increases in the shares of the construction, energy and mining sectors. In the SHIFT scenario, the GDP structure projected for 2025 remains about the same as that for 2000, with only a slight increase in the services sector, from 56.6% to 57.9%. The sectoral annual growth rates for both scenarios are presented in Table 10.3.

TABLE 10.3. SECTORAL ANNUAL GROWTH RATES (%)

Sector	2000–2005	2005–2010	2010–2015	2015–2020	2020–2025
			REF		
Agriculture	3.59	3.51	3.47	3.27	3.10
Construction	3.52	6.52	6.44	6.19	6.02
Mining	11.24	6.63	6.09	5.91	5.74
Manufacturing	3.83	5.10	4.68	4.51	4.42
Energy	5.90	4.41	4.14	3.99	3.88
Services	2.95	3.61	3.47	3.44	3.49
			SHIFT		
Agriculture	5.51	4.41	3.25	2.45	2.00
Construction	1.27	5.74	6.78	3.92	2.53
Mining	9.08	4.15	2.77	1.31	0.47
Manufacturing	2.88	4.60	4.36	3.95	3.78
Energy	5.99	4.93	4.39	2.59	1.57
Services	3.37	3.80	3.65	4.58	5.03

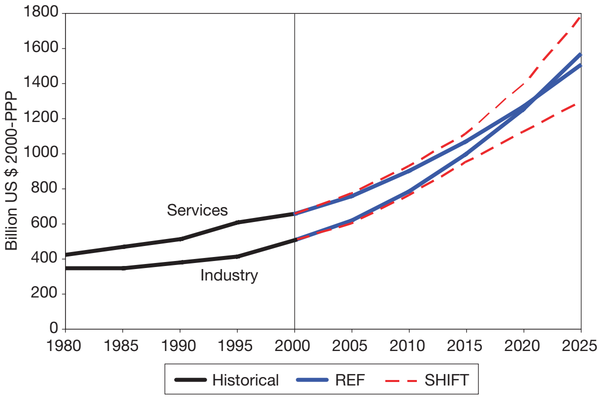

FIG. 10.4. Value added of major economic sectors, historical values and projections.
Note: *Historical data from Ref. [10.8].*

The historical evolution and the projections for the two major economic sectors (industry and services) for both scenarios are presented in Fig. 10.4.

MAED considers the evolution of the economy at a sectoral level and only for an aggregated selection of subsectors of the manufacturing sector. Further changes are assumed within subsectors and in specific industries of the manufacturing sector, which are major factors determining energy use in the REF and SHIFT scenarios.

Within the manufacturing sector, in line with the overall shift away from highly energy intensive industries, the SHIFT scenario assumes a reduction of about 1.9 percentage points by 2025 in the share of value added by the basic material industries and an increase of about 3.2 percentage points in the share of value added by non-durable (consumer) goods (Table 10.4). In the REF scenario, the value added shares of the basic materials and the machinery, equipment and miscellaneous subsectors increase by 2.1 and 5.9 percentage points, respectively, while those of the non-durable goods subsector decrease by about 7.9 percentage points. The shares of value added by the chemical industries are projected to decrease slightly in the SHIFT scenario and to remain stable in the REF scenario. These structural changes within the manufacturing sector will have a significant impact on energy requirements in the two scenarios, as the energy intensities in these subsectors are different from each other.

The expected evolution of value added by the subsectors of the manufacturing sector is presented in Table 10.5 for the REF and SHIFT scenarios.

10.4.1.3. Lifestyle parameters

Scenario data for selected lifestyle parameters are presented in Table 10.6. The selected parameters are for the household, transport and services sectors. The number of persons per dwelling is assumed to decrease at the same rate in both scenarios. The share of electrified dwellings is assumed to increase in both scenarios, reaching 100% by 2025, implying full accessibility of electricity. Specific electricity use per dwelling increases over the entire period in both scenarios; however, the values for 2005 are lower than those for 2000, because after the 2001 electricity crisis

TABLE 10.4. MANUFACTURING SUBSECTORS, SHARES OF VALUE ADDED (%)

Subsector	2000	2005	2010	2015	2020	2025
			REF			
Basic materials	16.8	16.8	17.2	17.8	18.4	18.9
Machinery, equipment and miscellaneous	37.3	38.9	40.2	41.3	42.3	43.2
Non-durables	25.3	23.8	22.1	20.4	18.9	17.4
Chemicals	20.6	20.6	20.5	20.5	20.5	20.5
			SHIFT			
Basic materials	16.8	15.9	15.9	15.6	15.3	14.9
Machinery, equipment and miscellaneous	37.3	38.4	38.2	37.9	37.8	37.6
Non-durables	25.3	25.6	26.6	27.5	28.0	28.5
Chemicals	20.6	20.0	19.3	19.0	18.9	18.9

TABLE 10.5. VALUE ADDED BY MANUFACTURING SUBSECTORS (10^9 US $ 2000-PPP)

Subsector	2000	2005	2010	2015	2020	2025
			REF			
Basic materials	36.0	43.4	56.9	74.0	95.4	122.2
Machinery, equipment and miscellaneous	80.0	100.6	133.4	172.2	219.8	278.8
Non-durables	54.3	61.4	73.3	85.2	98.0	112.1
Chemicals	44.1	53.2	68.1	85.5	106.5	132.1
Total	214.3	258.6	331.7	416.9	519.7	645.2
			SHIFT			
Basic materials	36.0	39.2	49.2	59.8	71.2	83.4
Machinery, equipment and miscellaneous	80.0	95.0	118.1	145.2	175.5	210.5
Non-durables	54.3	63.3	82.4	105.3	130.3	159.7
Chemicals	44.1	49.5	59.7	72.8	87.9	106.0
Total	214.3	247.0	309.4	383.0	464.9	559.6

there was a slow recovery, and a full recovery was not expected by 2005. Automobile ownership is assumed to increase at the same rate in both scenarios, but the rate of increase in intercity travel by automobile is slightly higher in the REF case than in the SHIFT case.

10.4.1.4. Technology

Like structural economic change, technology is a major factor that determines energy intensities (i.e. the energy required per unit of value added or per unit of physical production/activity). While energy intensities in Brazil have not been improving recently, annual average improvements of 1% per year have been observed at the global level over extended periods of time. Thus, there will likely be some autonomous improvements, as have been observed in the past, but specific and targeted policies and programmes (e.g. PROCEL, see Chapter 4) will result in higher reductions in the energy intensities compared with those experienced in the past. The SHIFT scenario therefore assumes a considerable reduction in energy intensities,

TABLE 10.6. SELECTED LIFESTYLE PARAMETERS IN THE REF AND SHIFT SCENARIOS

Parameter		2000	2005	2010	2015	2020	2025
Household size* (persons/dwelling)		3.8	3.5	3.4	3.3	3.2	3.1
Electrified dwellings* (%)		94.5	95.6	96.7	97.8	98.9	100
			Specific electricity use (kW·h) per dwelling				
	REF	1488	1235	1510	1783	2076	2140
	SHIFT	1488	1201	1430	1709	1953	1917
Automobile ownership* (automobiles/1000 persons)		93	105	111	121	135	155
		Mobility — Intercity travel (average distance travelled, km/automobile/year)					
	REF	2716	2740	3146	3748	4552	6779
	SHIFT	2716	2740	3116	3692	4470	6634
Total service floor area* (10^6 m^2)		264	292	315	336	356	373

* Same for both scenarios.

TABLE 10.7. ENERGY INTENSITY ASSUMPTIONS FOR THE MANUFACTURING SECTOR (2000 = 1.00)

Scenario	2000	2005	2010	2015	2020	2025
			Motor fuel			
REF	1.00	1.00	1.01	1.02	1.03	1.04
SHIFT	1.00	0.99	0.98	0.97	0.97	0.96
			Electricity			
REF	1.00	1.00	1.00	1.01	1.02	1.03
SHIFT	1.00	0.98	0.96	0.94	0.92	0.90
			Thermal use			
REF	1.00	0.98	0.96	0.95	0.94	0.93
SHIFT	1.00	0.98	0.96	0.92	0.88	0.84

TABLE 10.8. ASSUMED CHANGES IN ENERGY INTENSITY FOR THERMAL USES, 2000–2025 (% per year)

Sector	REF	SHIFT
Agriculture	0	–0.35
Mining and construction	–0.42	–0.88
Manufacturing	–0.31	–0.71

especially in the manufacturing sector, as shown in Table 10.7. These reductions will occur as a result of new additions and replacement of existing capital stock with more efficient technologies and processes. According to Geller [10.9], there is a considerable technical potential throughout the Brazilian economy for reduction in energy intensities.[1] The REF scenario assumes energy intensity reductions only in thermal use. The energy intensities in motor fuel and electricity are assumed to increase in the REF case during the period considered here. This case assumes that the increasing trends observed in these two categories in the past will continue, but at a much slower pace.

Table 10.8 shows the average annual rate of reduction in energy intensities for thermal uses of energy in the agriculture, mining and construction, and manufacturing sectors assumed in the two scenarios.

10.4.2. Results — Final energy demand

The projections of final energy demand by sector are presented in Tables 10.9 and 10.10 for the REF and SHIFT scenarios, respectively. The total final energy demand grows 2.5-fold in the REF scenario and 2.1-fold in the SHIFT scenario over the 25-year period. The SHIFT scenario projects a total final energy demand of 13 973 PJ by 2025 (from 6662 PJ in 2000), or about 16% lower than the

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[1] See Chapters 2, 4 and 9.

TABLE 10.9. TOTAL FINAL ENERGY DEMAND, REF SCENARIO

	2000	2005	2010	2015	2020	2025
Total final (PJ)	6 662	7 810	9 379	11 177	13 647	16 654
			Shares by sector (%)			
Industry	38.5	38.3	41.1	43.7	45.1	46.6
Agriculture	4.6	4.7	4.6	4.6	4.4	4.2
Transport	29.8	30.9	28.5	26.6	25.7	25.1
Residential	13.0	12.2	11.6	10.4	9.9	8.9
Services/commercial	5.2	4.8	4.2	3.7	3.2	3.0
Feedstocks	9.0	9.2	10.1	11.0	11.6	12.2

TABLE 10.10. TOTAL FINAL ENERGY DEMAND, SHIFT SCENARIO

	2000	2005	2010	2015	2020	2025
Total final (PJ)	6 662	7 724	9 042	10 405	11 981	13 973
			Shares by sector (%)			
Industry	38.5	37.2	39.2	40.8	41.4	41.2
Agriculture	4.6	5.2	5.5	5.5	5.4	5.0
Transport	29.8	31.3	29.5	28.8	28.5	29.9
Residential	13.0	12.2	11.6	10.5	10.3	9.5
Services/commercial	5.2	4.6	4.1	3.7	3.3	3.1
Feedstocks	9.0	9.5	10.2	10.8	11.1	11.2

energy demand of 16 654 PJ projected in the REF scenario for the same year. The low demand in the SHIFT scenario is due to the fact that this scenario assumes an economy based on less energy intensive industries and larger reductions in energy intensities.

In the REF scenario, the industrial sector experiences the largest increase in total energy demand, with its share increasing 8.1 percentage points and reaching 46.6% in 2025. Conversely, the shares of the agriculture, transport, residential and services/commercial sectors decrease during the same period. In the SHIFT scenario, the final energy demand share of the industrial sector increases, but only to 41%. In both scenarios, the biggest consumer is the industrial sector, followed by the transport sector. Figure 10.5 presents the projections of total final energy demand by sector in the REF and SHIFT scenarios.

10.5. ENERGY SUPPLY ANALYSIS

MESSAGE defines optimal energy supply systems for the alternative scenarios based on a set of inputs including the following:

- A description of the existing energy supply system and associated infrastructure from domestic resource extraction of all primary sources available (coal, oil, natural gas, biomass, nuclear, hydropower, wind, solar, etc.) to refineries, power plants, other conversion plants, and transmission and distribution systems for all fuels, including oil products, other liquids, natural gas, solids, electricity and heat;
- Technical, economic and environmental characteristics of all energy conversion technologies and processes of the national energy supply system, as well as the technology candidates potentially available in the future;
- Energy trade, for example, oil and oil products, natural gas, ethanol, coal and electricity;
- Environmental protection requirements.

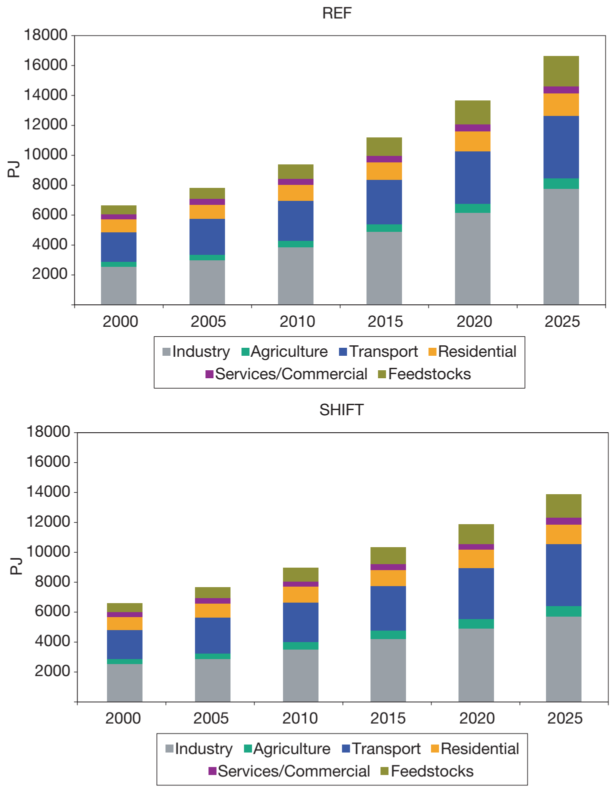

FIG. 10.5. Final energy demand (PJ) by sector.

10.5.1. Energy supply system and scenario assumptions

The specific assumptions, constraints and other conditions stipulated by the Brazilian experts for the definition of the two scenarios are listed in Table 10.11.

10.5.1.1. Oil and natural gas

Future production of oil and gas from indigenous resources is expected to increase considerably as a result of continued efforts in exploration, resulting in new discoveries. Most of the undiscovered oil and gas resources are located

TABLE 10.11. SCENARIO ASSUMPTIONS, CONSTRAINTS AND OTHER CONDITIONS

	Scenario	Assumptions, constraints and conditions
Coal	REF	No restrictions on imports of coal Domestic coal production kept at current levels
	SHIFT	Domestic coal production kept at current levels Charcoal replaces 90% of coal requirements for metallurgical industry by 2025
Natural gas	REF and SHIFT	GASBOL (Bolivia) pipeline expanded from 30 to 60 million m^3/d MERCOSUR (Argentina) pipeline fully operating at 15 million m^3/d by 2015 Domestic production of associated gas linked to oil production and non-associated gas based on resource depletion
Oil/oil products	REF	No restrictions
	SHIFT	No net oil imports (trading of crude and products) Upper limit on oil product imports set at 30% of total oil imports (today LPG alone is 30%) LPG and diesel imports limited to 15%
Hydropower	REF	Minimum power density of 64 kW/ha 10% above today's average costs for large plants (US $1110/kW in Amazonia; US $800/kW in other regions)
	SHIFT	Minimum power density of 64 kW/ha 10% above today's average costs for large plants (US $1110/kW in Amazonia; US $800/kW in other regions) Maximum 20% exploitation of remaining resources in Amazonia
Nuclear	REF	No new plants except Angra III
	SHIFT	No new plants, not even Angra III
Wind, small hydropower and biomass for electricity (PROINFA)	REF and SHIFT	A minimum 10% share in national electricity matrix in 2025
Sugar cane	REF	Starting in 2010, 40% of new light vehicles to be flex-fuel, using pure ethanol 70% and gasohol 30% of the time
	SHIFT	Starting in 2010, 70% of new light vehicles to be flex-fuel, using pure ethanol 70% and gasohol 30% of the time
Coal fired thermal plants	REF	New plants with minimum technology requirements: pulverized coal firing + scrubbers, precipitators, filters (particulates and SO_x controls)
	SHIFT	All plants required to have fluidized bed combustion technology and particulates, SO_x and NO_x controls or integrated gasification combined cycle (IGCC)
Natural gas fired plants	REF and SHIFT	Dry cooling

offshore. In 2003, the oil production from offshore fields was 1.27 million bbl/d (2648 PJ/year), or 85% of total production, while that from onshore fields was only 0.224 million bbl/d (467 PJ/year). The share of offshore in total oil production is expected to remain about the same. Keeping this resource picture in view, assumptions about the maximum oil production profile were developed following the trend of an adjusted Hubbert curve [10.10]. An increasing trend in domestic oil production is assumed to continue until 2020, when resource limitations will force a reversal in this trend.

Gas production assumptions take into account both associated and non-associated gas. Future associated gas production is linked to the corresponding oil production levels. Assumptions about production of non-associated gas consider recent discoveries, such as the 2003 offshore natural gas field discovery in São Paulo State. Most of Brazil's gas reserves are located offshore. Limits on the production of non-associated gas are based on an assumed depletion rate of the total amount of gas resources available.

As for crude oil refining, four groups of refineries differentiated on the basis of product mix and investment costs are considered in the analysis. Table 10.12 lists the refinery groups with corresponding product mixes.

10.5.1.2. Coal

In view of the poor quality of domestic coal, no increase beyond the present production levels is assumed for the future. Imports of coal are assumed to continue and may increase, but strict environmental standards will be imposed on its use, particularly for power plants. In the SHIFT scenario, coal imports are not allowed for electricity generation. In the REF scenario, coal power plants with flue gas desulphurization equipment are allowed, whereas in the SHIFT scenario only fluidized bed combustion technology is allowed.

10.5.1.3. Renewables

In addition to hydropower, the model includes fuelwood, sugar cane, energy crops for biodiesel, wind and solar. Sugar cane is considered for ethanol production (for direct use in neat ethanol and/or flex-fuel vehicles and for blending with gasoline in gasoline and/or flex-fuel vehicles), and its by-product, bagasse, is considered for both industrial thermal uses and electricity production. Likewise, fuelwood is considered for charcoal conversion and direct burning in households and in the commercial and industrial sectors, as well as for power generation. In the SHIFT case, charcoal replaces 90% of coal requirements in the metallurgical industry by 2025. Wind power technology is assumed to be introduced both for grid and non-grid supply. Its investment cost declines as a result of technology learning worldwide, while performance increases as experience with this technology accumulates in the country. Photovoltaics are also considered for electricity supply, but for remote areas only.

10.5.1.4. Hydropower system

Hydropower is one of the most important options for energy supply in Brazil, currently contributing about 80–85% of the total electricity generation or 75–80% of the total electricity supply (when electricity imports are considered in the total). The water flows in rivers vary drastically within any given year, but the large storage dams help smooth out, to a large extent, the electric generating capability during the year. In fact, the capacity of dams is designed for multi-year water storage and regulation. They provide a security margin in case of an abnormally dry year.

TABLE 10.12. REFINERY GROUPS AND CORRESPONDING PRODUCT MIXES

	Oil products (%)				
	Light	Medium	Heavy	LPG	Non-energy
Group 1	19.5–23.8	39.0–47.5	10.1–22.9	8.1–9.1	9.6–11.3
Group 2	26.0–43.0	12.7–30.0	14.0–52.6	6.0–6.3	2.0–2.1
Group 3	23.8–34.1	14.6–44.6	11.6–46.6	9.0–9.5	5.0–5.3
Group 4	22	21	19.8	2.4	14

For this study, the hydropower plants are grouped into several categories based on size and geographic location. On the basis of size, the plants are classified as small (up to 30 MW), medium sized (from 30 to 600 MW) or large (more than 600 MW). The small and medium sized categories are grouped into three regions — North and Northeast (NNE), South and Southeast (SSE) and Remote Areas (RA) — whereas the large hydropower plants are grouped into four regions — South, Southeast, North and Northeast. This representation of hydropower allows supply and demand to be matched on a regional basis and, more importantly, allows the use of water to be optimized within a year and over a number of years for large hydropower plants.

There is a large potential for additional hydropower development in Brazil. In the Amazon region alone, over 100 000 MW of unexploited hydropower potential exists. Two large hydropower projects with a total capacity of about 20 000 MW are being considered for development in this region. Additionally, some 10 000 MW capacity can be developed in the SSE region.

As for small and medium sized hydropower, a total of about 6300 MW of additional capacity (with respect to the capacity available in 2000) is expected to be put online by 2006. Additionally, some 9000 MW capacity in this size group can be developed. In this study, all these hydropower projects are expected to comply with the criterion of a minimum of 64 kW per hectare of submerged land. Altogether, it is assumed that about 50 000 MW of additional hydropower capacity can be built by 2025. These hydropower developments are staggered over time and are included in the model as maximum capacity buildup bounds.

10.5.1.5. Import–export

Trade in all main fuels, primary as well as refined, is allowed in the REF scenario and with some restrictions in the SHIFT case. No ‘net’ imports of oil (oil and oil products) are allowed in the SHIFT scenario, and a limit on imports of oil products is set at 30% of total oil imports. Imports of liquefied petroleum gas (LPG) and diesel are also limited to 15%. Coal imports are excluded for electricity generation in the SHIFT scenario.

With respect to gas imports, planned and proposed expansions in the gas pipeline from Bolivia are included. Currently, this pipeline is 1173 km and has a capacity of 16 million m^3/d (0.60 PJ/d). The capacity can be increased to 30 million m^3/d (1.12 PJ/d) by 2008 by adding a compression facility. Further expansion of up to 60 million m^3/d (2.24 PJ/d) by 2025 is considered. Additionally, a new gas pipeline from Argentina, being planned at a cost of US $250 million with a capacity of 15 million m^3/d (0.56 PJ/d), is expected to become operational by 2015. Also, there is the possibility of importing liquefied natural gas from Trinidad and Tobago.

Table 10.13 lists the assumed prices for imported fuels. The assumed prices for various petroleum products are linked to crude oil price projections according to specific proportions.

10.5.1.6. Electricity supply system

Based on demographic and industrial concentrations and transmission capacities for flow of electricity among various geographical regions, the model categorizes electricity demand separately for the NNE, SSE and RA regions. The model considers all available options for electricity

TABLE 10.13. ASSUMED PRICES FOR IMPORTED FUELS

Fuel	2005	2010	2015	2020	2025
Crude oil (US $/bbl)	40.9	29.0	30.1	30.0	30.0
(US $/toe)	300.0	212.4	220.4	220.4	220.4
Light oil products (US $/toe)	396.1	280.4	290.9	290.9	290.9
Medium oil products (US $/toe)	366.1	259.1	268.9	268.9	268.9
Heavy oil products (US $/toe)	240.0	169.9	176.3	176.3	176.3
LPG (US $/toe)	264.0	186.9	193.9	193.9	193.9
Natural gas (US $/1000 m^3)	130.0	130.0	130.0	130.0	130.0
(US $/toe)	146.0	146.0	146.0	146.0	146.0
Coal (US $/tce)	47.3	47.3	47.3	47.3	47.3

generation, including hydropower, coal, gas, oil, nuclear and a number of renewable technologies. An important feature for electricity supply is transmission lines for exchange of power between the NNE and SSE regions. As the peak occurs at different times in the two regions, the flow could be in both directions. Also, as most of the new hydropower sites are in the North, if economically justified, larger amounts of power are expected to flow from North to South.

A review of the load pattern in the two grid systems shows that the peak demand occurs at different times in the two systems and shifts during different seasons. The grids are interconnected with limited power transfer capacity, which in 2000 was 920 MW from SSE to NNE and 726 MW from NNE to SSE (the difference in exchange capacity is due to stability conditions). The two systems exchange power at different hours depending on the timing of the respective peaks and the available generating capacity. The capacity of interconnection was expanded to about 2600 MW in 2005. Further expansion of up to 10 000 MW is assumed by 2025.

In addition to hydropower, which continues to be the main option for new capacity for electricity generation, a number of power technologies are considered for future expansion of the electricity systems. The cost and performance data for these technologies are presented in Table 10.14.

10.5.2. Scenario results

10.5.2.1. Primary energy supply and final energy demand

Based on the assumptions discussed in previous sections, the energy supply system is optimized for the two scenarios to satisfy the respective total energy demand. The resulting projections of primary energy supply are presented in Table 10.15 for the REF scenario and in Table 10.16 for the SHIFT scenario. Figure 10.6 shows the primary energy supply by fuel for both scenarios.

The total primary energy supply (TPES) grows at a faster pace in the REF scenario (4.2% per year) than in the SHIFT scenario (3.7% per year). By 2025, the TPES in the SHIFT scenario is about 13% below that of the REF scenario.

Primary energy supplies from domestic sources are very similar in both scenarios throughout the period considered, reflecting the optimal use of projected availability of domestic resources. The main differences in the evolution of the energy supply structures are the level of imports and the share of renewables.

TABLE 10.14. COST AND PERFORMANCE DATA FOR VARIOUS ELECTRICITY GENERATION TECHNOLOGIES

Technology	Efficiency (%)	Capacity factor (%)	O&M costs[a] (US $/MWh)	Investment[a,b] (US $/kW)	Construction time (years)
Hydropower, small	n.a.[c]	64	4.4	1570	2
Hydropower, medium	n.a.[c]	55	1.5	1230	4
Hydropower, large	n.a.[c]	53.5	2.3	1110 or 800[d]	7
Coal	35	80	15	1300	4
Gas combined cycle	50	85	7	495–420[e]	3
Gas open cycle	35	85	8.7	350	2
Oil	30	85	7	1070	3
Biomass	25	70	2.7	900	3
Nuclear	33	80	10.5[f]	1535–1228[e]	5
Wind	n.a.[c]	25	10	1000–800[e]	2

[a] All costs are in 2000 US $; O&M: operation and maintenance costs.

[b] Investments do not include interest during construction.

[c] Not applicable.

[d] US $1110/kW for Amazonia and US $800/kW for large hydropower plants in other regions.

[e] Investment costs decrease over time.

[f] Includes fuel costs.

TABLE 10.15. TOTAL PRIMARY ENERGY SUPPLY, REF SCENARIO (PJ)

Domestic	2000	2005	2010	2015	2020	2025
			Domestic			
Coal	109	110	110	110	110	110
Gas	348	482	931	1 304	1 389	1 255
Oil	2 668	3 311	4 983	6 528	7 092	6 875
Hydropower	1 096	1 246	1 396	1 517	1 763	1 955
Nuclear	84	150	250	199	199	199
Renewables	1 984	3 184	4 049	4 927	6 156	7 584
Total	6 289	8 484	11 719	14 585	16 710	17 979
			Net imports			
Coal	456	568	680	878	1 129	1 501
Gas	81	309	543	941	1 461	1 955
Oil	1 042	561	–539	–1 486	–1 041	998
Electricity	160	113	70	66	112	225
Total	1 739	1 551	755	399	1 662	4679
			Domestic + Imports			
Coal	566	678	791	988	1 239	1 612
Gas	429	791	1 474	2 245	2 850	3 210
Oil	3 710	3 872	4 443	5 042	6 052	7 873
Hydropower	1 096	1 246	1 396	1 517	1 763	1 955
Nuclear	84	150	250	199	199	199
Renewables	1 984	3 184	4 049	4 927	6 156	7 584
Electricity (imports)	160	113	70	66	112	225
Total	8 028	10 036	12 473	14 984	18 372	22 659
			Fuel share (%)			
Coal	7.05	6.76	6.34	6.59	6.74	7.11
Gas	5.35	7.88	11.82	14.98	15.51	14.17
Oil	46.21	38.59	35.62	33.65	32.94	34.75
Hydropower	13.65	12.42	11.19	10.12	9.59	8.63
Nuclear	1.04	1.50	2.00	1.33	1.09	0.88
Renewables	24.71	31.73	32.46	32.88	33.51	33.47
Electricity (imports)	1.99	1.13	0.56	0.44	0.61	0.99
Total	100	100	100	100	100	100

Total imports follow a decreasing trend during the first time periods but face a reversal by 2015 in both scenarios. The reduction in total imports is mainly related to major increases in domestic oil production. In fact, oil imports are projected to stop before 2010, when the country actually becomes a net oil exporter. The trend in net oil exports continues in the SHIFT case up to the end of the period considered, but is reversed in the REF case before 2025. By 2025, total imports represent 21% of the TPES in the REF case and 9% in the SHIFT case.

In terms of fuel shares, renewables and gas gain considerable shares throughout the projected period against all other fuels and mainly with respect to oil. The renewables share grows from 25% to 33% in the REF scenario and to 39% in the SHIFT scenario. The gas share grows from 5% to 14% in the REF scenario and 12% in the SHIFT scenario. The gain in the shares of renewables

TABLE 10.16. TOTAL PRIMARY ENERGY SUPPLY, SHIFT SCENARIO (PJ)

Domestic	2000	2005	2010	2015	2020	2025
Domestic						
Coal	109	110	110	110	110	110
Gas	348	482	931	1 304	1 389	1 255
Oil	2 668	3 311	4 983	6 528	7 092	6 875
Hydropower	1 096	1 244	1 401	1 602	1 796	1 950
Nuclear	84	150	150	100	100	100
Renewables	1 984	3 178	4 041	5 087	6 234	7 645
Total	6 289	8 476	11 616	14 731	16 722	17 935
Net imports						
Coal	456	578	663	656	723	971
Gas	81	243	250	415	529	1 102
Oil	1 042	593	–500	–1 526	–1 380	–389
Electricity	160	76	82	63	122	126
Total	1 739	1 490	495	–392	–5	1 810
Domestic + Imports						
Coal	566	688	773	766	834	1 082
Gas	429	724	1 181	1 718	1 918	2 357
Oil	3 710	3 905	4 483	5 002	5 713	6 486
Hydropower	1 096	1 244	1 401	1 602	1 796	1 950
Nuclear	84	150	150	100	100	100
Renewables	1 984	3 178	4 041	5 087	6 234	7 645
Electricity (imports)	160	76	82	63	122	126
Total	8 028	9 966	12 111	14 339	16 716	19 745
Fuel share (%)						
Coal	7.0	6.9	6.4	5.3	5.0	5.5
Gas	5.3	7.3	9.8	12.0	11.5	11.9
Oil	46.2	39.2	37.0	34.9	34.2	32.8
Hydropower	13.6	12.5	11.6	11.2	10.7	9.9
Nuclear	1.0	1.5	1.2	0.7	0.6	0.5
Renewables	24.7	31.9	33.4	35.5	37.3	38.7
Electricity (imports)	2.0	0.8	0.7	0.4	0.7	0.6
Total	100	100	100	100	100	100

results from strong market penetration of alcohol, biomass and wind, and for gas from strong annual growth rates in the use of both domestic and imported gas. Recent uncertainties related to the potential for incorporating non-associated natural gas reserves from the Santos Basin do not weaken the assumptions made about natural gas supply for the domestic market, as additional imports of liquefied natural gas could make up the difference.

Hydropower supply almost doubles by 2025 in both scenarios; however, its share in total primary energy supply decreases from 14% in 2000 to about 9–10% by 2025. Energy supplies from nuclear differ in the two scenarios because of the assumption in the SHIFT scenario that not even the third Brazilian nuclear plant currently under construction (Angra III) will enter operation between now and 2025.

The final energy demand by fuel is presented in Tables 10.17 and 10.18 for the REF and SHIFT scenarios, respectively. The evolution of the final energy demand is very similar in the two scenarios. The main difference is the relatively higher demand

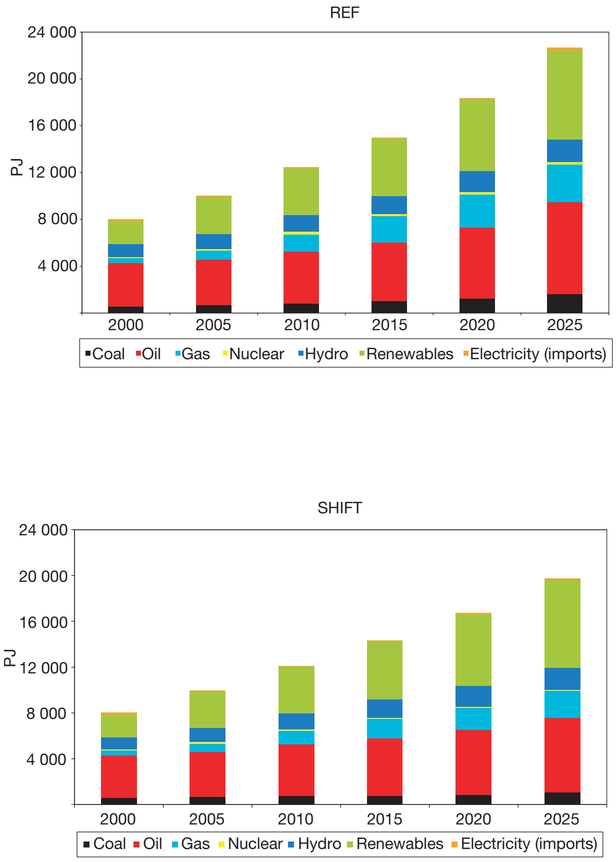

FIG. 10.6. Total primary energy supply (PJ).

for alcohol and other renewables in the SHIFT scenario balanced by the relatively lower demand for fossil fuels. Other renewables include fuelwood, biodiesel, charcoal, bagasse and other vegetable residues.

10.5.2.2. Electricity generation

Electricity generation and imports for the REF and SHIFT scenarios are presented in Tables 10.19 and 10.20, respectively. Total electricity generation grows at a slower pace in the SHIFT scenario (3.3% per year) than in the REF scenario (4.0% per year). By 2025, electricity generation in the SHIFT scenario is about 14% lower than in the REF scenario.

In both scenarios, hydropower continues to be the largest contributor to electricity generation throughout the period considered (see Fig. 10.7). Its share, however, decreases from 77% in 2000 to 52% in the REF scenario and 61% in the SHIFT scenario by 2025. This reduction is mainly balanced by share increases in gas, renewables and wind. Gas becomes the second largest contributor to electricity generation, and by 2025 its share reaches 23% in both scenarios. Wind and renewables also grow at a rapid pace, gaining considerable shares.

TABLE 10.17. FINAL ENERGY DEMAND BY FUEL, REF SCENARIO (PJ)

	2000	2005	2010	2015	2020	2025
Oil	3 354	3 397	3 957	4 763	5 687	6 726
Coal	443	563	702	889	1 148	1 501
Gas	211	420	549	644	904	1 288
Electricity	1 156	1 331	1 650	2 014	2 496	3 057
Alcohol	270	307	529	712	909	1 198
Other renewables	1 227	1 535	1 828	2 150	2 522	2 979
Total	6 661	7 554	9 215	11 172	13 667	16 750

TABLE 10.18. FINAL ENERGY DEMAND BY FUEL, SHIFT SCENARIO (PJ)

	2000	2005	2010	2015	2020	2025
Oil	3 354	3 434	3 893	4 455	5 092	5 865
Coal	443	573	685	680	767	1 002
Gas	211	355	467	609	629	686
Electricity	1 156	1 294	1 559	1 863	2 233	2 605
Alcohol	270	307	529	712	909	1 314
Other renewables	1 227	1 538	1 821	2 225	2 612	2 967
Total	6 661	7 501	8 955	10 545	12 242	14 439

TABLE 10.19. ELECTRICITY GENERATION AND IMPORTS, REF SCENARIO (TW·h)

	2000	2005	2010	2015	2020	2025
Hydropower	304.4	346.2	387.8	421.3	489.6	543.2
Coal	8.3	8.1	4.8	4.8	2.5	2.5
Oil	15.2	6.5	6.3	4.1	4.2	64.8
Gas	4.1	38.3	105.3	189.8	235.6	235.6
Nuclear	6.0	13.8	22.9	18.3	18.3	18.3
Renewables	10.9	14.4	19.2	28.0	56.1	79.7
Wind	0.0	0.1	1.6	6.5	17.0	36.3
Imports	44.2	31.5	19.4	18.2	31.2	62.5
Total	393.1	458.8	567.2	690.9	854.6	1043.0
				Share (%)		
Hydropower	77.44	75.46	68.37	60.98	57.30	52.08
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	0.50	6.22
Gas	1.03	8.34	18.56	27.46	27.57	22.59
Nuclear	1.54	3.00	4.04	2.65	2.14	1.75
Renewables	2.77	3.13	3.39	4.05	6.56	7.64
Wind	0.00	0.02	0.28	0.94	1.99	3.48
Imports	11.24	6.86	3.43	2.64	3.66	5.99
Total	100	100	100	100	100	100

TABLE 10.20. ELECTRICITY GENERATION AND IMPORTS, SHIFT SCENARIO (TW·h)

	2000	2005	2010	2015	2020	2025
Hydropower	304.4	345.7	389.2	445.0	498.8	541.5
Coal	8.3	8.1	4.8	4.8	2.5	2.5
Oil	15.2	6.1	10.1	4.7	7.3	1.1
Gas	4.1	38.0	75.9	121.5	144.3	200.7
Nuclear	6.0	13.8	13.8	9.2	9.2	9.2
Renewables	10.9	13.7	19.2	34.0	56.3	79.7
Wind	0.0	0.2	1.3	5.3	13.9	22.3
Imports	44.2	21.2	22.7	17.6	34.0	35.1
Total	393.1	446.6	536.8	642.0	766.2	892.2
				Share (%)		
Hydropower	77.44	77.39	72.50	69.31	65.10	60.70
Coal	2.10	1.81	0.89	0.74	0.33	0.28
Oil	3.88	1.37	1.87	0.74	0.95	0.13
Gas	1.03	8.50	14.13	18.92	18.84	22.49
Nuclear	1.54	3.09	2.57	1.43	1.20	1.03
Renewables	2.77	3.06	3.57	5.30	7.34	8.94
Wind	0.00	0.05	0.24	0.82	1.81	2.50
Imports	11.24	4.74	4.22	2.74	4.43	3.93
Total	100	100	100	100	100	100

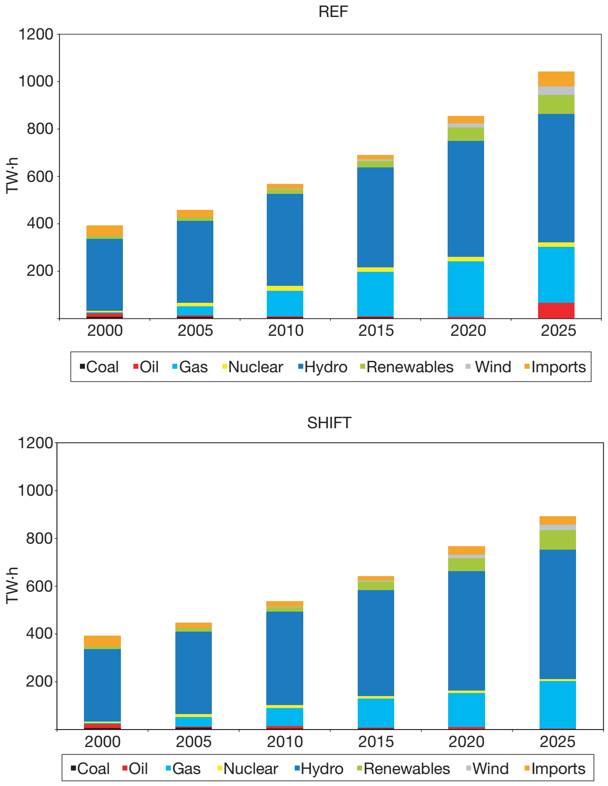

FIG. 10.7. Electricity generation (TW·h) by fuel.

Electricity generation using coal and oil decreases considerably in both scenarios, although in the REF case an increase in the use of oil is observed in the last period, when least cost scenario options are exhausted. The return to higher electricity imports and oil electricity generation in the REF case reflects constraints in the use of least cost scenario options in the later years.

10.5.2.3. Electric generating capacity

The evolution of electric generating capacity is shown in Table 10.21 for the REF scenario and in Table 10.22 for the SHIFT scenario. The overall capacity grows at an annual rate of 4.0% in the REF scenario and 3.6% in the SHIFT scenario. By 2025, the capacity in the SHIFT scenario is about 9% lower than that in the REF case. The hydropower capacity almost doubles by 2025, growing at an annual rate of 2.6% in both scenarios; however, the hydropower capacity share decreases from 85% in 2000 to 61% in the REF case and to 68% in the SHIFT case by 2025. Gas has the second largest share (17%), followed by renewables and wind. The nuclear capacity share increases slightly in the REF case from 0.9% to 1.4%, while it decreases to 0.8% in the SHIFT case. In both scenarios, it is assumed that the nuclear plant Angra I is retired before 2015,

TABLE 10.21. ELECTRIC GENERATING CAPACITY, REF SCENARIO (GW)

	2000	2005	2010	2015	2020	2025
Hydropower	60.8	75.9	83.7	90.5	104.6	116.0
Coal	1.6	1.2	0.7	0.7	0.4	0.4
Oil	4.6	4.3	3.5	2.3	2.2	8.2
Gas	1.1	6.2	15.6	26.8	32.9	33.0
Nuclear	0.7	2.0	3.3	2.6	2.6	2.6
Renewables	2.5	2.5	3.3	4.8	9.8	14.4
Wind	0.0	0.1	0.7	3.0	7.8	16.6
Total	71.3	92.0	110.7	130.6	160.2	191.1
			Share (%)			
Hydropower	85.31	82.46	75.59	69.26	65.29	60.68
Coal	2.27	1.25	0.61	0.52	0.22	0.19
Oil	6.45	4.67	3.16	1.74	1.35	4.30
Gas	1.49	6.71	14.04	20.51	20.57	17.26
Nuclear	0.93	2.14	2.95	2.00	1.63	1.37
Renewables	3.52	2.72	2.99	3.71	6.10	7.52
Wind	0.03	0.05	0.65	2.27	4.84	8.68
Total	100	100	100	100	100	100

TABLE 10.22. ELECTRIC GENERATING CAPACITY, SHIFT SCENARIO (GW)

	2000	2005	2010	2015	2020	2025
Hydropower	60.8	75.8	84.0	95.5	106.5	115.7
Coal	1.6	1.2	0.7	0.7	0.4	0.4
Oil	4.6	4.3	3.5	2.3	2.2	1.0
Gas	1.1	5.9	11.7	17.7	20.7	28.3
Nuclear	0.7	2.0	2.0	1.3	1.3	1.3
Renewables	2.5	2.4	3.3	5.9	9.8	14.4
Wind	0.0	0.1	0.6	2.4	6.3	10.2
Total	71.3	91.5	105.7	125.8	147.2	171.1
			Share (%)			
Hydropower	85.31	82.76	79.44	75.94	72.38	67.60
Coal	2.27	1.26	0.64	0.54	0.24	0.21
Oil	6.45	4.70	3.31	1.80	1.47	0.56
Gas	1.49	6.42	11.05	14.06	14.05	16.51
Nuclear	0.93	2.15	1.86	1.04	0.89	0.77
Renewables	3.52	2.60	3.12	4.70	6.66	8.40
Wind	0.03	0.11	0.57	1.92	4.30	5.95
Total	100	100	100	100	100	100

while Angra III is assumed to enter into operation by 2010 in the REF case. Figure 10.8 shows the electric generating capacity by fuel for both scenarios.

10.5.2.4. Environmental impacts

Table 10.23 shows estimates of carbon emissions associated with the projected energy and electricity supplies in the REF and SHIFT scenarios. In the REF case, carbon emissions from the overall energy system grow at an annual rate of 3.0%, and those from electricity at about 7.8% (see Fig. 10.9). In the SHIFT case, carbon emissions from the energy system increase at an annual rate of 2.0%, and those from electricity at about 5.4%. The increasing trend in carbon emissions is due to the projected higher level of fuel diversification in both energy and electricity, and in particular to the substitution of gas for hydropower. These emissions are higher for the REF case than for the SHIFT case because of the higher amount of fossil fuels used to satisfy the additional demand projected in this scenario.

Table 10.24 and Fig. 10.10 show estimates of SO_2, nitrogen oxides (NO_x) and particulate emissions from electricity generation in the REF and SHIFT scenarios. SO_2 and particulate emissions follow a decreasing trend in both scenarios resulting from reductions in the use of coal and oil for electricity generation. These trends, however, are reversed in the last period in the REF scenario, when the scenario constraints cause an increase in oil generated electricity. NO_x emissions increase

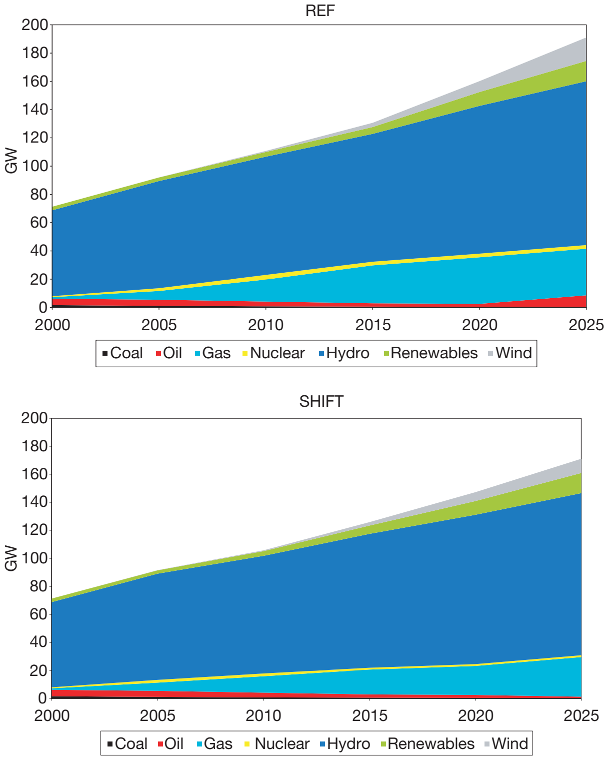

FIG. 10.8. Electric generating capacity (GW) by fuel.

TABLE 10.23. ESTIMATED CARBON EMISSIONS (Mt)

Scenario	2000	2005	2010	2015	2020	2025	Annual growth rate (%)
				Energy			
REF	97.1	97.8	117.2	137.6	162.2	204.4	3.0
SHIFT	97.1	97.4	111.6	120.2	131.4	157.4	2.0
				Electricity			
REF	6.1	7.4	14.2	23.9	27.1	39.8	7.8
SHIFT	6.1	7.5	11.1	15.5	17.3	22.7	5.4

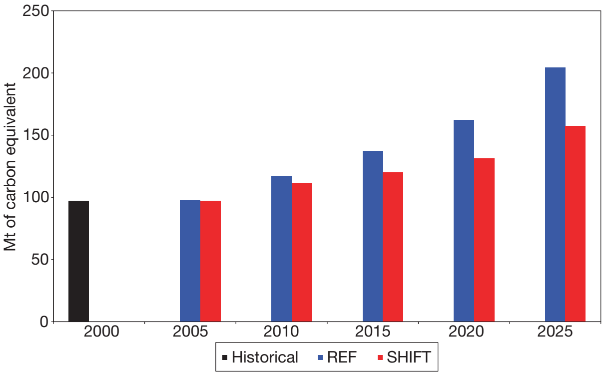

FIG. 10.9. Carbon emissions from the energy system.

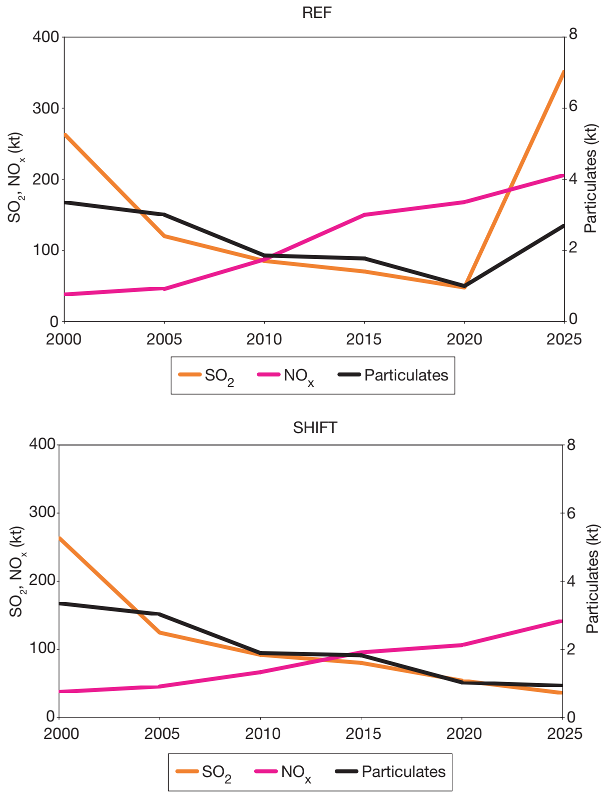

FIG. 10.10. SO_2, NO_x and particulate emissions.

throughout the whole period in both scenarios, reflecting the substitution of gas generation for hydropower (see Fig. 10.10).

10.5.2.5. Economic aspects

Figure 10.11 shows average annual energy investments in the REF and SHIFT scenarios. There is a need to increase investments in the energy sector. This increase is lower in the SHIFT case, since the energy requirements are lower in this scenario.

Figure 10.12 compares the evolution of indices of energy prices (final energy) for consumers for both scenarios. These values are estimated based on weighted average marginal supply costs of fuels. In general, the prices decrease first and then remain stable throughout the projected period, except for a considerable increase observed in the last time period for the REF case. The higher energy demand projected for this scenario implies that the supply system has to tap into more expensive sources such as oil and imports. The same trend is observed in the evolution of the indices of electricity prices (Fig. 10.13).

10.5.3. Sensitivity analysis

In view of the large uncertainties in some of the important assumptions for the supply analysis, a number of variants for both the REF and SHIFT scenarios have been analysed. These variants involve modifications of specific assumptions or the removal of some constraints that may alter the resulting energy supply system. The main variants are (1) new large hydropower delayed and (2) new nuclear allowed. In the REF scenario, two other variants are explored: (3) no new nuclear allowed

TABLE 10.24. SO_2, NO_x AND PARTICULATE EMISSIONS FROM ELECTRICITY GENERATION (kt)

	2000	2005	2010	2015	2020	2025
			REF			
SO_2	263.75	120.08	85.11	70.22	47.67	352.34
NO_x	37.56	45.63	87.25	149.88	167.93	206.15
Particulates	3.35	3.00	1.85	1.77	1.00	2.70
			SHIFT			
SO_2	263.75	124.64	92.16	80.28	54.17	35.96
NO_x	37.56	45.67	66.60	95.70	106.29	142.25
Particulates	3.35	3.03	1.89	1.83	1.03	0.93

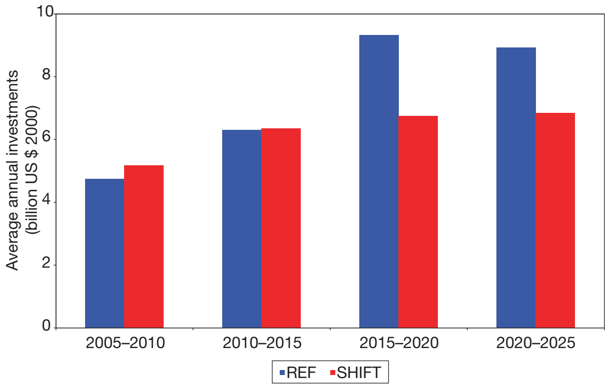

FIG. 10.11. Average annual energy investments.

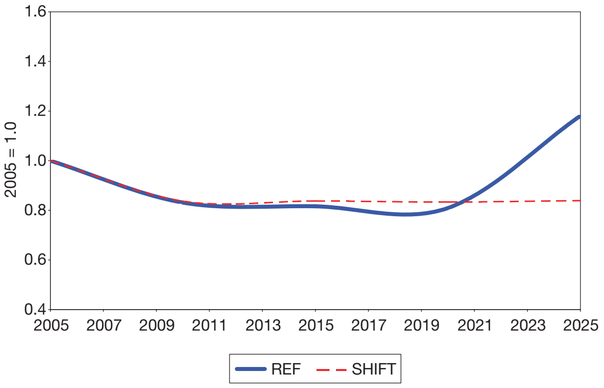

FIG. 10.12. Evolution of indices of marginal cost of final energy supplies, weighted by fuel shares.

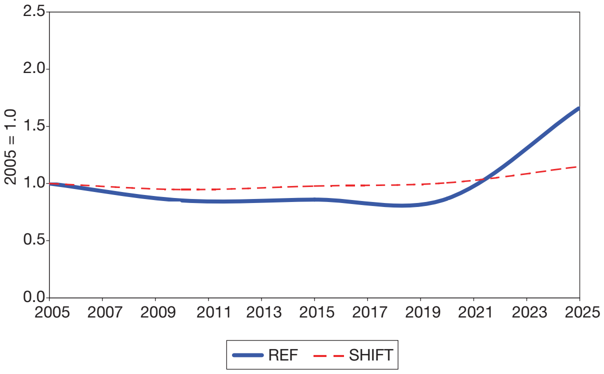

FIG. 10.13. Evolution of indices of marginal cost of electricity, weighted by fuel shares.

(not even Angra III) and (4) 50% higher capital cost for new hydropower. Total electricity generation and fuel shares for the REF and SHIFT scenarios and corresponding variants are shown in Table 10.25 and Table 10.26, respectively.

Variant 1: The capacity resulting from new ‘large’ hydropower plants is assumed to be delayed by five years in both the REF and SHIFT scenarios, starting in 2010. The delay may result from stricter environmental regulations imposed in sensitive areas or from potential financial limitations.

In the REF case, electricity imports represent the main substitute for hydropower during the 2010–2020 period. In 2025, the hydropower capacity is replaced mainly by oil. In the SHIFT case, the primary consequence of the assumed delay in hydropower development is the need to resort to imports of electricity during the 2015–2025 period. To a lesser extent, the delayed hydropower is also compensated for by renewables and wind.

Variant 2: New nuclear power plants are allowed to enter into operation during the 25-year period considered. For the REF case, after Angra III enters into operation, similar nuclear units are allowed at a rate of one every five years, as a maximum capacity addition for nuclear power. In the SHIFT case, Angra III is assumed to become operational first and then subsequent nuclear units are allowed.

TABLE 10.25. TOTAL ELECTRICITY AND FUEL SHARES, REF VARIANTS

	2000	2005	2010	2015	2020	2025
			REF — Base case			
Total (TW·h)	393.1	458.8	567.2	690.9	854.6	1043.0
			Share (%)			
Hydropower	77.44	75.46	68.37	60.98	57.30	52.08
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	0.50	6.22
Gas	1.03	8.34	18.56	27.46	27.57	22.59
Nuclear	1.54	3.00	4.04	2.65	2.14	1.75
Renewables	2.77	3.13	3.39	4.05	6.56	7.64
Wind	0.00	0.02	0.28	0.94	1.99	3.48
Imports	11.24	6.86	3.43	2.64	3.66	5.99
			REF — Variant 1: New hydropower delayed			
Total (TW·h)	393.1	458.8	566.8	690.0	852.7	1039.6
			Share (%)			
Hydropower	77.44	75.45	67.60	60.32	54.04	48.19
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	1.31	8.97
Gas	1.03	8.34	18.94	27.18	29.05	22.66
Nuclear	1.54	3.00	4.04	2.65	2.14	1.76
Renewables	2.77	3.13	3.33	4.42	6.60	7.67
Wind	0.00	0.03	0.48	1.36	2.67	4.50
Imports	11.24	6.86	3.67	2.78	3.89	6.01
			REF — Variant 2: New nuclear allowed			
Total (TW·h)	393.1	458.8	567.4	691.1	854.5	1043.5
			Share (%)			
Hydropower	77.44	75.45	68.57	61.02	56.30	52.06
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	0.45	3.84
Gas	1.03	8.34	18.40	26.17	27.57	22.58
Nuclear	1.54	3.00	4.03	3.96	4.27	4.37
Renewables	2.77	3.13	3.39	4.04	6.56	7.64
Wind	0.00	0.02	0.24	0.85	1.85	3.28
Imports	11.24	6.86	3.43	2.65	2.70	5.99

TABLE 10.25. TOTAL ELECTRICITY AND FUEL SHARES, REF VARIANTS (cont.)

	2000	2005	2010	2015	2020	2025
REF — Variant 3: No new nuclear allowed (not even Angra III)						
Total (TW·h)	393.1	458.8	567.5	690.8	854.7	1042.6
Share (%)						
Hydropower	77.44	75.45	68.94	60.99	58.08	52.10
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.10	0.60	0.47	6.91
Gas	1.03	8.34	18.91	28.68	27.57	22.60
Nuclear	1.54	3.00	2.43	1.33	1.07	0.88
Renewables	2.77	3.13	3.38	4.09	6.56	7.65
Wind	0.00	0.02	0.30	1.00	2.08	3.63
Imports	11.24	6.86	4.10	2.63	3.88	5.99
REF — Variant 4: Hydropower cost 50% higher than in REF base case						
Total (TW·h)	393.1	458.7	566.3	688.8	850.4	1038.3
Share (%)						
Hydropower	77.44	75.45	66.21	55.98	49.72	52.10
Coal	2.10	1.76	0.84	0.69	0.30	0.24
Oil	3.88	1.42	1.11	0.56	1.31	3.26
Gas	1.03	8.34	18.91	30.07	28.99	22.60
Nuclear	1.54	3.00	4.03	2.65	2.14	1.75
Renewables	2.77	3.18	3.36	4.91	7.53	7.65
Wind	0.00	0.16	0.87	2.06	3.72	6.00
Imports	11.24	6.68	4.45	2.80	5.80	5.99

In the REF case, the nuclear share in 2025 increases from 1.8% (base case) to 4.4%. The additional electricity generated using nuclear replaces electricity imports and gas up to 2020, after which the new nuclear generation mainly replaces oil. In the SHIFT case, the nuclear share in 2025 increases from 1% (base case) to 5%, and the additional electricity generated with nuclear replaces electricity imports throughout the whole time period.

Variant 3: No new nuclear plants are allowed in this variant of the REF case, not even Angra III. The variant provides a set of results for the REF scenario for the case that this partly built plant does not begin operation in the 2005–2025 period. As of December 2005, a decision had not been made regarding completion of this plant. This restriction is already part of the basic SHIFT scenario. The electricity generated by this plant is replaced mainly by increases in electricity imports. In the 2020–2025 period, oil is the main replacement for nuclear generation.

Variant 4: The capital cost of new hydropower plants is assumed to be 50% higher than the cost assumed in the REF base case. In this case, the share of hydropower is reduced considerably during the 2010–2020 period. This reduction is compensated for with higher shares of gas, imports and renewables. However, by 2025 the hydropower share reaches the same level as in the REF case, reflecting the need to satisfy electricity needs in this period with hydropower, even at the higher cost.

10.6. ASSESSING SUSTAINABILITY

The scenarios developed in this study can be evaluated with respect to the sustainable energy development criteria specified by Brazil (see Section 10.3.2.) using some of the corresponding Energy Indicators for Sustainable Development (EISD) (see Table 1.1, Chapter 1). Table 10.27 lists the criteria and the corresponding EISD.

TABLE 10.26. TOTAL ELECTRICITY AND FUEL SHARES, SHIFT VARIANTS

	2000	2005	2010	2015	2020	2025
			SHIFT — Base case			
Total (TW·h)	393.1	446.6	536.8	642.0	766.2	892.2
			Share (%)			
Hydropower	77.44	77.39	72.50	69.31	65.10	60.70
Coal	2.10	1.81	0.89	0.74	0.33	0.28
Oil	3.88	1.37	1.87	0.74	0.95	0.13
Gas	1.03	8.50	14.13	18.92	18.84	22.49
Nuclear	1.54	3.09	2.57	1.43	1.20	1.03
Renewables	2.77	3.06	3.57	5.30	7.34	8.94
Wind	0.00	0.05	0.24	0.82	1.81	2.50
Imports	11.24	4.74	4.22	2.74	4.43	3.93
			SHIFT — Variant 1: New hydropower delayed			
Total (TW·h)	393.1	446.6	535.8	639.0	763.3	886.1
			Share (%)			
Hydropower	77.44	77.39	71.43	65.53	60.25	56.36
Coal	2.10	1.81	0.89	0.75	0.33	0.29
Oil	3.88	1.37	1.98	1.14	1.64	0.29
Gas	1.03	8.50	14.16	19.01	18.91	22.65
Nuclear	1.54	3.09	2.57	1.44	1.20	1.03
Renewables	2.77	3.06	3.69	5.50	8.43	9.00
Wind	0.00	0.05	0.56	1.51	3.00	5.01
Imports	11.24	4.74	4.73	5.13	6.23	5.37
			SHIFT — Variant 2: New nuclear allowed			
Total (TW·h)	393.1	446.6	536.6	641.2	766.9	892.4
			Share (%)			
Hydropower	77.44	77.39	72.08	67.49	65.03	60.68
Coal	2.10	1.81	0.89	0.74	0.33	0.28
Oil	3.88	1.37	1.57	0.68	0.56	0.13
Gas	1.03	8.50	14.14	18.94	18.82	22.49
Nuclear	1.54	3.09	4.27	4.27	4.76	5.11
Renewables	2.77	3.06	3.38	5.31	7.33	7.94
Wind	0.00	0.05	0.19	0.71	1.38	2.18
Imports	11.24	4.74	3.49	1.86	1.79	1.19

10.6.1. Social dimension

The first social criterion of ‘optimal national energy services’ implies full accessibility of modern energy services throughout the country. This requirement is explicitly assumed to be achieved in both scenarios. With respect to the goal of more jobs and income from energy services, both scenarios reflect progress in the achievement of these aims, since both involve further development and increased use of domestic energy resources, in particular, renewables such as alcohol and other biofuels for transport, and biomass, wind and bagasse for electricity generation. Greater development of domestic resources (including renewables, oil and gas to replace imports) would translate into the creation of more jobs.

TABLE 10.27. SUSTAINABLE ENERGY CRITERIA AND CORRESPONDING EISD*

Sustainable energy criteria	Corresponding EISD	
Social	SOC1:	Household share without electricity or commercial energy
1. Optimal national energy services	SOC2:	Share of income spent on energy
2. More jobs and income from energy services	SOC3:	Energy use and fuel mix per income group
	ECO1:	Per capita energy use
Economic	ECO11:	Fuel shares
3. More renewables	ECO13:	Renewables share
4. More indigenous technologies and security of supply	ECO15:	Net import dependence
5. Minimum energy vulnerability	ECO2:	Energy use per unit of GDP
6. More efficiency	ECO3:	Efficiency of energy conversion
7. Long term sustainable energy supply	ECO6–10:	Energy intensities
	ECO16:	Stocks of critical fuels
	ECO4–5:	Reserves/resources to production ratio
Environmental	ENV1:	Greenhouse gases
8. Less environmental impact	ENV3:	Air pollutants

* For a complete list of the Energy Indicators for Sustainable Development (EISD), see Table 1.1. in Chapter 1

Progress with respect to other social goals in the areas of affordability and disparity is difficult to measure, since demographic, income and household data at a regional level are not explicitly projected in this study. Nevertheless, two valuable indicators to assess progress in some of the social criteria are the per capita energy use (ECO1) and the evolution of the marginal cost of final energy and its relationship to the per capita GDP (proxy for SOC2).

Figure 10.14 shows the evolution of per capita final energy use and electricity consumption for the 1980–2025 period. The projections for the two scenarios indicate an increase in per capita energy use and electricity consumption to levels that, in principle, should allow more and better satisfaction of the energy needs of the Brazilian population. This is assuming higher 'commercial' energy use (rather than traditional or unsustainable energy) and more equitable use of energy by the population throughout the country. It is important to note that the levels of per capita energy use in Brazil in 2000 were substantially lower than those in developed countries and perhaps not enough to satisfy minimum social energy requirements. For example, the Brazilian per capita electricity consumption in 2000 was only about 2000 kW·h, compared with about 11 000 kW·h for OECD–North America and about 6500 kW·h for the European Union for the same year [10.11]. By 2025, the per capita electricity consumption reaches 4500 kW·h in the REF case and 3900 kW·h in the SHIFT case. Per capita final energy use grows from 39 GJ in 2000 to 73 GJ for the REF scenario and 63 GJ for the SHIFT scenario in 2025.

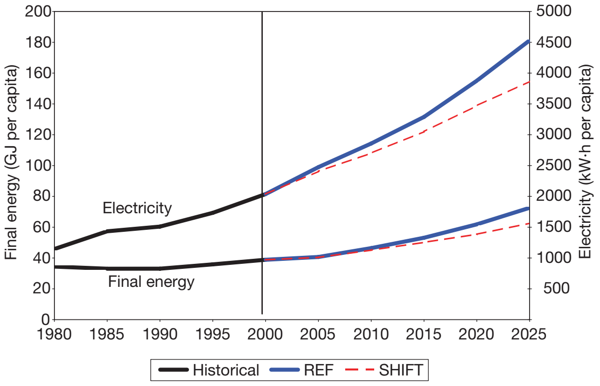

FIG. 10.14. Per capita final energy use and electricity consumption.

The evolution of per capita GDP and the indices of marginal cost of final energy supplies, weighted by fuel shares, in the REF and SHIFT scenarios are shown in Fig. 10.15. A comparison of the evolution of these indices represents an indirect way to assess energy affordability. The per capita GDP grows over the entire period, whereas the marginal costs of final energy decrease and then remain stable in both scenarios, except in 2025 for the REF case. This implies a significant improvement in energy affordability.

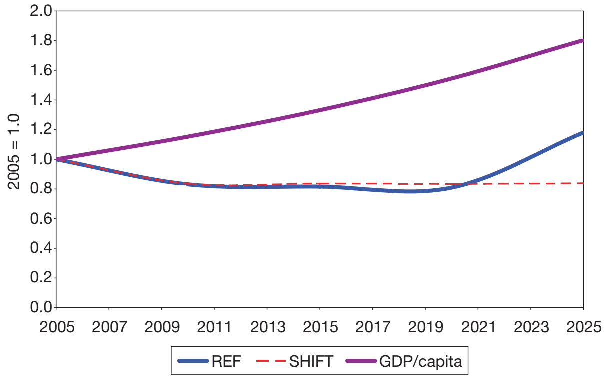

FIG. 10.15. Evolution of per capita GDP and indices of marginal cost of final energy supplies, weighted by fuel shares.

10.6.2. Economic dimension

The Brazilian sustainable energy criteria in the economic dimension can be summarized as: (a) more diversity and security of supply, (b) more use of renewables and domestic energy resources and (c) less energy intensity.

Progress on the first two issues can be assessed by looking at trends in fuel shares (ECO11) and the renewables share (ECO13), and in net import dependence (ECO15). Figure 10.16 shows the fuel shares in TPES for the REF and SHIFT scenarios. In both scenarios there is a clear trend towards fuel diversification, with a reduction in the share of coal and oil, and substantial increases in the shares of natural gas and renewables. It is important to note that during the 1985–2000 period, the shares from oil, gas and hydropower increased rapidly, affecting the share of renewables, which also reflected a decrease in the use of traditional or unsustainable biomass. The projected increase in renewables is based on commercial or sustainable renewable resources. The overall projected diversification process as well as the emphasis on renewables and gas are compatible with the specified sustainable development criteria.

Figure 10.17 shows the shares of fuels in electric generating capacity for the REF and SHIFT scenarios. As in the case of TPES, a clear trend towards fuel diversification in generating capacity is observed. In this case, reductions in the shares of hydropower, coal and oil are compensated for with substantial increases in the shares of natural gas, renewables and wind. Similar fuel diversification trends are observed in the fuel shares of projected final energy use and electricity generation (see Tables 10.17–10.20).

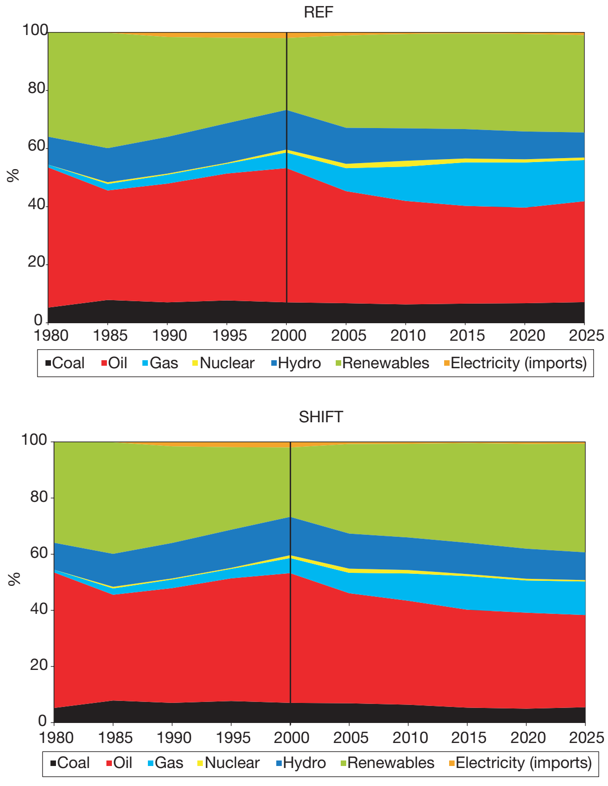

FIG. 10.16. Fuel shares in total primary energy supply.

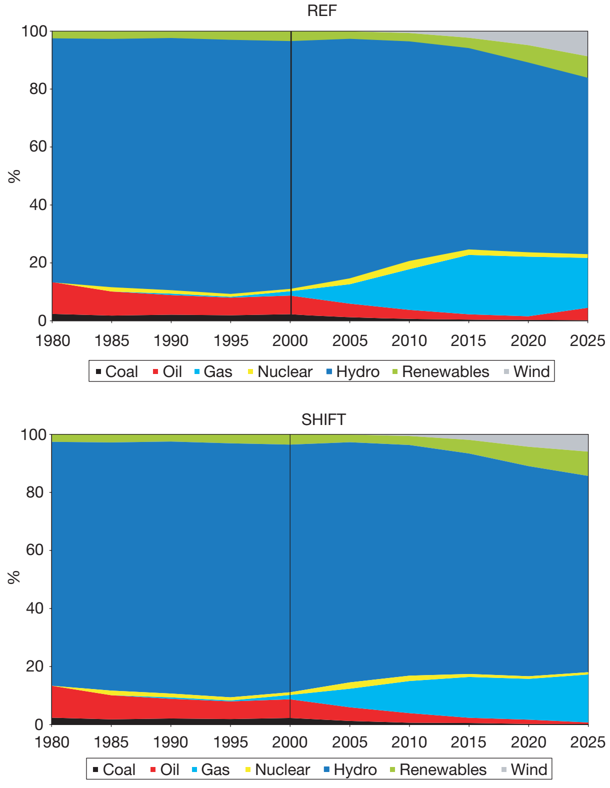

FIG. 10.17. Fuel shares in electric generating capacity.

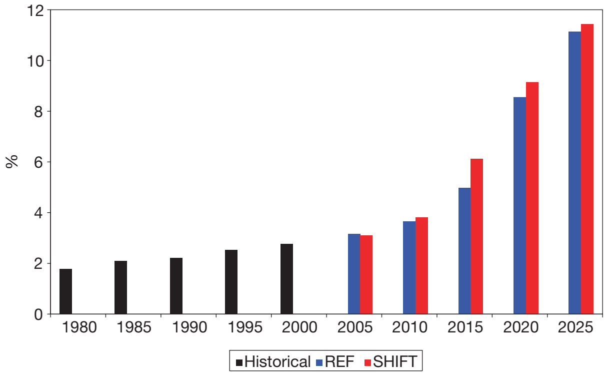

FIG. 10.18. Share of renewables in electricity generation.

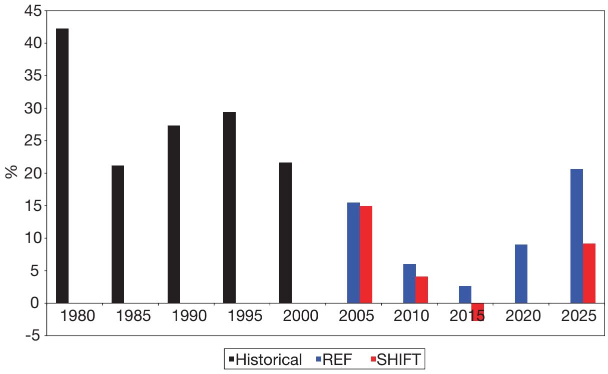

FIG. 10.19. Share of imports in total primary energy supply.

Figure 10.18 shows the increase in the share of renewables (excluding hydropower) in electricity generation for both scenarios. Electricity generation from renewables includes biomass (in particular bagasse) and wind. The share of renewables increases throughout the projected period for both scenarios and at a slightly faster pace in the SHIFT case. If the share of 'small' hydropower is added (as considered in the Brazilian PROINFA programme[2]), the renewables share reaches 10% before 2015 in the SHIFT case and before 2020 in the REF case.

One way to assess the relative security of energy supplies is by looking at net import dependence. Figure 10.19 shows the share of net imports in TPES. The share of imports follows a decreasing trend up to 2015, when imports are less than 5% for the REF case and turn negative (implying net exports) in the SHIFT case. By 2020, however, the trend is reversed in the REF case and imports start to increase, reflecting limitations on domestic supplies of oil and natural gas. Exports continue in the SHIFT case through 2020 but turn into net imports in the last period. This indicator reflects reduced dependence on imports in the mid-term but a need to use imports to satisfy future energy demand in the long term.

To review the criteria related to less energy intensity and more efficiency, the intensity indicators (ECO6–ECO10) can be evaluated. The trend in aggregated energy intensity at the national level in terms of TPES per GDP (ECO2) is shown in Fig. 10.20. The overall intensity projected for both scenarios indicates, in the long term, the stabilization or reversal of the increasing trends in intensities observed in the past. Similar trends are observed in the overall intensity of final energy use and electricity consumption per GDP.

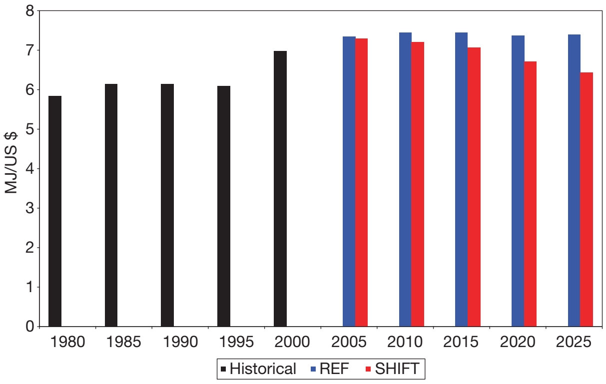

FIG. 10.20. Total primary energy supply per GDP.

To illustrate the trends in intensities at the sectoral level, the intensity in the industrial (ECO6) sector is depicted in Fig. 10.21. The overall intensity in this sector also reflects a reversal of the increasing trends of the past and is similar to the

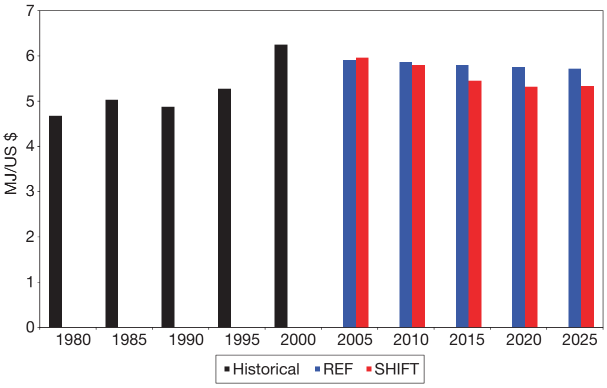

FIG. 10.21. Overall energy use in the industrial sector per GDP value added.

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[2] See Chapter 9 for details on the PROINFA programme.

trends observed for overall energy intensities for TPES. These trends are compatible with the sustainable development criteria.

10.6.3. Environmental dimension

The main impacts on the environment from the two scenarios can be assessed by looking at indicators of greenhouse gas (GHG) emissions (ENV1) and other air emissions (ENV3). Figure 10.22 shows GHG emissions from the energy sector per capita (bars) and per unit of energy supplied (lines). Although the carbon emissions per capita follow an increasing trend, the corresponding emissions per unit of energy supplied show a decreasing trend in both scenarios. The higher values on a per capita basis result from a higher per capita use of energy compared with per capita carbon dioxide emissions. The decreasing trend for carbon emissions per unit of energy supplied indicates an increasing dependence on non-carbon fuels in the future in both scenarios, with the dependence being higher in the SHIFT case.

Figure 10.23 shows carbon emissions from electricity generation in terms of kilowatt-hours. The emissions increase in both scenarios owing to a projected rapid growth in electricity generation that hydropower and renewables cannot fully satisfy; therefore, the share of gas in electricity generation increases, resulting in higher carbon emissions on a per kilowatt-hour basis. Nevertheless, compared with other countries, Brazil will still be in a favourable position with respect to GHG emissions. For example, carbon emissions from electricity generation in 2001 were 166 g/kW·h in the United States of America, 90 g/kW·h in Japan and 271 g/kW·h in China [10.11]. In 2025, carbon emissions are projected to be around 40 g/kW·h in the REF case and about 25 g/kW·h in the SHIFT case.

SO_2 and particulate emissions from electricity generation per kilowatt-hour are projected to follow a decreasing trend in both scenarios (see Table 10.24 and Fig. 10.10). These environmental trends point towards progress in the environmental goals specified by Brazil.

10.6.4. Concluding remarks

In general, the analysis conducted with the EISD shows that, in both scenarios, Brazil moves towards fulfilling the sustainable energy development goals specified by the Brazilian experts in this study. The SHIFT scenario represents an image of the future that is more consonant with the Brazilian sustainable development criteria than the REF case, since the SHIFT scenario projects lower energy requirements to achieve the same economic growth using relatively more renewables and fewer imports with fewer negative environmental impacts.

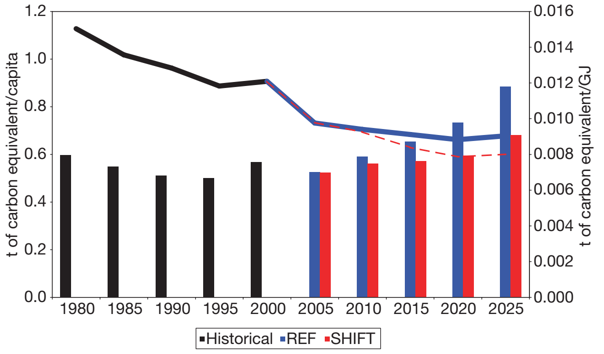

FIG. 10.22. GHG emissions from the energy sector per capita (bars) and per unit of energy supplied (lines).

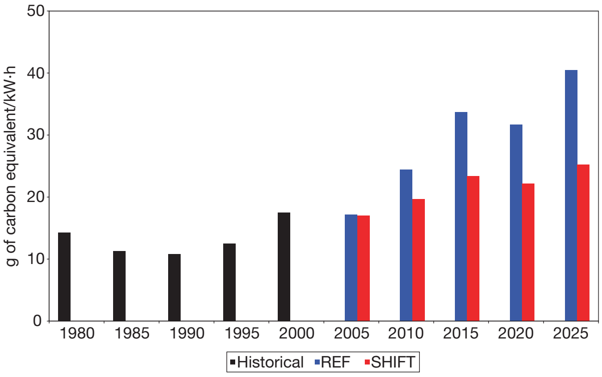

FIG. 10.23. Carbon emissions from electricity generation per kilowatt-hour.

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Chapter 11

CONCLUSIONS AND LESSONS LEARNED

**J. GOLDEMBERG, J.R. MOREIRA, R. SCHAEFFER, K. ABDALLA,
H.-H. ROGNER, L. LANGLOIS, I. VERA**

This study is the first in a series of national studies conducted under a unique partnership initiative officially registered with the United Nations Commission on Sustainable Development by the IAEA, in cooperation with participating Brazilian organizations and the United Nations Department of Economic and Social Affairs (UNDESA). Similar studies for South Africa and Cuba, modelled after this study, are expected to be completed in 2006.

This chapter presents the main conclusions derived from this comprehensive assessment of the Brazilian energy system performed within a sustainable development framework. The chapter also outlines ‘other accomplishments’ of and ‘lessons learned’ from the cooperative effort conducted jointly by Brazilian and international experts. It concludes with some reflections about ‘next steps’ that may be followed to continue advancing the concepts and ideas supporting sustainable development at the national and international levels.

11.1. CONCLUSIONS

The major conclusions described in this section result from the analysis of the Brazilian energy system within the primary dimensions of sustainable development — social, economic and environmental — consistent with the major themes used by the United Nations.

Social indicators show important inequities in energy services among social and economic groups. The several social indicators help to define and delineate the nature of these inequities and hence point the way to policies for their mitigation. Brazil has made extraordinary progress in the past several decades, ensuring almost universal (93.5%) access to electricity, mainly through service programmes with Government established targets for distribution companies and subsidized tariffs for low level electricity consumers in the residential sector. More needs to be done to facilitate access to modern energy services for over 10 million people living in remote areas where these services are still not available. Current policies (e.g. universalized electricity services and financial support for liquefied petroleum gas use for low income groups) need to be implemented effectively if access to modern energy is to increase in isolated regions in Brazil within the next decade.[1] The positive trends shown by the accessibility indicators, however, do not reflect the major remaining social problems related to energy affordability and disparity. Large segments of the Brazilian population in both rural and urban areas have access to modern energy services but simply cannot afford these services and, in some cases, have to depend on non-commercial forms of energy. Another considerable share of the population uses a very limited amount of commercial energy insufficient to meet basic energy needs without being supplemented by traditional fuels. The current low level of per capita energy and electricity use, as reflected by social indicators disaggregated by income group and by region, provides some insight into this significant problem. Household electricity consumption by the lowest income groups is only about half the country’s already low average household electricity consumption of around 2000 kW·h/year. Policies based on support schemes for low income households in urban and rural areas to cover part of their energy expenses are discussed in this study (see Chapters 7 and 9). Specific instruments to implement this policy (e.g. refunds and funding for energy efficiency improvements) need to be assessed to determine their effectiveness in improving affordability while maintaining efficient energy pricing.

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[1] The programme Luz para Todos (Electricity for All), which has been in place for several years, is being implemented by electricity utilities with financial support from the Federal Government. The objective is for the utilities to provide electricity to around 10 million people currently without access to these services by 2015.

The two scenarios developed in this study project increases in per capita energy use and electricity consumption through the year 2025 to levels that, in principle, should allow more and better satisfaction of energy needs. Higher per capita energy use in these scenarios results from relatively lower energy prices due to energy investments and relatively faster growth in incomes. A comparison of the evolution of the indices of marginal cost of final energy supplies and per capita gross domestic product implies significant improvement in energy affordability.

With respect to the economic dimension, the study focused on several important issues of the Brazilian energy system that have affected and continue to have an impact on economic development. Brazil is a leading developer of technologies related to the production and use of alcohol as a transport fuel, as well as alcohol by-products for electricity generation, and provides an example of the potential for modern biomass use in a developing country. Advances in technologies related to alcohol production from sugar cane and deep oil exploration and development have substantially decreased oil imports. Advances in the alcohol industry have also driven important innovations in the country's automotive industry. Similarly, although less well documented, deep oil exploration has increased the oil equipment industry and engineering know-how. Also, the significant number of hydropower plants constructed in the past 35 years demonstrates the extensive technical and economic know-how developed in the country, which has allowed the provision of clean and low cost electricity for the population. Despite financial ups and downs, the significant effort to control inflation since 1994 has allowed Brazil to be relatively successful in attracting investment in its energy sector, particularly in innovative indigenous energy supply industries like the biofuels industry and deepwater and ultra-deepwater drilling technologies. Significant investment in the electricity supply sector between 1996 and 2000 was used for the acquisition of existing infrastructure by the private sector as a follow-up to the privatization programme. Investment in new electric generating capacity is needed and is planned.

Brazil has made modest improvements in the technological efficiency of its energy supply and use, as shown by slow upward trends in energy intensities in the past two decades. The current situation demonstrates that the electricity conservation programme (PROCEL) and the oil derivative conservation programme (CONPET) in place for almost 20 years have achieved only modest results, although policies calling for further improvements are being implemented, particularly in the industrial sector. There is still great potential to improve energy efficiency throughout the energy system by implementing policies such as (a) new energy efficiency standards, especially in the transport sector; (b) programmes for the development and use of more efficient technologies; and (c) programmes that stress demand-side management and reduced demand for electricity and fuel use. A change in the structure of the economy towards less energy intensive industries with higher value added products could also result in a less energy intensive economic profile, but this shift would require investments and major changes that go beyond the energy system. Additional policies are proposed that allow progress towards the decoupling of energy use and economic growth.

Energy security as an economic issue in Brazil raises several concerns: (a) investment requirements, mainly by the private sector; (b) the need to protect against import disruption and price volatility; (c) the vulnerability of the electricity transmission system; and (d) the need for operational reserves of critical fuels. In relation to energy investments, Brazil's economic growth is tied to expected high electricity demand growth rates that require continuous investments. Policies are in place to stimulate private companies to compete for a share of the electricity generation market. Although these policies should provide incentives for energy investments, results so far are inconclusive. With regard to imports, Brazil has made major strides because of its ethanol programme, enhanced domestic oil production and diversification trends in the country's fuel mix. In relation to the transmission system, Brazil is seeking to reduce bottlenecks and increase system flexibility by expanding the power transfer capacity of the grid between main regions; by building new generating capacity, diversifying generation away from remote hydropower sites; and by improving the efficiency of the transmission system. With respect to fuel reserves, a policy for consideration is the creation of national or regional operational reserves of critical fuels (e.g. oil and ethanol) to address transient interruptions or unexpected surges in demand, as well as to reduce seasonal cost variations. Another major thrust also under way aimed at improving supply security is simply to reduce the amount of energy required, particularly in the industrial sector.

In the environmental dimension, from the perspective of atmospheric emissions, impacts from energy supply and use in Brazil are relatively low compared with those of other countries with similar energy demand, primarily because of the ethanol programme for bio-transport fuels and because of the high share of hydropower. However, air pollution in major cities represents a significant environmental concern, and while it has been continuously addressed,[2] with visible improvements, air quality in Brazil has not reached the levels of most countries of the Organisation for Economic Co-operation and Development.[3] Furthermore, the expected increase in energy demand combined with the need to use more gas to supplement hydropower will translate into more atmospheric emissions. Policies that de-emphasize road transport, that limit automobile fuel emissions and that improve fuel quality are proposed. These efforts can help to mitigate environmental degradation and to make further progress in the decoupling of energy use and emissions.

Brazil's current development stage, its rich variety of energy resources, its leadership in the development of important energy technologies and its success in implementing some of the energy policies currently in place provide an excellent opportunity for the country to 'leapfrog' to higher levels of sustainable energy development. Policies proposed in this study (e.g. expansion of natural gas supply and use, renewable energy portfolio standards, expansion of production and use of ethanol fuel, and reduced electricity demand and fuel use) may represent effective mechanisms to achieve this goal.

The integrated picture resulting from the scenario and energy indicator analyses shows that Brazil is generally heading in the right direction for realizing many of its sustainable development goals, and that some of its energy policies and investments have been supporting this development for some time. However, there is room for improvement. The regular application of indicator analysis can be a powerful tool for monitoring the continuing appropriateness of energy policies in the context of sustainable development over time. Such continuous monitoring is invaluable as a means of identifying, at an early stage, policy areas that need correction or adjustment.

11.2. OTHER ACCOMPLISHMENTS

The present study comprises a first of its kind interlinking of energy system modelling and the use of indicators for sustainable energy development to assess the consonance between energy policies and energy development strategies, on the one hand, and the social, environmental and economic development goals of the country, on the other hand. This marriage of scenario and indicator analysis is a unique feature of the project that has already captured international attention and has begun to be emulated in a number of countries.

Capacity building in the areas of energy and environmental planning within a sustainable development context was one of the main goals of this project. This was planned and accomplished on a number of different levels, primarily (a) through a process of defining sustainable development criteria in the context of the energy sector, and reconciling the several different objectives and elements thereof; (b) by developing expertise in modelling a number of different possible futures for the national energy system under a variety of policy assumptions; and (c) by using indicators to measure progress in achieving selected sustainable development goals.

Defining sustainable development and its various components, and selecting appropriate policies to achieve sustainable development goals, is a continuous process. The same is true for delineating the relationship between energy use, sustainable economic development and environmental protection. Reaching a consensus for the purposes of this study was an essential but iterative process, with no single correct outcome. In this regard, the project could be described as developing a rigorous discipline of introspection with regard to energy policy and sustainable development choices in Brazil. Scenario modelling has great advantages in such cases for exploring and comparing a range of possible outcomes for further consideration.

Developing scenarios permits analysts to probe the possible future outcomes of present and past policy choices. The national teams in Brazil developed expertise in the use of energy system assessment models, to be used for devising scenarios

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[2] As air pollution in major cities is mainly due to the transport sector, a significant Government regulatory effort has been under way in this area through the definition of increasingly stringent pollution standards.

[3] For example, one issue affecting air quality is the high amount of sulphur in diesel oil, which only recently was reduced to 500 ppm for fuel sold in major cities.

of possible future energy system development paths and for mapping their consequences. IAEA and Brazilian experts worked together to develop credible quantitative assessments of energy system developments. The two scenarios (a 'Reference' and a 'Shift' or alternative scenario) and a number of related variants chosen for the present study show different outcomes but by no means cover all possible futures. More complete analysis would require more scenarios, but the limited scenario assessment of this study serves to illustrate the importance of present-day policy choices for future progress towards sustainable development.

The national teams developed expertise in the construction and application of indicators as a measure of progress towards sustainable development goals and the contribution of the energy sector thereto. The indicators were used to review past and current trends in the social, economic and environmental dimensions of sustainable development, and permitted the teams to link these trends to future scenarios developed with the integrated modelling tools.

11.3. LESSONS LEARNED

This Brazilian study has proved to be a challenging but very valuable exercise. Extensive discussions were necessary among major stakeholders to accomplish very important tasks within a holistic framework. One of these tasks was the definition of the Brazilian criteria for sustainable energy development. This task required stakeholders to reflect on the most desirable path to follow to reach energy sustainability. When final consensus was reached, it was recognized that defining sustainable development criteria is a moving target, that is, a continuous and ever changing process. Nevertheless, having experts from different organizations working together and brainstorming about this subject proved to be a valuable activity.

Another challenging task was the formulation of future scenarios based on consistent sets of assumptions using integrated modelling tools. The complexity of Brazil's energy system, which is highly dependent on hydropower resources scattered throughout its extensive territory, and the emphasis on renewables, as specified in the Brazilian sustainable development criteria, required adaptation of the modelling tools MAED (Model for Analysis of Energy Demand) and MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) to the specific case of Brazil. The modelling exercise proved to be a dynamic process in which assumptions and parameters needed to be considered in a flexible and transparent manner allowing the necessary sensitivity analysis.

The overall analysis with the Energy Indicators for Sustainable Development (EISD) allowed experts to link past and current trends with possible future consequences developed with the integrated modelling tools. The task proved to be enlightening, especially when assessing the scenarios with respect to the sustainable development criteria and goals specified by Brazil.

Finally, quantitative and qualitative analyses were interwoven within each and among all the sustainable development dimensions. This was necessary to be able to incorporate in the analysis a number of important issues difficult to quantify or simulate but necessary for the formulation of effective policies.

11.4. NEXT STEPS

The benefits of capacity building tend to be lost over time unless the skills and expertise acquired are continually used and enhanced. The national teams in this respect have already started to build upon the modelling and analytical skills developed during the course of this project, providing further scenario analysis for developing national energy plans and associated policy strategies. In this respect, the capacity building part of this project has been highly successful.

With the habit of introspection and self-criticism ingrained, further use of these tools for policy analysis can provide continued insight. The present study should therefore be viewed not as the end of a process but rather as a beginning. Developing viable policies for sustainable energy development requires balancing a number of sometimes conflicting variables and interests. Further analysis of this balancing act is always worthwhile. More detailed strategies for further development and refinements to the domestic biofuels industry and related sectors could be one fruitful avenue of discussion. Exploring the conditions that have fostered development of innovative domestic energy technologies could be another profitable study. Looking more deeply at the development impact of different levels of quality in delivered energy services in the context of affordability and access could be a most useful approach for clarifying pricing strategies. The potential for enhancing energy efficiency in energy intensive industries and for shifting towards a less energy intensive industrial profile are interesting propositions for sustained energy development. Studies that map the consequences of optimizing different energy mixes could prove instructive as to the costs and consequences of different development paths.

At the international level, the approach, modelling framework and guidelines developed in this study will permit other countries to systematically construct their country profiles of sustainable energy development. Information exchange among countries on experiences and lessons learned will allow improvements and refinements in the approach and methods proposed in this study.

Countries will find this study about Brazil useful as an example to review before embarking on the overall assessment of their own energy systems, in the formulation of potential future energy demand and supply scenarios, and in the definition of sustainable energy strategies designed to help policy makers pursue their sustainable energy development objectives. Indicators for sustainable energy development can be used to monitor progress towards meeting national development goals.

Annex I

ACRONYMS AND ABBREVIATIONS

ANEEL	National Electricity Regulatory Agency
ANP	National Petroleum Agency
ASD	adjustable speed drive
BEI	Brazilian Energy Initiative
BIG/GT	Biomass Integrated Gasification/Gas Turbine
BNDES	Brazilian National Development Bank
CCBS	Central de Cogeração da Baixada Santista
CCC	Conta de Consumo de Combustível (Fuel Consumption Account)
CDM	Clean Development Mechanism
CENBIO	Brazilian Reference Centre on Biomass, University of São Paulo
CENIBRA	Celulose Nipo Brasileiro S.A.
CEPEL	Eletrobras Research Centre
CETESB	State Environmental Sanitation Technology Company
CFL	compact fluorescent lamp
CHP	combined heat and power
CNEN	Brazilian Nuclear Energy Commission
CNP	National Petroleum Council
CNPE	National Council for Energy Policy
CONPET	Brazilian National Programme for Rationalization of Oil Products and Natural Gas Use
CONSERVE	Brazilian petroleum fuel conservation programme
COPPE	Energy Planning Programme, Graduate School of Engineering, Federal University of Rio de Janeiro
CSD	Commission on Sustainable Development
ECLAC	United Nations Economic Commission for Latin America and the Caribbean
EEA	European Environment Agency
EISD	Energy Indicators for Sustainable Development
EMI	electromagnetic interference
EPE	Empresa de Pesquisa Energética
ESCO	energy service company
FACTS	flexible alternating current transmission systems
FDI	foreign direct investment
FISIM	financial intermediation services indirectly measured
FPS	floating production system
FTAA	Free Trade Area of the Americas
GDP	gross domestic product
GHG	greenhouse gas
GNP	gross national product
HC	hydrocarbon
HDI	Human Development Index
HVDC	high voltage direct current

IAEA	International Atomic Energy Agency
IBGE	Brazilian Institute of Geography and Statistics
ICMS	value added tax in Brazil
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
INMETRO	National Testing and Standards Agency
IPCC	Intergovernmental Panel on Climate Change
IPI	industrial products tax in Brazil
IPT	Institute of Technological Research
ISED	indicators for sustainable energy development
ISO	Independent System Operator
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAED	Model for Analysis of Energy Demand
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impacts
MME	Ministry of Mines and Energy
MSW	municipal solid waste
MTBE	methyl tertiary-butyl ether
m.w.	minimum wage
NGCHP	natural gas fired combined heat and power
NGO	non-governmental organization
NMVOC	non-methane volatile organic compound
NREL	National Renewable Energy Laboratory
NSO	National System Operator
OECD	Organisation for Economic Co-operation and Development
OLADE	Latin American Energy Organization
O&M	operation and maintenance
OPEC	Organization of Petroleum Exporting Countries
PAFC	phosphoric acid fuel cell
PBR	Programa Brasileiro de Reciclagem
PCH-COM	Small Scale Hydro Programme
PM	particulate matter
PM2.5	particulate matter with a diameter of 2.5 μm or smaller
PM10	particulate matter with a diameter of 10 μm or smaller
PND	National Development Plan
PPE	Parcela de Preço Específica
PPP	purchasing power parity
PPT	Thermoelectric Priority Programme
PROALCOOL	Brazilian Alcohol Programme
PROCAP	Technological Development Programme on Deepwater Production Systems
PROCEL	National Electricity Conservation Programme
PROCONVE	National Vehicle Emission Control Programme
PRODEEM	Energy Programme for Small Communities
PROEN	Brazil’s energy efficiency financing programme
PROINFA	Alternative Energy Sources Incentive Programme
PV	photovoltaic(s)

RCC	rolled compacted concrete
RD&D	research, development and demonstration
RFCC	residual fluid catalytic cracking
RGR	Reserva Global de Reversão
RPS	renewable portfolio standard

SABESP	Companhia de Saneamento Basico do Estado de São Paulo
SEC	specific energy consumption
SINTREL	National Electric Transmission System
SPE	Specific Purpose Enterprise
SSH	small scale hydro

TCSC	thyristor controlled series capacitor
TLP	tension-leg platform
TPES	total primary energy supply
TPP	Termoelétrica do Planalto Paulista
TRS	total reducing sugars

UFRJ	Federal University of Rio de Janeiro
UNCED	United Nations Conference on Environment and Development
UNCHE	United Nations Conference on the Human Environment
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICAMP	State University of Campinas

VA	value added
VASPS	vertical annular separation and pumping system
VOC	volatile organic compound

WEA	World Energy Assessment
WEC	World Energy Council
WEM	Wholesale Energy Market
WSSD	World Summit on Sustainable Development
WTO	World Trade Organization

Annex II

UNITS

bbl	barrel
boe	barrel of oil equivalent
EJ	exajoule
g	gram
Gg	gigagram
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
ha	hectare
Hz	hertz
kg	kilogram
km	kilometre
km^2	square kilometre
kV	kilovolt
kW	kilowatt
kW·h	kilowatt-hour
kWp	kilowatt peak
L	litre
m	metre
m^2	square metre
m^3	cubic metre
MJ	megajoule
Mt	million tonnes
MW	megawatt
MW·h	megawatt-hour
MWp	megawatt peak
PJ	petajoule
t	tonne (metric ton)
tC	tonne of carbon
Tg	teragram
TJ	terajoule
toe	tonne of oil equivalent
TW	terawatt
TW·h	terawatt-hour

CONTRIBUTORS TO DRAFTING AND REVIEW

Abdalla, K.	United Nations Department of Economic and Social Affairs
Achao, C.	Empresa de Pesquisa Energética, Brazil
Bergschneider, E.	International Atomic Energy Agency
Cima, F.	Petrobras—Petroleo Brasileiro S.A., Brazil
Coelho, S.	São Paulo State Environmental Secretariat, Brazil
Cohen, C.	Graduate School of Engineering, Federal University of Rio de Janeiro, and Fluminense Federal University, Brazil
Cunha, R.	Brazilian National Development Bank, Brazil
Esparta, R.	University of São Paulo, Brazil
Firmo, H.	Federal University of Rio de Janeiro, Brazil
Geller, H.	Southwest Energy Efficiency Project, United States of America
Goldemberg, J.	São Paulo State Environmental Secretariat, Brazil
Guardabassi, P.	São Paulo State Environmental Secretariat, Brazil
Jalal, I.	International Atomic Energy Agency
Langlois, L.	International Atomic Energy Agency
Lucon, O.	São Paulo State Environmental Secretariat, Brazil
Macedo Costa, M.	Brazilian National Development Bank, Brazil
Machado, G.	Graduate School of Engineering, Federal University of Rio de Janeiro, Brazil
McDonald, A.	International Atomic Energy Agency
Moreira, F.	Federal University of Salvador, Bahia, Brazil
Moreira, J.R.	Brazilian Reference Centre on Biomass, University of São Paulo, Brazil
Pereira Aragao, A.	Agência Nacional do Petróleo, Brazil
Pereira, A.O., Jr.	Empresa de Pesquisa Energética, Brazil
Rogner, H.H.	International Atomic Energy Agency
Rosillo, F.	Imperial College London, United Kingdom
Schaeffer, R.	Graduate School of Engineering, Federal University of Rio de Janeiro, Brazil
Schiozer, D.	State University of Campinas, Brazil
Simoes, A.F.	State University of Campinas, Brazil

Soares, J.	Empresa de Pesquisa Energética, Brazil
Strubegger, M.	International Institute for Applied Systems Analysis
Suslick, S.	State University of Campinas, Brazil
Szklo, A.	Graduate School of Engineering, Federal University of Rio de Janeiro, Brazil
Tiago Filho, G.L.	Federal University of Itajuba – Minas Gerais, Brazil
Toth, F.	International Atomic Energy Agency
Vera, I.	International Atomic Energy Agency
Walter, A.	State University of Campinas, Brazil

This publication is the product of an international effort to develop a novel approach for the comprehensive assessment of national energy systems within a sustainable development context. The study represents the first of a series of national studies being conducted through a partnership initiative under the World Summit on Sustainable Development and the United Nations Commission on Sustainable Development. The study comprises a quantitative and qualitative analysis of Brazil's energy needs, supply and security; domestic resources; technology development and innovation; and alternative future scenarios taking into consideration sustainable development criteria and goals defined by Brazilian experts. Social, economic and environmental issues and trends are examined in detail using statistical analysis of historical data, integrated demand and supply modelling systems and Energy Indicators for Sustainable Development. The quantitative assessment is complemented by discussions of major institutional and infrastructural considerations. The report summarizes the analyses, identifies major energy priority areas for Brazil and explores policy options useful to decision makers and specialists in energy and the environment.

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