IAEA Nuclear Energy Series

No. NG-T-4.5

Basic Principles

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# Indicators for Nuclear Power Development

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International Atomic Energy Agency

# IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

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# INDICATORS FOR NUCLEAR POWER DEVELOPMENT

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

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# INDICATORS FOR NUCLEAR POWER DEVELOPMENT

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# FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

Many IAEA Member States are considering adding nuclear energy to their national energy supply portfolios, or increasing its portfolio share, for various reasons. The indicators presented in this publication are intended to help stakeholders assess the broader context of establishing or expanding a nuclear power programme with regard to the macro-, techno- and socioeconomic aspects of nuclear power as well as the energy and environmental dimensions. The indicators can be used in various phases of such projects, from early assessments to decision support activities.

The indicators are expected to provide users with guidance for answering basic questions about nuclear energy development and extension; based on the answers given to these questions, a better informed decision can be made about the next step (e.g. a prefeasibility study) in the decision making process. In addition, many indicators in this publication can help explore issues in nuclear energy development that cannot be addressed by energy planning models; hence, they can complement results obtained using other analytical tools.

These indicators are meant to provide a first order assessment of the situation and identify in a balanced and objective manner the issues that present benefits and challenges, and thereby help guide more detailed evaluations in the next stage of planning and preparation. They are by no means intended to provide any thresholds or 'go/no-go' criteria for the potential implementation of a nuclear power programme. Moreover, it is at the discretion of users to determine the relative importance of the indicators in their assessment, with a view to national circumstances and the objectives of their analysis.

The publication provides a comprehensive set of indicators that cover the key aspects of nuclear power development. Methodology sheets are provided to help users in data collection, quantification and interpretation of the indicators. The methodology sheets adopt the well established and proven templates developed for the publication Energy Indicators for Sustainable Development, published by the IAEA in 2005. The application of the indicators is flexible. Users can select a subset of indicators that are most relevant for the questions they wish to explore in a given exploratory study or decision making process.

The IAEA officers responsible for this publication were F.L. Toth and T. Alfstad of the Department of Nuclear Energy.

EDITORIAL NOTE

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# 1. INTRODUCTION

## 1.1. BACKGROUND

There are many reasons why countries consider adding nuclear energy to their national energy supply portfolios or increasing its portfolio share. The reasons span from supporting overall socioeconomic development and fostering energy security by expanding dependable and autonomous sources of supply, to environmental considerations such as reducing emissions of energy related greenhouse gases (GHGs) and other air pollutants that cause damage at local and regional scales.

In the ‘golden age’ of economic growth of the 1950s and 1960s, fast economic growth and an associated optimism about technology prevailed, especially in North America, Western Europe and Japan, the latter two of which were on a fast track to recovery after a devastating war. Fast growing economies required energy and some countries were running out of cheap domestic coal and oil reserves, while others lacked domestic energy resources altogether. Low cost energy was considered to be an important factor for replacing increasingly expensive labour and fostering international competitiveness. Energy supply security and diversifying the energy supply mix were also important policy goals by that time. Nuclear power was widely believed to be a cheap, clean, safe and reliable energy source, was perceived as an advanced technology and benefited from positive technological spillover, and hence it enjoyed a positive public perception and was the subject of great expectations.

The relative importance of these factors varied across countries depending on national circumstances such as physical geography (size and topography of the country, barriers of energy transport and transmission, availability of non-fuel resources) including climate and economic geography, and especially economic structure and spatial locations; the nature and magnitude of energy intensive sectors (such as copper, aluminium, steel, pulp and paper); and the concentration of population and economic activities determining the energy demand density.

The phase of economic development a particular country finds itself in can influence the amounts and types of energy services required. At earlier stages of development, the priority is typically to supply huge quantities of cheap (and consequently often polluting) energy forms to fuel growth, while at later stages smaller energy amounts are required per unit of value added but with higher requirements with respect to reliability (defined as the probability of meeting performance requirements), quality (e.g. no voltage fluctuations) and environmental impacts. In many countries, it was an explicitly declared or an undeclared social objective to provide cheap electricity as a social service. Finally, emerging environmental concerns also played a role: urban air quality (heavy hydrocarbons, visibility degradation) and regional air pollution (acid rain) on the one hand and impacts of large hydropower projects, for example, on the other.

Many of these drivers are still valid in the 2010s and are likely to remain valid in the future. So are the statements about the diversity of national circumstances shaping thinking on whether or not to pursue nuclear power. The four general drivers from the 1960s (fast growth, resource availability, supply security and diversification) are particularly relevant, but are now present at a different order of magnitude: more than 2.6 billion people alone in China and India need energy to drive socioeconomic development (to build and run factories and establish and expand physical infrastructure) on the one hand and to enjoy the fruits of development (better housing and more household appliances, leisure travel, etc.) on the other. At higher levels of affluence, people tend to prefer convenient, clean and safe forms of energy, typically electricity.

Satisfying fast growing energy needs in the early twenty-first century takes place in the context of a much more interconnected global energy economy than was the case 50 years ago. Consideration of nuclear power is motivated by various reasons in developing and developed countries. Development aspirations and food and water security are important concerns mostly in developing countries, while supply security and fluctuating fossil fuel prices are concerns across all countries. Export orientated development strategies, economic efficiency and competitiveness supported by cheap and reliable energy are also shared concerns. With the establishment of the Ad Hoc Working Group on the Durban Platform for Enhanced Action as a subsidiary body under the United Nations Framework Convention on Climate Change (UNFCCC), combatting climate change has also become an important policy issue for developing countries. Many of them (especially in East and South-East Asia) are also facing severe local and regional air pollution problems. Climate change and sustainable energy are important components of the post-2015 development agenda of the United Nations. A lot of progress has been made with renewable energy alternatives to fossil fuels in recent years in terms of technical maturity and costs but they will need to improve further to make a significant contribution to a dependable energy supply.

All the above issues require quantitative assessments in order to explore their relevance in the early stages of considering the establishment or extension of nuclear energy programmes. Member States considering embarking on a nuclear energy programme will find comprehensive guidance on how to develop a safe, secure and sustainable infrastructure for nuclear power in the publication Milestones in the Development of National Infrastructure for Nuclear Power [1]. It covers all relevant aspects organized into 19 issues and spanning three phases of nuclear programme development. The indicators presented in this publication are not formally included in the Milestones process but they might be useful for exploring some broader issues, especially in the early exploratory period of the national strategy assessment. The indicators might also contribute to early assessments of some of the issues in the Milestones process, such as national position, funding and financing, electrical grid, environmental protection, nuclear fuel cycle and radioactive waste management. However, the Milestones process includes many other issues that need to be addressed, ranging from nuclear safety and safeguards to the regulatory framework, radiation protection and stakeholder involvement that are beyond the scope of the indicators presented here (see Ref. [1]).

## 1.2. OBJECTIVE

The indicators presented in this publication are intended to shed light on a range of issues that are important for nuclear power development. A number of countries are considering introducing nuclear power and some of them are close to beginning the construction of their first nuclear power plant (NPP) in the coming years or decades while a number of other countries are expanding existing programmes. The aim of the publication is therefore to present a fairly comprehensive list of indicators. These indicators serve as a tool to identify issues that are relevant for investing in nuclear power as well as to identify areas where such investment could yield benefits.

## 1.3. SCOPE

This publication intends to help to explore a range of considerations in the broader context surrounding the introduction or expansion of nuclear power programmes in four main areas: the macro- and socioeconomic, energy and electricity, techno-economic aspects of nuclear power and the environmental dimensions. It presents a set of indicators together with methodology sheets for quantifying and assessing them.

## 1.4. USERS

The indicators for nuclear power development (INPD) methodology sheets are intended to provide key stakeholders who are considering nuclear power development or expansion, such as energy planners, policy makers, NPP companies and lobbyists, with tools that will enable them to capture wider considerations and conditions linked to energy system analysis. These considerations may or may not explicitly reveal a need for nuclear energy. They help users interested or involved in nuclear power development to explore energy, economic, environmental and — if applicable — existing nuclear conditions, covering key dimensions of relevance.

## 1.5. STRUCTURE

Section 2 provides detailed information about various issues related to INPDs, including the historical background of nuclear power development, the indicators sorted into four main indicator groups, the related methodology sheets and the main sources of data for quantifying the indicators. Methodology sheets for all INPDs are presented in Section 3.

# 2. THE CONTEXT OF THE INDICATORS

This section presents an overview of issues related to the INPDs. After a short historical overview, selected aspects of the indicators are discussed and the full list of indicators is presented. This is followed by an introduction to the methodology sheets and the main sources of data for quantifying the indicators.

## 2.1. HISTORICAL OVERVIEW

The world's first commercial nuclear reactor, the Obninsk NPP in the Soviet Union, started operation in 1954. Over the following decades, the generation of nuclear power expanded rapidly as a number of countries pursued ambitious nuclear programmes. The oil crisis of 1973 added impetus to the expansion of nuclear power as several member countries of the Organisation for Economic Co-operation and Development (OECD) adopted policies to reduce their dependence on imported oil by substituting it in the power sector with nuclear power [2]. The construction boom reached a peak in 1979, when 234 reactors were under construction, and by the late 1980s, nuclear power reached a share of 17% of total electricity generation worldwide (see Fig. 1). However, construction delays, cost overruns and the accidents at Three Mile Island and Chernobyl led to a slowdown in the construction of NPPs, but their share in electricity generation remained constant for most of the 1990s before it started to decline to around 12% by the early 2010s. Two decades of accident free operation, steadily improving performance and increased demand for low carbon electricity led to talks of a nuclear renaissance and an increase in the number of planned reactors. These plans were re-evaluated and scaled back following the financial crisis of 2008 and the accident at the Fukushima Daiichi power plant, but nuclear power still looks set to expand over the coming decades (see Ref. [3]).

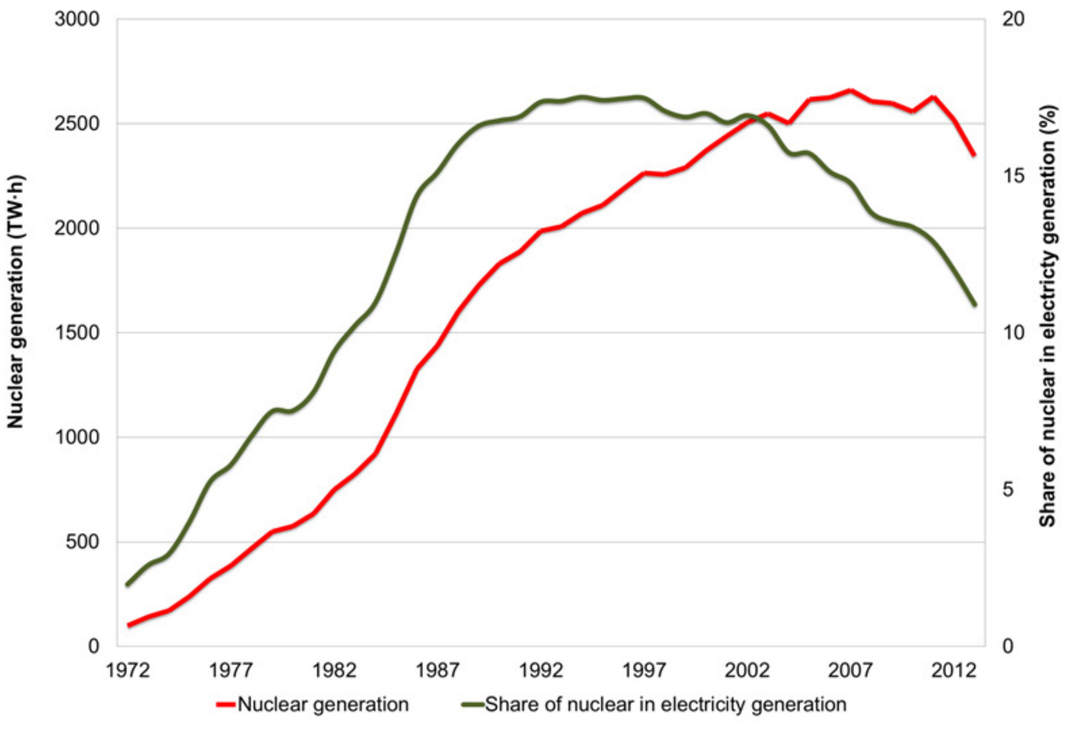


*FIG. 1. Global electricity generation from nuclear power and its share in total electricity generation from 1971 to 2012. Data sources: Refs [4, 5].*

As of October 2015, there were 438 reactors in operation in 30 countries with a total capacity of approximately 379 gigawatt (electrical) (GW(e)). In 2014, these reactors generated 2410 terawatt-hour (TW·h) of electricity, which was around 11% of the world total. Also in October 2015, 68 reactors were under construction with a total planned capacity of 67 GW(e) [4]. Two countries, Belarus and the United Arab Emirates, are currently constructing their first power reactors. A further 166 reactors, for a total capacity of 187 GW(e), have approvals, funding or major commitment in place, and Fig. 2 shows their distribution across the continents.

It is uncertain how many of the planned reactors will actually be constructed, but the numbers demonstrate that there is considerable interest in expansion of nuclear power in many regions. The IAEA estimates that somewhere between 385 GW(e) and 632 GW(e) of nuclear power will be in operation by 2030, with the majority of new constructions expected in Asia [3].

While there is great uncertainty in the level of installed capacity in the future, other forecasters also predict an expansion of nuclear power (see Fig. 3). The uncertainty, reflected in the wide range of potential outcomes depicted in Fig. 3, is tied to the extent of new builds and to a lesser degree to the retirement of existing reactors. A wide range of factors such as technology development, fuel prices, policy and public opinion, amongst others, will shape the future investment climate for nuclear power. The IAEA low estimate, for instance,

> "…represents expectations about the future assuming that current market, technology and resource trends continue and there are few additional changes in laws, policies and regulations affecting nuclear power. Policy responses to the accident at the Fukushima Daiichi NPP, as understood in April 2015, are included in the projections. This case was explicitly designed to produce a 'conservative but plausible' set of projections. Additionally, the low case does not automatically assume that targets for nuclear power growth in a particular country will necessarily be achieved" (Ref. [3], p. 6).

In contrast,

> "The high case assumes that current rates of economic and electricity demand growth, especially in the Far East, will continue. Changes in country policies toward climate change are also included in the high case" (Ref. [3], p. 6).

Similarly, the OECD International Energy Agency (IEA) explores the energy mix implications in the context of global climate policies. It evaluates current policies, new policies and 450 scenarios reflecting increasing efforts by policy makers to reduce carbon emissions, with stronger policies likely to lead to increased investment in nuclear power and other low carbon technologies. An overview of capacity projections is presented in Fig. 3. It is important

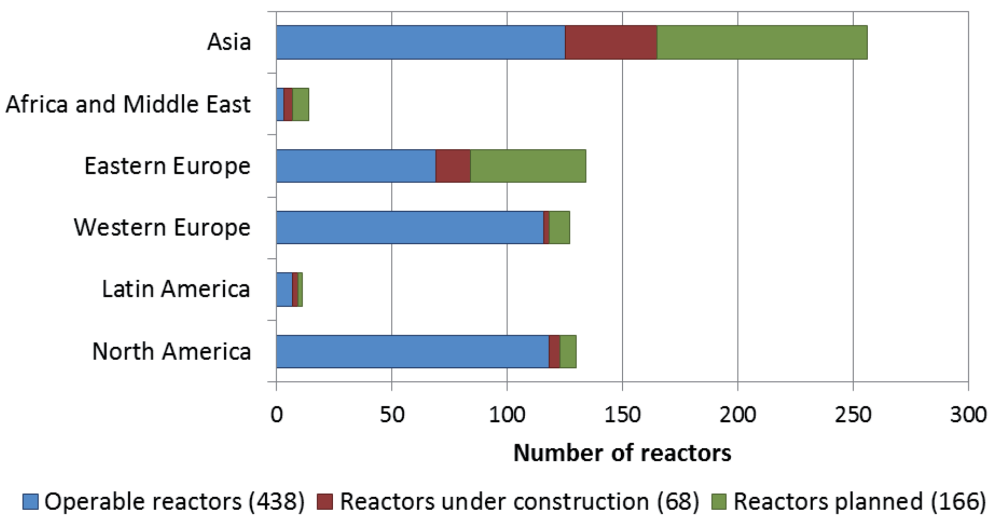


*FIG. 2. Number of reactors in operation, under construction or planned as of February 2014. Data sources: Refs [4, 6].*

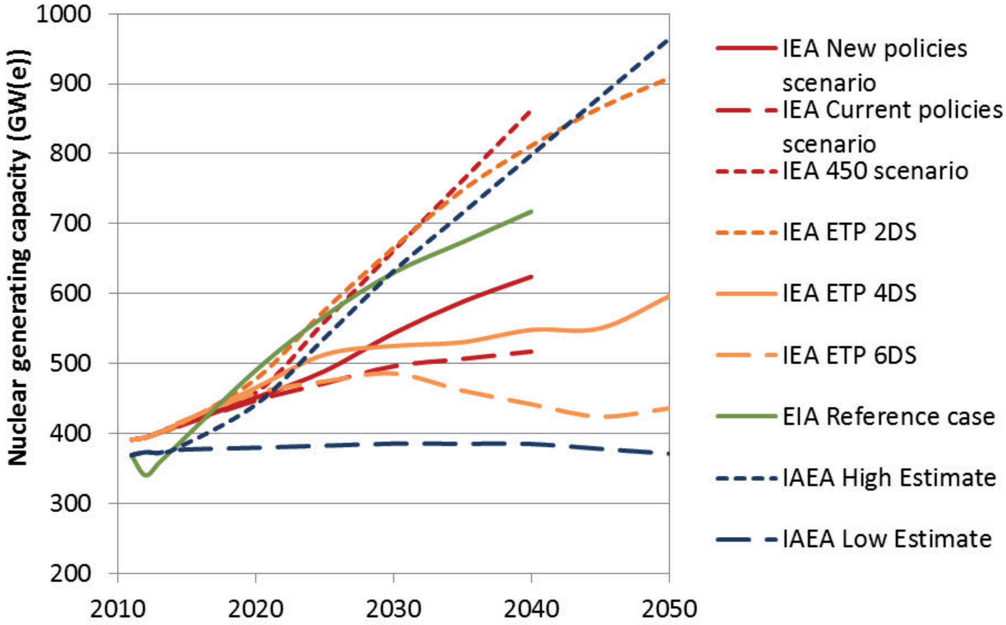


*FIG. 3. Projections of nuclear electricity generating capacity. Sources: Refs [3, 7–9].*

to note that the projections included in Fig. 3 use different definitions for generating capacity and the numbers are therefore not directly comparable. However, regardless of definition, the scenarios depicted here all indicate an expected expansion of nuclear power.

Given the scale of planned nuclear new builds and the prospect of a number of countries constructing their first NPPs, it might be useful to consider the broader economic, energy and environmental context in which national nuclear programmes evolve and will be implemented. These aspects of nuclear programmes can be explored in various ways: simple desk studies assessing the various aspects of quantifying and interpreting indicators portraying key features, detailed energy-technology models searching for the optimal energy mix under a range of economic, resource and environmental constraints or general equilibrium models that explore energy demand and supply as part of the national economy.

This publication provides a set of indicators for nuclear power development that can serve as a tool to help explore broader circumstances in a country with respect to investments in nuclear energy. These indicators are intended to provide a first order assessment of the situation and identify the energy–economy–environment (3E) issues that are most relevant for establishing or expanding nuclear power programmes, and thereby help guide more detailed evaluations in the subsequent steps of programme preparations.

The indicators cover various aspects related to nuclear power programmes. The first group of indicators address macroeconomic conditions and are intended to assess a country’s ability to finance and pay for a nuclear power project. The second category is intended to assess the energy and power systems in the country. The main aim of these indicators is to evaluate the prospects for integrating an NPP into the power system, current budget and policy support in the energy sector, as well as other issues to help determine the benefits and drawbacks of introducing or expanding nuclear power. A set of indicators on nuclear energy is included specifically for countries that already have a nuclear industry to determine the current state of the sector. Finally, the last group of indicators addresses environmental issues to assess the impacts an NPP or a broader nuclear programme could have on the environment.

## 2.2. APPLICATION

An analysis based on these indicators will not be comprehensive or detailed enough to give ultimate answers about introducing or expanding nuclear power, but it can help identify aspects and issues concerning nuclear power development that warrant further investigation. The indicators themselves are in a way too broad and simplistic to serve as *the* tool for a pre-feasibility study or to develop a fully fledged national position, but might be rather useful as an initial screening tool to help identify issues that in-depth studies and analyses should address in more detail. This implies that there is nothing definitive about the conclusions reached through an analysis based on these indicators.

Furthermore, the indicators provide a quantitative basis for sound analysis and good judgement. They should not be applied blindly without due consideration of local needs, challenges and other unique circumstances in the country under study. Users need to determine to what extent a given indicator is relevant in their context, if it helps answer pertinent questions and if the information required to quantify the indicator is available. In many cases, some of the indicators contained here may not be applicable as they are meant to address issues that are not of relevance under certain circumstances. For instance, most of the indicators in the nuclear category are aimed at countries that already have NPPs and would not be relevant for countries that are just considering launching a nuclear programme. In some cases, additional indicators may be necessary to address all relevant aspects. In any case, it is up to the user to judge which indicators to apply for any given assessment. This always depends on the objectives of the specific application.

## 2.3. LIST OF INDICATORS

A total of 42 indicators are included in this publication. They are grouped into four thematic areas: macro- and socioeconomics, energy and electricity, nuclear power and environment (see Fig. 4).

## 2.4. ISSUES UNDER CONSIDERATION

The indicators contained in this publication are designed to describe, illustrate or evaluate conditions for the introduction or expansion of nuclear power. They are a set of tools designed to help analysts assess various aspects of nuclear power development. The idea is that this set of indicators can help shed light on a range of issues that can help guide future assessments.

The indicators are intended to serve three main purposes:

- Explore broader 3E issues;
- Identify issues that should be further explored to assess the feasibility of nuclear power;
- Identify areas where introduction or expansion of nuclear power may yield benefits or have detrimental side effects.

The first aspect is addressed by assessing some economic (MAC1–MAC4) and financial (MAC5 and MAC6) issues to support a mammoth project such as an NPP in the context of the national economy. NPP construction projects are major investments that can exceed US $10 billion [10], and financing such large investments can be one of the biggest hurdles to nuclear power development. Such large projects could also lead to other investments being crowded out, and could require significant external borrowing or other long term financial commitments. It is important to consider the size and state of the national economy in this respect. Feasibility is also examined by evaluating to what extent conditions in the energy and power systems are ready to accommodate an NPP and by identifying development needs in these areas (ENE1–ENE5, ENE16 and ENE17). NPPs are usually very large power sources and their size entails codependency with the power grid. The grid needs to be able to support the NPP when it is in operation as well as to supply power when the plant is out of operation for refuelling or maintenance.

### Macro- and socioeconomics

| Code | Indicator name |
|---|---|
| MAC1 | Gross domestic product (GDP) |
| MAC2 | Gross fiscal balance |
| MAC3 | Current account balance |
| MAC4 | External debt |
| MAC5 | Credit rating of project sponsors |
| MAC6 | Large scale projects financed in the past ten years (in excess of US $250 million) |

### Energy and electricity

| Code | Indicator name |
|---|---|
| ENE1 | Primary energy supply |
| ENE2 | Final energy demand |
| ENE3 | Electricity generation |
| ENE4 | Total installed capacity |
| ENE5 | Peak electricity demand |
| ENE6 | Reserve margin |
| ENE7 | End user price of electricity |
| ENE8 | Cost of electricity generation |
| ENE9 | Levelized cost of electricity |
| ENE10 | Fuel price increase sensitivity |
| ENE11 | National energy budget |
| ENE12 | Government expenditures for power generation |
| ENE13 | Share of imported fossil fuels in power generation |
| ENE14 | Diversification of energy sources in electricity supply |
| ENE15 | Share of intermittent generation in electricity supply |
| ENE16 | Capacity of transmission lines |
| ENE17 | Reliability of the transmission and distribution system |
| ENE18 | Power generation plant vintage |
| ENE19 | Export and import prices of fuels used in electricity generation |
| ENE20 | Reserve to production ratios for various fuels |
| ENE21 | Rate of return on investments in the power sector |

*FIG. 4. List of indicators for nuclear power development.*

**Nuclear power**

| Code | Indicator name |
|---|---|
| NUC1 | Installed nuclear power capacity |
| NUC2 | Nuclear power reactors in operation |
| NUC3 | Planned nuclear power investments and retirements |
| NUC4 | Production of fissile material (uranium) |
| NUC5 | Estimated cost of the new NPP |
| NUC6 | Estimated size of the new NPP |
| NUC7 | Public investments in nuclear power generation |
| NUC8 | National and foreign direct private investments in nuclear electricity generation |

**Environment**

| Code | Indicator name |
|---|---|
| ENV1 | $CO_2$ emissions intensity of power production |
| ENV2 | Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates) |
| ENV3 | Production of low level radioactive waste |
| ENV4 | Production of spent fuel and high level radioactive waste |
| ENV5 | Solid waste generation from electricity production |
| ENV6 | Power density |
| ENV7 | Water use in electricity generation |

*FIG. 4 (cont.). List of indicators for nuclear power development.*

Other aspects are addressed by evaluating the extent and nature of the costs and benefits that are likely to arise from the introduction or expansion of nuclear power. The primary areas of focus here are energy, environmental and economic impacts. The environmental impacts addressed include emissions of GHGs (ENV1) and air pollutants (ENV2) emissions as well as land (ENV6) and water (ENV7) use. Production of low level waste (LLW) (ENV3) and spent fuel and high level radioactive waste (SF&HLV) (ENV4) is also included. The economic impacts focus on the cost of energy supply (ENE7–ENE10) as well as budget impacts (ENE11, ENE12). Energy security is also included (ENE13, ENE19).

Some of the indicators are unambiguous in that a higher or lower (depending on the indicator) value clearly signifies a more favourable situation. A large market (ENE3) and a large electric grid (ENE4), for instance, is relatively better equipped to receive a large reactor of the size typically on offer from vendors at the present time. Similarly, a large economy (MAC1) might more easily support the large investment required, and a good credit rating (MAC5) indicates better prospects for attracting financing on favourable terms. For other indicators, it is less clear whether a higher or lower value is more advantageous as the value will need to be considered in context.

A large current account deficit (MAC3) or external debt (MAC4) might raise concerns in small and medium sized economies, but they are less likely to affect nuclear investments in large economies. Deficit and debt are seen not just in absolute terms and in relation to gross domestic product (GDP), but also in relation to the projected cost of a new NPP (NUC5). The user must therefore apply skills and judgement to determine the relevance and implications of the resulting values.

## 2.5. ASPECTS OF NUCLEAR POWER DEVELOPMENT NOT CONSIDERED BY THE INDICATORS

Some aspects of nuclear power development are not included here because they do not lend themselves well to indicator based assessment or because they are addressed more comprehensively in other IAEA publications. For instance, issues such as legal and regulatory frameworks, institutional capacity, human resource management and safeguards are not within the scope of this publication. The IAEA Milestones publication, a guide for nuclear newcomers [1], provides a systematic coverage of these issues.

## 2.6. METHODOLOGY SHEETS

A complete description of each of the INPDs is provided in the methodology sheets in Section 3. The objective of these sheets is to provide the user with all the information necessary to develop the indicators. Each methodology sheet consists of five components (see Table 1).

TABLE 1. STRUCTURE OF THE METHODOLOGY SHEETS

| Section | Content |
|---|---|
| Brief definition | Definition of the indicator; units of measurement; alternative definitions (if applicable) |
| Policy relevance | Purpose and relevance to nuclear power development and sustainable development as well as any relevant international conventions or agreements, targets or recommended standards (if applicable); links to other related INPDs |
| Methodological description | Underlying definitions and concepts, measuring methods, limitations and alternative definitions (if applicable) |
| Assessment of data | Primary and auxiliary data needed to quantify the indicator, national and international data availability and sources |
| References | Literature sources and additional reading |

The INPDs follow the concept and framework of the interagency publication Energy Indicators for Sustainable Development [11]. The methodology sheets are consistent in their content and format with those in that report, which, in turn, are based on the format used by the United Nations Commission on Sustainable Development for general sustainable development indicators [12].

## 2.7. INPD INFORMATION SOURCES

The quantification, assessment and interpretation of INPDs requires obtaining a number of primary and auxiliary statistics from various information sources, some of which can be used for several indicators, especially those listed within the same indicator group. They include on-line databases as well as relevant regularly updated publications from various organizations containing relevant data.

The primary and most obvious source of data in all countries with a reasonably good (comprehensive and quality checked) statistical system would usually be the national statistical office, the statistical divisions of the economy, energy and environment ministries and their background and support organizations, public and private utilities, and other stakeholders with clear mandates and procedures regarding data collection, quality checking and dissemination. Various international organizations also collect data and disseminate them in electronic or printed form. International data sources are presented briefly in four thematic areas below.

***Economic and demographic data***

The World Bank and the International Monetary Fund (IMF) are useful sources of data for several macroeconomic INPDs. The World Bank's World Development Indicators [13] time series is a collection of development indicators presenting the most current and accurate global development data compiled from officially recognized international sources. It includes topics in agriculture, aid, economy and growth, financial sector, external debt, infrastructure, poverty, social development, and so on. To provide more detailed financial information, the IMF [14] publishes a range of time series on lending, exchange rates and other economic and financial indicators. Relevant IMF databases include the World Economic Outlook Databases, the International Financial Statistics and the Balance of Payments Statistics.

***Energy data***

Key information sources for international energy data include the IEA, the United States Energy Information Administration (EIA) and the World Energy Council (WEC). The IEA [15–18] provides regularly updated authoritative statistics for many countries, including information on energy supply, production, trade and balances. Publications of the IEA that are relevant to the INPDs include the Key World Energy Statistics, which contains timely data on supply, transformation and consumption of all major energy sources, and the joint report series Projected Cost of Generating Electricity by the IEA and the OECD Nuclear Energy Agency (NEA), which presents the latest generation cost data available for a wide variety of fuels and technologies. Similarly to the IEA publications, the EIA's International Energy Statistics database [9] includes energy data on production, consumption, imports, exports, capacity, stocks and emissions for all fuels and countries. For information on energy resources, the WEC's triennial World Energy Resources [19] report presents a key source, with a focus on proven recoverable fossil fuel reserves.

***Nuclear data***

The IAEA is the primary international source of data for nuclear indicators. The IAEA/NEA Uranium Group's biennial publication Uranium: Resources, Production and Demand (The Red Book) [20] compiles data on world trends and developments in uranium resources, production and demand. The IAEA's Power Reactor Information System (PRIS) [4] is a comprehensive database focusing on NPPs worldwide, containing reactor specific data and technical design characteristics as well as performance data.

***Environmental data***

The primary source for pollutant emissions data is the United Nations Environment Programme's (UNEP) Environmental Data Explorer [21]. The IAEA's Net Enabled Radioactive Waste Management Database (NEWMDB) [22] is an on-line source for information on radioactive waste management, including information on radioactive waste inventories and radioactive waste disposal. The data in the NEWMDB are supplied by the designated government representatives of Member States.

# 3. INDICATOR METHODOLOGY SHEETS

## 3.1. THE MACRO- AND SOCIOECONOMIC DIMENSION

*MAC1: Gross domestic product (GDP)*

| | |
|---|---|
| Brief definition | The sum of gross value added by all resident producers in the economy, plus any product taxes, minus any subsidies not included in the value of the products |
| Units | National currency or US $ |
| Alternative definitions | Gross national product (GNP) |

**Policy relevance**

**(a)** **Purpose:** To evaluate the size and performance of an economy in a country that is considering a nuclear power programme.

**(b)** **Relevance to nuclear power development:** The quoted overnight capital costs for a typical 1000 megawatt (electrical) (MW(e)) nuclear reactor range from US $2 to US $6 billion, which would constitute a considerable share of total GDP in many countries. This indicator should therefore be viewed in conjunction with the total cost of an NPP to determine if an investment of this size can be supported without unduly stretching the country's economic resources. If a cost estimate for an NPP exists, this indicator could be measured as the ratio of that estimate to the size of the economy. This would measure the cost of the NPP as a share of GDP.

**(c)** **Relevance to sustainable development:** GDP is the most widely used measure of the total size and wealth creation of an economy. The annual change in GDP, the GDP growth rate, is therefore an indicator of the pace of economic development. An increase in (real) GDP signifies that an economy is growing, which is usually a requirement for increased employment and income. Economic growth is a prerequisite for sustainable development as it is essential for eliminating poverty as well as for sustaining and expanding an economy's resource base in a way that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** Ideally, the size of the economy would be large enough to allow sufficient savings to cover the investment and the costs associated with establishing and maintaining the necessary physical and institutional infrastructure, and to cover the liability for potential environmental and health damage in case of an accident.

**(f)** **Links to other indicators:**
- MAC2: Gross fiscal balance;
- MAC3: Current account balance;
- MAC4: External debt;
- ENE1: Primary energy supply;
- ENE2: Final energy demand;
- ENE11: National energy budget;
- NUC5: Estimated cost of the new NPP;
- NUC7: Public investments in nuclear power generation.

**Methodological description**

**(a)** **Underlying definitions and concepts:** GDP measures the monetary value of final goods and services (goods and services paid for by the end user) produced in a country within a given period of time (e.g. 3 months or 12 months). It is an aggregate of all the output produced within the borders of a country. GDP consists of goods and services produced for sale in the market as well as some non-market production, such as defence or education services provided by the government [23, 24].

**(b)** **Measuring methods:** There are three main approaches to calculating GDP: the production approach, the expenditure approach and the income approach. The production approach sums the value added (i.e. total sales less the value of intermediate inputs into the production process) at each production stage. The expenditure approach sums the value of expenditures made by final users (including households, companies, government and foreigners) to purchase final goods and services. The income approach adds up the incomes generated by production (e.g. salary of employees or operating surplus of companies) [23].

**(c)** **Limitations of the indicator:** Although a country's GDP may serve as an indicator for its ability to absorb the large investment associated with the development of a nuclear power programme, it does not directly assess savings or investment. Furthermore, it does not give any information about a country's ability to obtain financing for such a large project (e.g. sovereign credit rating).

**(d)** **Alternative definitions/indicators:** An alternative indicator is the gross national product (GNP) that accounts for the total output of a country's citizens, irrespective of their location.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Depending on the method chosen for calculating this indicator, one needs to obtain data about the total sales and total value of intermediate inputs over the course of the same accounting period; or the sum of purchases made by final users; or the sum of incomes generated by production.

**(b)** **National and international data availability:** For the majority of countries, data is available from national and international sources, generally based on international guidelines for the compilation of the indicator. GDP data are typically reported on a yearly basis by national statistical offices or central banks, and collected internationally via the United Nations National Accounts Questionnaire. The OECD makes GDP estimates for its member countries on a quarterly basis, obtained through census or surveys. GDP data are also available from the United Nations Statistics Division, the World Bank and the IMF.

*MAC2: Gross fiscal balance*

| | |
|---|---|
| Brief definition | The amount by which government revenues exceed or are below government expenditures, divided by total GDP |
| Units | % of GDP |
| Alternative definitions | Government debt |

**Policy relevance**

**(a)** **Purpose:** To assess the fiscal conditions in a country.

**(b) Relevance to nuclear power development:** The state of public finances can be important for the prospects of an NPP. Nuclear power projects are capital intensive and can constitute a major component of total investment in small or medium sized economies. Since direct public investment or loan guarantees are often required for NPPs, healthy public finances are important for securing financing at favourable terms.

In addition, deficit financing can lead to higher interest rates, higher taxes and inflationary pressure, all of which can have consequences for the economics of large capital intensive projects with long lifetimes such as an NPP. Higher deficits can lead to the need to raise tax rates in order to service government debt and hence a reduction in after tax profits. Higher deficits could also entail higher interest rates as a government's increased demand for credit drives up the cost of debt. Finally, inflation may ensue if a government resorts to financing deficits by money creation [25–27].

**(c) Relevance to sustainable development:** Fiscal policies have a significant impact on economic growth, macroeconomic stability, inflation and therefore on sustainable economic development. Economic theory postulates a number of relationships between fiscal deficit and sustainable economic development and growth. In general, responsible fiscal management can help spur economic growth and job creation over the long term. Key aspects are the level and composition of government expenditure and revenue, budget deficit and government debt. As such, fiscal discipline is a chief element of macroeconomic stability [28].

Any positive effect on growth of fiscal expansion (e.g. financing of public investment in health, education and infrastructure) is likely to be partially or entirely offset by adverse effects of deficit financing on investments through higher interest rates, higher taxes and inflationary pressure. Fiscally dominant governments running persistent deficits may finance those deficits with money creation at some point, thus causing inflation [29].

Deficit reductions, on the other hand, can increase private consumption and investment through the wealth effect as lower deficits imply reduced future taxes to service government debt and hence increase the present value of perceived private permanent income or wealth and increase growth through increases in private spending on investment and consumption. Overall, reduced public deficit signals that public services are sustainable over the long run [27].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** For European Union (EU) Member States, the basic rule of budgetary policy enshrined in the Treaty on European Union is that they shall avoid excessive government deficits. Compliance with this rule is to be examined on the basis of reference values for the general government deficit, currently 3% of GDP [28].

**(f) Links to other indicators:**
- MAC1: Gross domestic product (GDP);
- MAC3: Current account balance;
- MAC4: External debt.

**Methodological description**

**(a) Underlying definitions and concepts:** The budget balance is the difference between government revenues and spending over the course of an accounting period, usually one year. A positive balance is called a government budget surplus, and a negative balance is called a government budget deficit. The gross fiscal balance (measured in percentage of GDP) can be obtained from national accounts published by the government or alternatively from the IMF either directly (biannual Fiscal Monitor [30]) or indirectly by using the IMF eLibrary's Government Finance Statistics.

**(b) Measuring methods:** This indicator is defined by government spending and government revenues, both scaled to nominal GDP, usually over the course of one year. Since the unit of this indicator is a percentage, the required data can be used in any currency as long as it is used consistently.

(c) **Limitations of the indicator:** None.

(d) **Alternative definitions/indicators:** An alternative indicator is government debt, which is the total debt owed by a central government, while the annual public deficit refers to the difference between government spending and revenues, and represents an increase in debt over a particular year. Public debt is a way of financing public deficits.

**Assessment of data**

(a) **Data needed to compile the indicator:** Total government spending (or total government spending as a percentage of GDP), total government revenues (or total government revenues as a percentage of GDP), total GDP — all over the course of the same accounting period.

(b) **National and international data availability:** The most important source of data on national government balances is national statistics bureaus. The IMF's Fiscal Monitor [30] is an international collection of data from contributing countries.

*MAC3: Current account balance*

| | |
|---|---|
| Brief definition | The sum of the trade balance, net income paid abroad and net transfers paid abroad; or the difference between gross domestic saving and gross domestic investment |
| Units | National currency or US $; % of GDP |
| Alternative definitions | — |

**Policy relevance**

(a) **Purpose:** To measure the difference between a country's savings and its investment.

(b) **Relevance to nuclear power development:** The current account balance (CAB) has implications for the financing cost of nuclear power projects. The current account can be expressed as the difference between national savings (public and private) and investment [31]. Therefore, high budget deficit levels, reflecting a low level of national savings relative to investment, over a long period of time, can accumulate large government debts, leaving the borrower less financial flexibility to borrow in the future, thereby further restricting access to international credit markets. This in turn indicates increased risk of sovereign default. The creditworthiness of a government involved either directly or indirectly in the development of a nuclear power project is essential to the viability of the project as it decreases the overall risk and therefore the cost of capital. Government participation typically greatly facilitates the process of raising debt finance, as lenders will take comfort in the loan being guaranteed by the government [25, 26].

However, this is not strictly the case, as countries with high levels of economic growth equally tend to exhibit high current account deficits for a long period, which does not necessarily indicate a higher risk of sovereign default. The current account can also be expressed as the difference between the value of exports of goods and services and the value of imports of goods and services. Expressed in these terms, a current account deficit reflects a higher level of imports of goods and services than exports [31]. To assess the implications for default risk, and thus for the NPP financing costs, the cause of the increase in deficit must be identified. If, for example, the increase is due to financing investments in the productive sector, increased export receipts or import reductions can be expected in the future with positive implications for the CAB. If, however, the deficit is due to increasing domestic consumption financed through the expansion of external indebtedness, it could become unsustainable in the medium term, resulting in default by the sovereign issuer [32].

**(c) Relevance to sustainable development:** The CAB reflects a country's underlying economic trends at a particular point in time, though it can be indicative of different situations. It can be expressed as the difference between total exports and total imports or between national savings and investment.

A CAB deficit, for instance, reflects an excess of imports over exports, and it may point to competitiveness problems. Countries characterized by low living standards and an underdeveloped industrial base are typically unable to produce standard goods and services that can compete in international markets and end up importing the majority of consumer goods and services. But as an economy develops, so do its structural bases of global competitiveness. Successful and sustainable economic development is a process of successive upgrading in which the private sector and its supporting environments evolve simultaneously, thereby enabling increasingly sophisticated ways of producing and competing [33].

A CAB deficit can equally be indicative of low levels of gross domestic savings compared with investments. And since savings are necessary to fund productive investments, countries that are unable to save sufficiently must either attract external funds or face slow progress in development. This financing gap tends to adversely affect income inequality [34]. Relatively equal income distribution, however, has been shown to be one of the most important factors that enable sustained long term economic growth and development [35].

When the aggregated savings of firms, households and the government exceed domestic investment, a country exhibits a current account surplus and effectively lends to the rest of the world. A CAB surplus can be a reflection of underlying distortions, such as inefficient financial intermediation leading to low investment, but also of more positive developments, such as an ageing population accumulating savings for retirement or a strong tradable sector leading to export-led growth [36].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** Clear criteria or standards cannot be set as the current account surplus or deficit must be evaluated in the context of current economic and fiscal policies and the prevailing economic situation. However, in general, a surplus or a low level of deficit is likely to be more conducive to NPP development.

**(f) Links to other indicators:**

- MAC1: Gross domestic product (GDP);
- MAC2: Gross fiscal balance;
- MAC4: External debt;
- ENE13: Share of imported fossil fuels in power generation.

**Methodological description**

**(a) Underlying definitions and concepts:** Current account balance is a key indicator of net lending or borrowing of an economy. It provides important information about the economic relations of a country with the rest of the world. It covers all transactions (other than those in financial items) that involve economic values and occur between resident and non-resident entities [37].

The CAB can be expressed as the difference between the value of goods and services exported and imported. It follows that a deficit means that the country is importing more goods and services than it is exporting [37].

The CAB equally mirrors the saving and investment behaviour of the domestic economy. It can be expressed as the difference between national (both public and private) savings and investments. A current account deficit may therefore reflect a low level of national savings relative to investments or a high rate of investments or both. In the case of capital-poor developing countries, which typically have more investment opportunities than financial capacity to implement them owing to low levels of domestic savings, a current account deficit may be expected [31].

(b) **Measuring methods:** The CAB can be calculated as follows [37]:

$$CAB = X - M + NY + NCT = S - I$$

where

$X$ is the total exports of goods and services;
$M$ is the total imports of goods and services;
$NY$ is the net income from abroad;
$NCT$ is the net total of current transfers;
$S$ is gross domestic savings;

and $I$ is investments.

(c) **Limitations of the indicator:** None.

(d) **Alternative definitions/indicators:** None.

**Assessment of data**

(a) **Data needed to compile the indicator:** CAB as a percentage of GDP or CAB (current national currency or US $) and GDP (current national currency or US $).

(b) **National and international data availability:** National data sources include the national statistical office or national ministries. A good international source is the Balance of Payments Statistics Yearbook [38] published by the IMF, which presents the most comprehensive dataset on country specific, regional and word totals of balance of payments, components and aggregates. It also includes information on methodologies and data sources used by individual countries in compiling their balance of payments [39]. Nominal and real GDP statistics are provided for most countries by the International Financial Statistics of the IMF.

*MAC4: External debt*

| | |
|---|---|
| Brief definition | Total debt owed to non-residents in foreign currency, goods or services |
| Units | Absolute US $ at market exchange rate and % of GDP |
| Alternative definitions | — |

**Policy relevance**

(a) **Purpose:** To measure the scale of debt owed to foreign creditors (in foreign currency) by a government.

(b) **Relevance to nuclear power development:** External debt is often used by governments to finance public investments. This indicator is relevant to nuclear power development because governments play a crucial role in promoting, developing and financing nuclear power, mainly owing to its high capital requirements. Direct government involvement may take the form of asset ownership, equity participation, risk sharing or provision of incentives such as loan guarantees. Indirect government involvement may include financing new NPPs through wholly or partially owned national utility companies. High levels of external debt, however, can impose constraints on a government's ability to borrow money in international financial markets. Such developments significantly decrease a nuclear power project's viability as they lead to a substantial increase in the associated cost of capital.

**(c) Relevance to sustainable development:** External debt as a way of financing public investment is relevant to sustainable development owing to the large and positive externalities from public investment, e.g. in key sectors such as health, education and infrastructure. As such, the overall economic return on public investment in developing countries tends to be greater than the cost of borrowed capital [40]. In addition, growth can be amplified by sensible use of debt without significantly compromising current consumption levels. Moreover, since it is not easy for domestic firms, especially small and medium enterprises, to access foreign capital, it can be beneficial for sovereign borrowers, who receive better terms, to use external debt for on-lending to productive sectors.

Nevertheless, a large external debt without debt servicing constitutes a major impediment to economic growth and development as it restricts much needed inflow of foreign resources. Limited access to international capital markets as well as other types of financial resources, such as official aid or concessional loans, depresses investment and consequently growth and employment, leaving private businesses at a competitive disadvantage.

The larger the total external debt of a country relative to its capacity to generate foreign currency, the more difficult the servicing of its debts becomes and the greater the risk of default by the government will be. As market participants react to the increased risk of default, a country's bond yields increase, leading to an increase in borrowing costs that may result in further deterioration in the country's finances. This evolvement, in turn, creates a negative feedback loop for the country and its ability to borrow funds as well as its ability to meet its financial obligations in full and on time [41]. Hence, excessive external debt is detrimental to long term sustainable economic growth and development, both of which are founded upon the ability to efficiently increase investments — a process that crucially requires financial intermediation and integration with international capital markets [42].

**(d) International conventions and agreements:** The EU's Stability and Growth Pact is designed to enable synchronized economic developments in the EU and the euro area countries. The two key principles of the pact are that the annual deficit should not be higher than 3% of GDP and that the debt–GDP ratio should not exceed 60% [43].

**(e) International targets/recommended standards:** See (d).

**(f) Links to other indicators:**

- MAC1: Gross domestic product (GDP);
- MAC2: Gross fiscal balance;
- MAC3: Current account balance;
- MAC5: Credit rating of project sponsors.

**Methodological description**

**(a) Underlying definitions and concepts:** The IMF provides the following definition in the External Debt Statistics Guide for Compilers and Users: "Gross external debt, at any given time, is the outstanding amount of those actual current, and not contingent, liabilities that require payment(s) of principal and/or interest by the debtor at some point(s) in the future and that are owed to nonresidents by residents of an economy" [44].

The World Bank defines total external debt as the "sum of public, publicly guaranteed, and private nonguaranteed long-term debt, use of IMF credit, and short-term debt. Short-term debt includes all debt having an original maturity of one year or less and interest in arrears on long-term debt" [24].

**(b) Measuring methods:** To calculate external debt, all current liabilities of residents to non-residents that require payments of principal and/or interest in the future need to be added up. The sum of these individual liabilities represents a future claim on the resources of the economy and makes up the total external debt of that economy [44].

**(c) Limitations of the indicator:** None.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** In order to quantify this indicator, one needs data on the current liabilities of all residents of a country to non-residents and the total GDP (in the same currency as total external debt in order to calculate the ratio of external debt to GDP).

**(b) National and international data availability:** The primary sources of data are national government organizations, typically ministries of finance, economy and/or foreign trade as well as central (national) banks. There are a number of international agencies actively involved in measuring and monitoring external debt. The IMF chairs the Task Force on Finance Statistics endorsed by the United Nations Statistical Commission to improve the timeliness and availability of data on external debt and international reserve assets. The World Bank Quarterly External Debt Statistics [45] is an on-line database updated every three months which compiles external debt statistics for 55 countries that are published individually by countries. Another data source is the Joint External Debt Hub, a database developed by the Bank for International Settlements, IMF, OECD and the World Bank that brings together national data from the Quarterly External Debt Statistics as well as creditor and market data from international agencies [46].

*MAC5: Credit rating of project sponsors*

| | |
|---|---|
| Brief definition | Evaluation by a credit rating agency of the debtor's ability to service the debt in full and on time |
| Units | Rating score |
| Alternative definitions | Sovereign credit rating |

**Policy relevance**

**(a) Purpose:** To evaluate the ability and willingness of a project sponsor (e.g. a government, a state owned energy company and/or major private sector players) in the energy market to meet its financial obligations in full and on time [47].

**(b) Relevance to nuclear power development:** Equity and debt are the basic components of capital project finance, and assurances about the project's viability are essential for attracting these elements. In general, creditors are attracted by the risk–return profile offered by a project and its creditworthiness (i.e. potential for repayment). In debt financing, a bank or other lender gives the project sponsor a loan for some percentage of the estimated cost of the project, against which some security or collateral is provided, typically recourse against some or all of the borrowers' assets. Assurance of repayment may also be given to (potential) lenders via some form of credit enhancement (such as a sovereign guarantee). The loan is then to be repaid with interest in accordance with the loan agreement.

The cost of financing the project is strongly affected by the type of organization sponsoring the new plant. Project sponsors such as large, financially strong utilities with high credit ratings and experience of managing and operating existing NPPs will typically find it easier to secure finance than less creditworthy sponsors. Creditworthiness will typically be defined by factors such as sponsors' assets, profitability or existing indebtedness [25, 26, 48]. This indicator is relevant to nuclear power development because a project sponsor with low credit ratings makes it challenging for the project company to obtain adequate funding for the development of a new NPP.

Note that if a creditworthy government (or other entity) guarantees the debt (a form of credit enhancement), both the risk of non-repayment and hence the cost of debt may fall significantly. Forms of government involvement other than providing a direct sovereign guarantee include asset ownership, equity participation, risk sharing or provision of other incentives. Governments may also be indirect investors, for example by wholly or partially owning a utility that is building a nuclear plant. In such circumstances, a government's sovereign credit rating will play a major role in facilitating the process of raising debt finance for nuclear power projects because lenders will view a government's involvement as a risk reducing factor if that government enjoys a good sovereign credit rating [25, 26].

**(c)** **Relevance to sustainable development:** Depending on the project under consideration, low credit ratings of project sponsors can have negative implications for all three pillars of sustainable development. The social and economic pillars are most directly concerned because low credit ratings of project sponsors may jeopardize the development of a project that would otherwise generate economic growth, employment or improvements in infrastructure. When the government is the project sponsor, credit ratings are crucial for attracting private capital because they serve as an indicator for international investors and bondholders of the risks associated with a country's ability to meet its public debt obligations in full and on time. Without a good credit rating, governments have limited access to international capital markets and other types of resource flows such as official aid or concessional loans by bilateral and multilateral donors to the detriment of domestic financial sector developments as well as financial integration with world capital markets [49].

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** Each credit rating agency has its own rating taxonomy, with ratings being variations on the scale A, B, C or D. The lower the rating, the higher the probability of default and vice versa. Project sponsors rated above BBB- or Baa3 are known as investment grade, while those rated below fall into the speculative grade category [47]. Each project sponsor targets the highest possible rating.

**(f)** **Links to other indicators:**
- MAC4: External debt;
- MAC6: Large scale projects financed in the past ten years (in excess of US $250 million).

**Methodological description**

**(a)** **Underlying definitions and concepts:** Rating agencies dealing with sovereign and/or corporate risks seek to evaluate the ability and willingness of a debt issuer to repay its debt within the maturity dates and in accordance with the terms agreed with the creditors at the time the loans were contracted. The results of this assessment — expressed in ratings — are sometimes viewed as akin to estimations of the probability of default by a given government or corporation. Default includes the suspension of interest payments and non-payment of the principal at maturity [32].

**(b)** **Measuring methods:** Credit ratings are based on a broad range of financial and business attributes that may affect the issuer's prompt repayment. The specific risk factors considered depend partly on the type of issuer. While the credit analysis of a corporate issuer would typically consider key financial and non-financial indicators such as economic, regulatory and geopolitical influences, as well as management and corporate governance attributes and competitive positions, rating a sovereign government may focus on political risk, monetary stability and the overall debt burden [47].

**(c)** **Limitations of the indicator:** Even though investors can use credit ratings in making investment decisions, ratings are not indications of investment merit (e.g. recommendations to buy, sell or hold assets, a measure of asset value or a signal of the suitability of an investment). Moreover, the assignment of credit ratings is not an exact science and ratings are therefore not exact measures of the probability that a particular issuer of debt will default, because future events and developments cannot be forecast. Ratings merely represent relative opinions about the creditworthiness of an issuer. In addition, ratings may not reflect less tangible considerations that could play a role in the risk of default such as social, historical and political factors [47].

**(d)** **Alternative definitions/indicators:** Sovereign credit rating.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Credit ratings of relevant project sponsor(s).

**(b)** **National and international data availability:** The main international official and private credit risk rating agencies that regularly carry out sovereign and corporate risk rating exercises are Moody's, Standard & Poor's and Fitch. Many credit ratings are publicly available on the internet sites of the rating agencies; others may require a subscription to access the rating information.

*MAC6: Large scale projects financed in the past ten years (in excess of US $250 million)*

| | |
|---|---|
| Brief definition | Number and total value of large scale infrastructure and industrial projects successfully financed in the past ten years |
| Units | Number or total US $ value |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To assess the prospects for financing large scale infrastructure and industrial projects by examining recent success in financing such projects.

**(b)** **Relevance to nuclear power development:** This indicator serves as an assessment of the track record or demonstrated ability of a country in obtaining financing for large projects, regardless of financing mechanism. A proven national track record in obtaining financing for large projects thus acts as one indication of the likeliness that the project sponsors will be in a position to successfully secure financing for the project. Underpinning this relationship is the fact that the perceived investment climate in a nation will affect the ability to obtain international financing. The availability and scale of domestic financing sources may also play a significant role [25, 26].

**(c)** **Relevance to sustainable development:** A country's proven track record in obtaining financing for large scale projects can serve as an indicator for (international) investors of the risks associated with a country's ability (or that of non-governmental entities in the country) to honour debt obligations and/or as an indicator of the ability of domestic capital markets to mobilize financial capacity. The ability to attract financing for large scale investments and thus the ability to efficiently manage investments are critical elements for long term sustainable economic growth and development [50].

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** No clear criteria or thresholds exist, but a higher number of projects and a higher total value are indicative of greater past success in financing large projects.

(f) **Links to other indicators:**
- MAC5: Credit rating of project sponsors;
- NUC5: Estimated cost of the new NPP.

**Methodological description**

(a) **Underlying definitions and concepts:** This indicator captures every project in excess of US $250 million financed in a country in the previous ten years.

(b) **Measuring methods:** This indicator is computed by counting and adding up the values of all large scale projects in excess of US $250 million financed in the past ten years in a country.

(c) **Limitations of the indicator:** This indicator provides a sense of how successful a country has been in attracting financing for large scale projects in the past. However, it is not necessarily a reflection of a country's current attractiveness.

(d) **Alternative definitions/indicators:** None.

**Assessment of data**

(a) **Data needed to compile the indicator:** The total number and total value of large scale projects in excess of US $250 million in the past ten years.

(b) **National and international data availability:** The primary sources of data are national government organizations, typically ministries of finance, economy and/or infrastructure as well the central (national) statistical office. The Private Participation in Infrastructure Projects Database is a joint product of the Infrastructure Policy Unit of the World Bank's Sustainable Development Network and the Public–Private Infrastructure Advisory Facility. It holds information on private participation in over 5000 infrastructure projects dating back to 1984 in low and middle income countries. It records total investment in infrastructure projects with private participation (though not private investment alone) [51]. Subscription-based data on non-recourse finance projects is available via the Project Finance Deals Database of the Euromoney Institutional Investor PLC. It is a fully searchable database that enables margin and volume comparison across the full range of project finance sectors, subsectors and geography, dating back to 1998 [52].

## 3.2. ENERGY DIMENSION

*ENE1: Primary energy supply*

| | |
|---|---|
| Brief definition | Total supply of primary energy to an economy |
| Units | Petajoule (PJ), tonne of oil equivalent (toe), British thermal unit (Btu) or other energy unit |
| Alternative definitions | Final energy demand |

**Policy relevance**

(a) **Purpose:** To measure the total primary energy inputs into the economy.

(b) **Relevance to nuclear power development:** Total primary energy supply is a measure of the total energy needs of a country and can help assess the potential generation of electricity from an NPP in the context of a national energy economy. A new NPP might be a large supplier of electricity, as it would typically be no smaller than 1000 MW(e) [53] and run at a high load factor. Alternatively, a small or medium sized reactor (SMR) might be considered, having an equivalent electric power of less than 700 MW(e) or even less than 300 MW(e). Depending on the choice, the introduction of nuclear power may lead to a significant shift in the energy mix (i.e. nuclear fuel may constitute a major share of total primary energy supply). This indicator could therefore be used in conjunction with the estimated fuel use of a new NPP to assess the potential role of nuclear energy in energy supply.

(c) **Relevance to sustainable development:** The provision of energy is essential for sustainable economic development. A safe and secure supply of affordable energy is therefore required to support human development. At the same time, the production, transformation and consumption of energy often have detrimental environmental impacts such as pollution of air, water and soil as well as the release of GHGs into the atmosphere. The long term aim for a primary energy supply with respect to sustainable development is twofold: to extend energy supply to reach those with currently limited energy access (as well as to meet future needs), and to achieve development and prosperity through gains in energy efficiency and reductions in GHG emissions associated with energy supply processes [11].

(d) **International conventions and agreements:** While there are no international agreements specifically regulating primary energy supply, there are numerous calls at an international level for prudent utilization of natural resources in general, for the improvement of energy efficiency and a transition to clean energy (e.g. Article 174 of the Treaty Establishing the European Community and the Energy Charter Protocol on Energy Efficiency and Related Environmental Aspects). There have been calls for limitations on total GHG emissions (e.g. UNFCCC and the Kyoto Protocol) [11]. A recent example of a major effort to enable increased energy consumption for those with currently limited access is the United Nations Secretary-General's Sustainable Energy for All initiative.

(e) **International targets/recommended standards:** No definite threshold exists, but the larger the energy economy relative to the expected annual electricity production from the proposed NPP, the better suited it is for nuclear power development.

(f) **Links to other indicators:**
- MAC1: Gross domestic product (GDP);
- ENE2: Final energy demand;
- ENE3: Electricity generation;
- ENE11: National energy budget;
- NUC6: Estimated size of the new NPP;
- ENV1: $CO_2$ emissions intensity of power production;
- ENV2: Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates).

**Methodological description**

(a) **Underlying definitions and concepts:** Primary energy supply refers to energy supply in a natural or unaltered form, typically the indigenous extraction of fossil fuels from reservoirs or deposits or the capture of renewable flows of energy such as wind or insolation. It also includes harvested biomass and nuclear fuel as well as imports net of exports. Total primary energy supply is the sum of all these sources.

(b) **Measuring methods:** The calculation methodology uses data on the supply of different energy resources including fossil fuels, renewables, nuclear fuel and heat [54]. Total primary energy supply is the sum of indigenous production, net imports (imports minus exports), international marine bunkers and stock changes [55].

**(c) Limitations of the indicator:** Although primary energy supply assesses the overall energy inputs to an economy, it does not distinguish between different uses. In most countries, a large share of energy supply will ultimately go to uses for which electricity (and hence nuclear power) is not a likely substitute. Consequently, this indicator can only give a very broad and high level view of the role of nuclear energy in the economy. The IAEA energy planning tool Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) can be used to assess the energy mix with the least cost, on the basis of economic, resource, technology and environmental constraints (Ref. [56], p. 3).

**(d) Alternative definitions/indicators:** Final energy demand.

**Assessment of data**

**(a) Data needed to compile the indicator:** Indigenous energy production, energy imports, energy exports, energy supplied to and taken from international marine and aviation bunkers, and energy stock changes.

**(b) National and international data availability:** Energy commodity data for production and use are typically compiled on a regular basis at the national and sometimes subnational level. They are usually obtainable from national statistics offices or national energy statistics bodies. International sources of energy supply data include the IEA [15–18], the United Nations Statistics Division [57] and the company BP [58].

*ENE2: Final energy demand*

| | |
|---|---|
| Brief definition | Total energy consumed by end users |
| Units | PJ, toe, Btu or other energy unit |
| Alternative definitions | Primary energy supply |

**Policy relevance**

**(a) Purpose:** To measure the total energy consumption of a country in a particular year.

**(b) Relevance to nuclear power development:** Total final energy consumption is a measure of the total energy consumed by end users and can help assess the potential demand for electricity from an NPP in the context of a national energy economy. A new NPP might be a large supplier of electricity, as it would typically be no smaller than 1000 MW(e) [53] and run at a high load factor. Alternatively, an SMR might be considered, having an equivalent electric power of less than 700 MW(e) or even less than 300 MW(e). Depending on the choice, the new NPP can be a major producer of and may supply a significant share of final energy consumption. This indicator could therefore be used in conjunction with the estimated electricity production from an NPP to assess the potential role of nuclear energy in meeting the energy needs of consumers.

**(c) Relevance to sustainable development:** Energy is required for virtually any human endeavour, whether it is for productive use, as a public utility service or for personal need. Yet, negative consequences associated with different uses and by-products of energy have negatively impacted the environment over time as a consequence of depletion of natural (non-renewable) resources as well as of pollution. For energy demand to be in line with sustainable development goals, more efficient demand-side management measures may be needed to achieve gains in energy efficiency and GHG emission reductions. At the same time, sustainable development goals with respect to energy demand also include an increase in energy consumption in developing countries where low consumption levels pose an obstacle to any efforts towards prosperity.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** In addition to calls for more efficient use of energy and a transition to clean energy, the EU's 2014 climate and energy package sets energy targets for 2030. These targets include energy efficiency improvements of 30% compared with projections, EU GHG emissions reduction by 40% (from 1990 levels) and at least a 27% share of renewable energy in total energy consumption [59].

**(f) Links to other indicators:**
- MAC1: Gross domestic product (GDP);
- ENE1: Primary energy supply;
- ENE3: Electricity generation;
- ENE12: Government expenditures for power generation;
- NUC6: Estimated size of the new NPP;
- ENV1: $CO_2$ emissions intensity of power production;
- ENV2: Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates).

**Methodological description**

**(a) Underlying definitions and concepts:** Final energy demand refers to the total energy consumed by end users, usually disaggregated into several sectors depending on the methodology, for example into industry, transport, buildings and other sectors [7]. It consists of the energy used by final consumers and excludes any energy used by the energy sector itself, for example for deliveries and transformation, as well as international marine and aviation bunkers [7, 60].

**(b) Measuring methods:** Final energy consumption is the sum of energy consumption in each final demand sector. It is calculated by totalling the consumption of energy by all users, except the energy sector itself, for example for deliveries, transformation processes or other internal uses [7].

**(c) Limitations of the indicator:** Even though this indicator gives some sense of scale for power consumption, it is an aggregation of energy consumption and therefore conceals a great deal of detail such as the share of different energy sources and end users within the total demand. It does not indicate the actual size of an electric grid and therefore cannot be compared directly to the size of the envisaged NPP. The IAEA energy planning tool Model for Analysis of Energy Demand (MAED) can be used to project the magnitude and composition of future demand for energy on the basis of assumed social, economic, resource, technology and environmental circumstances (Ref. [56], p. 3).

**(d) Alternative definitions/indicators:** Primary energy supply.

**Assessment of data**

**(a) Data needed to compile the indicator:** Energy consumption by different end use sectors.

**(b) National and international data availability:** Energy commodity data for production and use are typically produced on a regular basis at the national and sometimes subnational level. They are usually obtainable from national statistics offices or national energy statistics bodies. International sources of energy supply data include the IEA [15–18, 55], the United Nations Statistics Division [57] and BP [58].

*ENE3: Electricity generation*

| | |
|---|---|
| Brief definition | Total generation of electricity |
| Units | TW·h or other unit of energy |
| Alternative definitions | Total electricity demand |

**Policy relevance**

**(a)** **Purpose:** To measure the quantity of electricity produced in a country over a certain period (e.g. one year).

**(b)** **Relevance to nuclear power development:** NPPs can be very large, small or medium sized units of power production. Depending on the choice, the introduction of nuclear power could dramatically or modestly change the electricity generation mix in a country. This indicator should therefore be viewed in conjunction with the projected output of an envisaged NPP to determine the potential role nuclear energy could play in the electricity sector.

In addition, this indicator can help assess what size of an NPP can be best supported by the local power generation infrastructure (current or projected). Incorporating large units into a power grid can present certain challenges to system design and operation. If an NPP contributes a very large share of total generation, this could be an indication that a more thorough assessment of the generation and transmission system is required to determine whether an NPP can be effectively integrated into the transmission system. Such analysis would need to consider both operation when the NPP is producing power (i.e. whether the system is able to effectively distribute power from a large centralized source) and when it is shut down (i.e. there is sufficient spare generation and transmission capacity to ensure reliable power supply without the contribution of the NPP).

If the size and expected output of the envisaged plant is known, this indicator can be reported as a ratio: (expected NPP annual generation)/(expected total annual generation), which would yield an estimate of the share of total electricity provided by nuclear power.

**(c)** **Relevance to sustainable development:** Electricity is a high quality energy carrier that is clean and efficient at the point of use. It is frequently more convenient to the user than other forms of energy, and it is the only possible source of energy for some applications. It is a key energy form to provide basic services such as cooking, lighting, water and health care. Inadequate provision of power can therefore perpetuate poverty and deprivation. Poor service delivery (e.g. blackouts, voltage fluctuations) and high prices can also adversely impact the viability and competitiveness of local business and thereby hamper long term sustainable development [61].

**(d)** **International conventions and agreements:** Although there are no international conventions or agreements directly regulating electricity generation in terms of volume, there are numerous initiatives dedicated to significantly increasing access to modern energy services, including electricity, most notably the United Nations Secretary-General’s Sustainable Energy for All initiative. One of its main goals is to provide universal access to modern energy services by 2030 [62].

**(e)** **International targets/recommended standards:** No definite threshold exists, but the greater the total electricity generation relative to the expected annual electricity production from the proposed NPP, the better the prospects for nuclear power development.

**(f)** **Links to other indicators:**
- ENE1: Primary energy supply;
- ENE2: Final energy demand;
- ENE4: Total installed capacity;
- ENE15: Share of intermittent generation in electricity supply;

- NUC1: Installed nuclear power capacity;
- NUC6: Estimated size of the new NPP;
- ENV1: $CO_2$ emissions intensity of power production;
- ENV2: Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates);
- ENV7: Water use in electricity generation.

**Methodological description**

**(a)** **Underlying definitions and concepts:** This indicator aggregates electricity generation from all sources such as hydropower, coal, oil, gas, nuclear power, geothermal, solar, wind, tide, wave, combustible renewables and waste. It includes electric output from plants designed to generate power only and electricity from combined heat and power plants [7].

**(b)** **Measuring methods:** Electricity production is measured at all terminals of all alternator sets in a power station [7].

**(c)** **Limitations of the indicator:** This indicator does not directly assess whether an NPP can be effectively integrated into a given power system or what it would take to do so. Other indicators such as the amount of installed capacity of other sources, the operational flexibility of these resources and the capacity and design of the transmission system will ultimately determine if and how an NPP can be accommodated. The IAEA energy planning tool Wien Automatic System Planning Package (WASP) is designed to help assess potential power generation expansion plans. The tool can be used to explore all possible sequences of capacity additions that are capable of satisfying demand while also meeting system reliability requirements . It can also incorporate constraints such as limited fuel availability or emission restrictions. (Ref. [56], p. 4).

**(d)** **Alternative definitions/indicators:** The indicator total installed capacity shows the total potential generation capacity in the power system of a country.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Electric output of all individual power generators connected to the national grid over a certain time period, e.g. one year.

**(b)** **National and international data availability:** Data on individual plant output as well as total electricity produced in a country are typically available from national energy statistics bodies as well as from various international sources. International sources of energy supply data include the IEA [15–18], the United Nations Statistics Division [57] and BP [58].

*ENE4: Total installed capacity*

| | |
|---|---|
| Brief definition | The sum of maximum electric output that all power generators connected to a national grid can produce under specific conditions |
| Units | Megawatt (MW) or other unit of power |
| Alternative definitions | Total power generation |

**Policy relevance**

**(a)** **Purpose:** To measure total installed generating capacity.

(b) **Relevance to nuclear power development**: Incorporating large units into a power grid can present certain challenges to system design and operation. If an NPP constitutes a very large share of total installed capacity, this could be an indication that a more thorough assessment of the generation and transmission system is required to determine if it can be effectively integrated into the power system. Such analysis would need to consider both operation when the NPP is producing power (i.e. whether the system is able to effectively distribute power from a large centralized source) and when it is shut down (i.e. there is sufficient spare generation and transmission capacity to ensure reliable electricity supply without the contribution of the NPP) [53]. Alternatively, an SMR of less than 700 MW(e) can be considered. If the size of the envisaged plant is known, this indicator can be reported as a ratio (expected NPP installed capacity)/(total installed capacity), which would yield an estimate of the share of the new NPP in total electricity generating capacity.

(c) **Relevance to sustainable development:** Electricity is a high quality energy carrier that is clean and efficient at the point of use. It is frequently more convenient to the user than other forms of energy and it is the only possible source of energy for some applications. It is a key energy form to provide basic services such as cooking, lighting, water and health care. Inadequate provision of power can therefore perpetuate poverty and deprivation. Poor service delivery (e.g. blackouts or voltage fluctuations) and high prices can also adversely impact the viability and competitiveness of local business and thereby hamper long term sustainable development [61].

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** No definite threshold exists, but the greater the total installed capacity relative to the expected capacity of the proposed NPP, the better the prospects are for effective integration of an NPP into the domestic power system.

(f) **Links to other indicators:**
- ENE3: Electricity generation;
- ENE5: Peak electricity demand;
- ENE6: Reserve margin;
- ENE15: Share of intermittent generation in electricity supply;
- ENE16: Capacity of transmission lines;
- ENE18: Power generation plant vintage;
- NUC1: Installed nuclear power capacity;
- NUC2: Nuclear power reactors in operation;
- NUC3: Planned nuclear power investments and retirements;
- NUC6: Estimated size of the new NPP;
- ENV6: Power density;
- ENV7: Water use in electricity generation.

**Methodological description**

(a) **Underlying definitions and concepts:** A generator's electricity generation capacity is the potential to deliver power and is measured in MW. A nation's total installed generation capacity is the sum total of individual power generators' generating capacities [63, 64]. The maximum electric output a power system can produce under specific conditions is referred to as gross capacity. Each generator's manufacturer has indicated the maximum output a generator can produce (without surpassing design thermal limits), which is also known as nameplate capacity. Net generation is the gross power of a generator minus the electric power used for plant operation, e.g. fuel handling, feedwater pumps and other electricity needs [63].

(b) **Measuring methods:** This indicator can be computed by adding up the installed capacity of all power producing plants (measured in MW) in a country to arrive at that country's total installed capacity. A generator's power generation capacity is the maximum electric output it can technically produce as designated by the manufacturer. Installed generator capacity is typically expressed in MW [63].

(c) **Limitations of the indicator:** This indicator does not directly assess whether an NPP can be effectively integrated into a given power system or what it would take to do so. Other variables such as the amount of installed capacity of other sources, the operational flexibility of these resources and the capacity and design of the transmission system will ultimately determine if and how an NPP can be accommodated. The IAEA energy planning tool Wien Automatic System Planning Package (WASP) can be used to explore options and possible sequences of capacity additions that are capable of satisfying demand while also meeting system reliability requirements (Ref. [56], p. 4).

(d) **Alternative definitions/indicators:** Total power generation.

**Assessment of data**

(a) **Data needed to compile the indicator:** Installed generator (nameplate) capacity of all individual power generators connected to the national grid.

(b) **National and international data availability:** Data on individual plant installed capacity as well as total electricity installed capacity are available from the utilities that own and operate them as well as from national energy statistics bodies. International sources of information include the IEA's database [61] and the EIA's International Energy Statistics database which has data on each country's total installed electricity generation capacity dating back to 1980 [9].

*ENE5: Peak electricity demand*

| | |
|---|---|
| Brief definition | The highest amount of electricity consumption across the entire power network at any one point in time |
| Units | MW or other unit of power |
| Alternative definitions | — |

**Policy relevance**

(a) **Purpose:** To measure the maximum electricity demand.

(b) **Relevance to nuclear power development:** Peak electricity demand in several countries exceeds the total generation capacity. This leads to blackouts and brownouts in segments of the electricity grid and ultimately to the collapse of the grid. Adding an NPP to the generation capacities would alleviate this situation. The evolution of peak electricity demand over time is particularly relevant. Fast increasing peak demand is a strong motivation for adding large generation capacities, such as an NPP. Incorporating large units into a power grid can present certain challenges to system design and operation. If an NPP contributes a very large share of maximum demand, this could be an indication that a more thorough assessment of the generation and transmission system is required to determine whether an NPP can be effectively integrated into the transmission network. Such analysis would need to consider both operation when the NPP is producing power (whether a system is able to effectively distribute power from a large centralized source) and when it is shut down (i.e. there is sufficient spare generation and transmission capacity to ensure reliable electricity supply without the contribution of the NPP). These issues are explored in detail in an IAEA publication on NPP and grid reliability [53].

If the size of an envisaged NPP is known, this indicator can be reported as a ratio (expected NPP installed capacity)/(peak electricity demand) that provides an estimate of the share of peak demand a new NPP could provide when operating at full power.

**(c) Relevance to sustainable development:** No direct relevance.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** Peak electricity demand should be matched by a network's maximum supply level at all times. No definite threshold exists, but the greater the peak demand relative to the expected annual electricity production from the proposed NPP, the better the prospects for its effective integration into the domestic power system.

**(f) Links to other indicators:**
- ENE4: Total installed capacity;
- ENE6: Reserve margin;
- ENE16: Capacity of transmission lines.

**Methodological description**

**(a) Underlying definitions and concepts:** Demand for electricity varies considerably during a typical day or calendar week and over seasons. Consumers' habits and consumption patterns are such that the total load on the system is much higher at certain periods than at others. Since electricity is difficult and expensive to store, the generation, transmission and distribution systems need to be sized and designed so that they can meet fluctuating demand. A critical issue in this regard is the ability to deliver enough power at times when demand is at its highest. The highest electricity demand recorded over a certain period of time is referred to as the peak demand for that period.

**(b) Measuring methods:** Grid operators continuously monitor and record loads to be met.

**(c) Limitations of the indicator:** This indicator does not directly assess whether an NPP can alleviate shortfalls in generation capacities at times of peak demand. Other variables such as the amount of installed capacity of other sources, the operational flexibility of these resources and the capacity and design of the transmission system will ultimately determine the true benefits of an NPP in this respect.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Maximum (peak) electricity demand in the relevant power system.

**(b) National and international data availability:** Data on (estimated) peak power demand are typically available from grid operators, national energy statistics bodies and national electric power ministries. The IEA publishes statistics for peak demand for its member countries [65].

*ENE6: Reserve margin*

| | |
|---|---|
| Brief definition | The share of installed capacity in excess of peak demand |
| Units | % |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To measure the reserve capacity available in a power system.

**(b) Relevance to nuclear power development:** NPPs are typically large in size and therefore have an important impact on reserve capacity. They usually serve as baseload units providing a reliable and secure power supply to the grid. However, because of their large size, additional reserves may be required as sufficient capacity will need to be in place to ensure adequate supply when the reactors are temporarily shut down for maintenance or refuelling. Reserve margins are usually determined by regulators or system operators. Decision makers need to consider current as well as projected future reserve requirements, taking into account aspects such as yearly load growth, retirement of existing capacity and new plant installations.

If an NPP constitutes a very large share of total installed capacity, this could be an indication that a more thorough assessment of the generation and transmission system is required to determine whether an NPP can be effectively integrated into the power grid. Such an analysis would need to consider both operation when the NPP is producing power (whether a system is able to effectively distribute power from a large centralized source) and when it is shut down (i.e. there is sufficient spare generation and transmission capacity to ensure reliable operation in the absence of the NPP). A comprehensive assessment of grid reliability and interface with an NPP is presented by the IAEA [53].

**(c) Relevance to sustainable development:** A reliable supply of electricity is essential to support sustainable development. Blackouts interrupt production activities, resulting in losses of material and labour, and possibly damaging sensitive equipment. Reliable electricity supply is a pre-condition for attracting investments in manufacturing and services that provide employment and foster socioeconomic development. If the amount of new generation capacity coming on-line is not sufficient to provide the amount of capacity necessary to maintain reserve margins high enough to ensure reliable supply as prescribed by regulatory authorities, this could have detrimental impacts on the reliability and security of supply. Low reserve margins can therefore be a sign of inability to attract the needed investment in new generation assets, which again may jeopardize reliability of supply and thus growth and development.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** Each system operator has a set of rules and requirements for different categories of reserves designed to achieve a target level reliability. For instance, in the USA most power systems follow a standard where the probability of loss of load due to inadequate supply should be 0.1/year (i.e. one event in ten years). This could lead to different reserve margins depending on the particularities of individual systems, but it is often of the order of 15%.

**(f) Links to other indicators:**
- ENE4: Total installed capacity;
- ENE5: Peak electricity demand.

**Methodological description**

**(a) Underlying definitions and concepts**: Future demand for electricity is uncertain and demand levels can only be predicted with a limited degree of precision. Similarly, there is uncertainty with respect to the available generating capacity. Power plants sometimes need to be taken out of service and are therefore not available to supply power to the grid. This unavailability can be either planned (e.g. scheduled maintenance) or unplanned (e.g. unexpected equipment failure). Given the uncertainty both in demand levels and in available capacity, there is a need to keep spare capacity in reserve to help meet demand. It is the responsibility of regulators and system operators to ensure that such spare capacity is available. The reserve margin is the ratio of reserve capacity (i.e. excess capacity above peak demand) to peak demand, usually reported as a percentage.

Furthermore, there are significant costs associated with maintaining a high level of reliability. A cost effective reliability level is therefore the one at which the costs of carrying the reserve capacity are equal to the sum of the costs resulting from inadequate supply such as load shedding, voltage reduction, emergency response, and so on.

In addition to planning reserves, system operators need to ensure that various types of operating reserves (e.g. regulating, spinning, non-spinning and replacement reserves) are available to manage short term fluctuations in demand and sudden increases or decreases in supply in real time.

**(b)** **Measuring methods:** This indicator is calculated as the ratio of excess capacity (i.e. capacity net of peak demand) to peak demand, usually reported as a percentage. Peak demand and total capacity are therefore the only data required.

**(c)** **Limitations of the indicator:** The reserve margin does not directly measure reliability or supply adequacy. It does not capture the reliability of generation assets nor the extent to which the capacity is dispatchable and capable of adapting to supply disruptions or rapid shifts in load. Furthermore, it does not capture other operational or system constraints (e.g. transmission bottlenecks) that may impact the ability of the system to meet load. It is therefore possible to have a system with apparent ample reserve capacity that is still experiencing reliability problems.

**(d)** **Alternative definitions/indicators:** There are other metrics, such as the loss of load probability, that measure reliability more directly, but these can only be determined by detailed modelling of system reliability and adequacy. They are therefore not necessarily suitable for indicator assessment.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** The amount of installed capacity and the level of peak electricity demand.

**(b)** **National and international data availability:** National regulators, national power companies, grid operators and energy ministries frequently publish data on electric load including peak load. Information on installed capacity is commonly available from these sources as well. The IEA publishes statistics for both installed capacity and peak demand for its member countries [65] and capacity projections for major countries and regions in its World Energy Outlook [7]. Detailed information on NPP capacities is available from the IAEA's PRIS database [4].

*ENE7: End user price of electricity*

| | |
|---|---|
| Brief definition | The price of electricity |
| Units | National currency or US $/kilowatt-hour (kW·h) |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To measure the price of electricity for end users.

**(b)** **Relevance to nuclear power development:** This indicator measures the overall price level in the power sector. The prices paid by end users should normally cover the costs of generation, transmission and distribution. However, if the consumption of electricity is subsidized or if the utility is under-recovering its costs, this may not be the case.

A low price of electricity indicates that low cost sources of power are available, while higher prices indicate a lack of cheap energy sources. The end user price of electricity also covers transmission and distribution costs and cannot be directly compared with power generation costs (or the levelized cost of electricity (LCOE)) of an envisaged NPP (see also ENE8 and ENE9).

**(c) Relevance to sustainable development:** Access to modern forms of energy, and electricity in particular, are of paramount importance to sustainable development. They can provide for a range of services to improve the health, convenience and general conditions of life for people. Affordable electricity can thus be an important enabler of human development.

Low electricity prices can also make businesses more competitive and thus help create jobs and improve incomes. Electricity prices can constitute a major expense for businesses, in particular energy intensive industries such as heavy manufacturing. If electricity prices are high, they increase the costs of production, making producers less competitive and products less affordable to customers. Conversely, low electricity prices can improve conditions for businesses and boost economic growth.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** A high price environment will be more conducive to an NPP investment as the absence of low cost alternatives will make nuclear power more competitive. Furthermore, in regulated power markets, a high price could be an indication that an NPP could be financed without major increases in tariffs, while this may be more difficult when existing prices are low.

**(f) Links to other indicators:**

- ENE8: Cost of electricity generation;
- ENE9: Levelized cost of electricity;
- ENE21: Rate of return on investments in the power sector.

**Methodological description**

**(a) Underlying definitions and concepts:** The price of electricity is the total amount paid by customers for their electricity usage divided by the sum of all electricity consumption. It thus represents the average payment per unit of electricity. It can be calculated for all customers or for different groups of customers (e.g. residential, industrial and service sector customers). For jurisdictions with a flat electricity rate, the average for a customer group is simply the relevant tariff, while in jurisdictions with more complicated tariff structures (e.g. block tariffs or two-part tariffs) the averages need to be calculated based on consumer bills.

**(b) Measuring methods:** Aggregation of customer bills.

**(c) Limitations of the indicator:** The prices paid by end users for electricity are not necessarily a reflection of the cost level in the power sector even in price regulated environments. Subsidies or under-recovery of costs could mean that prices differ significantly from average costs. In competitive markets, prices reflect market conditions and may (at least in the short to medium term) deviate significantly from the marginal cost of production.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Data on the electricity supplied to various market sectors such as the domestic, commercial, industrial and transport sectors, and the revenues distributors derive from these sectors.

(b) **National and international data availability:** Electricity distribution companies and regulatory bodies, ministries of energy or commerce, statistical bodies or similar agencies will normally keep such data. The IEA publishes statistics for its member countries quarterly in its Energy Prices and Taxes report [66].

*ENE8: Cost of electricity generation*

| | |
|---|---|
| Brief definition | Current and historical system wide costs of electricity generation during a fiscal year |
| Units | National currency or US $/megawatt-hour (MW·h) |
| Alternative definitions | — |

**Policy relevance**

(a) **Purpose:** To assess the average (historical and actual) unit costs of producing electricity incurred by utilities/power producers during a fiscal year.

(b) **Relevance to nuclear power development:** The current (and historical) costs of generating electricity can serve as reference point for assessing the potential role of nuclear power in a power system. It is a measure of the cost levels in the industry and it can help assess the relative competitiveness of nuclear power relative to incumbent generators by comparing it to the LCOE of a new NPP (see ENE9). In regulated markets, this can also serve as a gauge for assessing whether current tariffs are sufficient to support an NPP or if an increase is needed.

(c) **Relevance to sustainable development:** The cost of power generation is important for economic development and growth as electricity powers basic services as well as providing an important input to business and industry. If electricity is generated at a low cost, this is an indicator of an efficient power sector where cheap energy resources are available. This will support households and businesses by providing affordable electricity. Higher costs, on the other hand, can be a sign of an inefficient industry or lack of cheap energy resources. In such an environment, prices for consumers are high and impede development. For industries and business activities, where the cost of electricity is a significant share of their total costs, the price of electricity is an important determinant of viability and competitiveness.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** The cost of generation needs to be weighed against other goals (e.g. reducing air pollutants or GHG emissions or diversity in energy supply) and a range of criteria needs to be considered. However, a market where the cost of both incumbent generators and alternatives are high indicates a more favourable investment climate for nuclear that will be more conducive to nuclear power development.

(f) **Links to other indicators:**
- ENE7: End user price of electricity;
- ENE9: Levelized cost of electricity;
- ENE10: Fuel price increase sensitivity;
- ENE13: Share of imported fossil fuels in power generation;
- ENE19: Export and import prices of fuels used in electricity generation;
- ENE21: Rate of return on investments in the power sector.

**Methodological description**

**(a)** **Underlying definitions and concepts:** The costs of electricity generation include the capital expenditures associated with a new plant, fuel (e.g. gas, coal or uranium) and other direct costs such as system charges, costs of electricity imported to sites and environmental costs (e.g. ash disposal costs) as well as indirect costs such as internal operating costs, including general office costs, repairs and maintenance [67, 68].

**(b)** **Measuring methods:** To obtain the system wide average cost of electricity generation, it is necessary to add up the total costs of power generation of individual power production companies/utilities and divide the sum by the total volume of electricity (MW·h) produced by the same production units. This data may be difficult to find in many circumstances.

**(c)** **Limitations of the indicator:** This indicator only captures historical costs and not the cost of the various technology alternatives for future investments. Owing to cost escalation in plant construction costs, increases in fuel prices as well as changes in policies and regulations, historical cost levels may not be indicative of future cost levels.

**(d)** **Alternative definitions/indicators:** None.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Reported total costs of power generation (national currency or US $) as well as total generated power (MW·h) for each utility/power production company in a power system.

**(b)** **National and international data availability:** Data on total costs of power generation and the amount of total electricity produced are available in financial records of utilities and power production companies, power sector regulators or similar government offices. Availability of these data to the public varies across countries, but in some cases, they can be sourced on-line.

*ENE9: Levelized cost of electricity*

| | |
|---|---|
| Brief definition | The total per unit cost of generating electricity accounting for all costs and output over the entire lifetime of a power plant |
| Units | National currency or US $/MW·h electricity supplied to the grid |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To determine the relative costs of new electricty generation technology options and allow benchmarking between different generation systems.

**(b)** **Relevance to nuclear power development:** The LCOE is a transparent and widely applied measure of total generating costs of a power plant. It can be applied to any prospective generation option to assess the cost of generating electricity under a specified set of current circumstances or assumptions about the future. It can therefore be used to compare the costs of different power generation technologies under similar conditions and thereby help establish their relative competitiveness [69]. The LCOE is therefore useful to assess the prospects for an NPP as it can help determine how the economics of nuclear power compare with other technologies under a variety of market and operating conditions.

The LCOE can be compared with historical and current costs of power generation as well as electricity tariffs and can help decision makers determine the viability of the envisaged NPP (see ENE7 and ENE8). This indicator is also a useful tool for testing the sensitivity of cost calculations to variations in underlying assumptions on key parameters such as construction costs, lead times, fuel prices, load factors and discount rates [70].

(c) **Relevance to sustainable development:** Levelized costs are employed to give a consistent baseline for cost comparisons. The LCOE generation values play an important role in electric system planning and the choice of the technology for the next investment will be determined by these costs. The levelized costs may (or may not) include costs for dealing with externalities (e.g. pollution control) and next step alternatives will be judged accordingly. While low levelized costs of a coal fired power plant without pollution control equipment might be good for economic development purposes, the negative impacts of that facility may be significant in a sustainable development context for environmental reasons. As always, it is essential to balance economic, social and ecological factors in assessing sustainability.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** Energy policy is driven by many considerations and cost is only one of them. However, in general, the lower the LCOE of nuclear power relative to other power sources, and in particular other low carbon sources, the better the prospects for nuclear power development.

(f) **Links to other indicators:**
- ENE7: End user price of electricity;
- ENE8: Cost of electricity generation;
- ENE10: Fuel price increase sensitivity;
- ENE19: Export and import prices of fuels used in electricity generation.

**Methodological description**

(a) **Underlying definitions and concepts:** The LCOE is a per unit estimate of the cost of generation for a prospective power project. It incorporates all the expected costs over the lifetime of the project and distributes them evenly over the expected amount of electricity generated. It can be thought of as the fixed price that project owners would have to receive to earn a specified return on their investment (discount rate). It is thus the present value of all costs divided by the present value of all generation.

(b) **Measuring methods:** The LCOE can be calculated as:

$$\mathrm{LCOE} = \frac{\Sigma_1^n \left(I_t + M_t + F_t + D_t\right) / \left(1+r\right)^t}{\Sigma_1^n E_t \, / \left(1+r\right)^t} = \frac{\text{Total costs over life of project}}{\text{Total electricity produced over life of project}}$$

where

$I_t$ is the capital invested in year *t*;
$M_t$ are the fixed and variable operation and maintenance costs in year *t*;
$F_t$ is the fuel cost in year *t*;
$D_t$ is the decommission cost (net of any salvage value) in year *t*;
$E_t$ is the electricity produced in year *t*;
$r$ is the discount rate;

and *n* is the lifetime of the project.

It is important that projects are compared on an equivalent basis so that project boundaries, financing, material and labour costs, and so on are harmonized. Inclusion or exclusion of taxes and subsidies depend on the nature of the analysis. For an assessment of overall economic cost to a society, transfer payments are generally excluded, while for cost comparison under a given regulatory and policy regime, any transfer payments could be included. However, the costs of externalities are generally not taken into account, largely because they are difficult to estimate in monetary terms [71].

**(c) Limitations of the indicator:** The LCOE only captures project specific costs and does not include any system effects. Integrating a power generation unit into a power system is likely to impact costs elsewhere in the system and this is not reflected in the LCOE. In particular, it does not include any penalty for lack of operator control (e.g. intermittency of wind power) or unpredictability of availability. The IAEA energy planning tool MESSAGE can be used to assess the total costs of the optimal energy mix on the basis of economic, resource, technology and environmental constraints and also accounting for grid connections and expansions (Ref. [56], p. 3).

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Investment, fuel, maintenance and decommissioning costs as well heat rate, capacity factor, discount rate and project lifetime.

**(b) National and international data availability:** Data for estimating current and near term levelized costs reside with utilities considering such investments and vendors offering different types of generation technologies. Estimates of project costs and parameters are available from a range of national studies, e.g. Ref. [72]. LCOE for the United States of America are reported annually by the EIA [73].

*ENE10: Fuel price increase sensitivity*

| | |
|---|---|
| Brief definition | The factor by which power production costs increase due to a doubling of fuel costs |
| Units | Factor |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To measure the extent to which power production costs for a given technology are sensitive to fuel costs.

**(b) Relevance to nuclear power development:** While fuel costs are an important risk parameter for all electricity generation investments, the sensitivity of power projects to variations in fuel costs vary markedly across generating technologies. The generation costs of gas fired plants, for example, are very sensitive to variations in fuel costs, because they comprise a large share of total costs. In the case of NPPs, the fuel price risk is much lower than for fossil fuelled plants because fuel costs are a small share of total production costs [74]. Moreover, uranium and fuel cycle services are usually bought under long term contracts that effectively eliminate fuel price risks.

In addition, changes in relative fuel price in the long term can significantly alter the overall cost picture. Relative fuel price changes affect a particular project's profitability owing to their impact on the cost structure of alternative investments considered. The perceived competitiveness of an NPP might be based on the expectation of high gas prices, but this could lead to overestimation if gas prices turns out to be lower [70].

**(c) Relevance to sustainable development:** The relevance of this indicator to sustainable development derives from the negative impact of volatile energy prices on the economy of a (fossil) fuel importing country. The higher a power plant's fuel price sensitivity, the higher the exposure of wholesale energy costs and, in turn, the consumers' bills to fuel price risks [75]. In countries with regulated prices, it is the oil and gas companies or the national budget (i.e. taxpayers) that are exposed to the volatility of fuel prices. Increasing the number of power producing technologies with very low or no fuel price sensitivity (renewable energy technologies have no fuel costs) in the power mix therefore contributes to the reliability and affordability of modern energy services that are key factors for sustainable development. High fuel price sensitivity of a power system typically leads to a deterioration of the balance of payments, dampened economic activity and an increased overall price level, potentially leading to an increased inflation rate [76].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** An NPP is relatively insensitive to fuel price fluctuations and the benefits of nuclear power in moderating electricity price volatility are therefore greater when the sensitivity to fuel price fluctuations in the power system is high.

**(f) Links to other indicators:**
- ENE3: Electricity generation;
- ENE9: Levelized cost of electricity;
- ENE19: Export and import prices of fuels used in electricity generation.

**Methodological description**

**(a) Underlying definitions and concepts:** Fuel price increase sensitivity is measured by varying the underlying assumptions for the fuel price component in the production cost calculation. This indicator is calculated by doubling the fuel price parameter. LCOE is the most transparent measure of generating costs and it is also the most widely used tool for comparing the costs of different power generation technologies. It is equal to the present value of the sum of discounted costs divided by the total production adjusted for its economic time value, assuming a constant discount (interest) rate *r* and a stable electricity price throughout the lifetime of the project [70].

**(b) Measuring methods:** To calculate the factor by which power production costs increase owing to the doubling of fuel costs, it is necessary to multiply the assumed fuel price parameter by two and divide the obtained LCOE by the original LCOE result.

$$\text{LCOE1} = \frac{\Sigma_1^n \left(I_t + M_t + F_t + D_t\right)/\left(1+r\right)^t}{\Sigma_1^n E_t\,/\left(1+r\right)^t} = \frac{\text{Total costs over life of project}}{\text{Total electricity produced over life of project}}$$

$$\text{LCOE2} = \frac{\Sigma_1^n \left(I_t + M_t + 2F_t + D_t\right)/\left(1+r\right)^t}{\Sigma_1^n E_t\,/\left(1+r\right)^t} = \frac{\text{Total costs over life of project}}{\text{Total electricity produced over life of project}}$$

where

$I_t$ is the capital invested in year $t$;
$M_t$ are the fixed and variable operation and maintenance costs in year $t$;
$F_t$ is the fuel cost in year $t$;
$D_t$ is the decommission cost (net of any salvage value) in year $t$;

$E_t$ is the electricity produced in year $t$;
$r$ is the discount rate;

and $n$ is the lifetime of the project.

Fuel cost factor = LCOE2/LCOE1

**(c) Limitations of the indicator:** This indicator only addresses fuel price risks and no other political, technical or market risks. Furthermore, it does not consider the opportunity or costs of mitigating these risks by signing long term contracts or hedging in financial markets.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** The amount of electricity produced in year *t*, the price of electricity, the discount factor for year *t*, investment cost in year *t*, operations and maintenance costs in year *t*, carbon costs in year *t*, decommissioning cost in year *t* and fuel costs in year *t*.

**(b) National and international data availability:** Data for estimating current and near term levelized costs reside with utilities considering such investments and vendors offering different types of generation technologies. Data needed to quantify the indicator across OECD and some non-OECD countries are available from IEA/NEA's Projected Cost of Generating Electricity [69, 70], and are based on principal information from questionnaires that were sent out for completion by member countries and experts.

*ENE11: National energy budget*

| | |
|---|---|
| Brief definition | The total government budget allocated to energy spending in a financial year |
| Units | National currency or US $ |
| Alternative definitions | Government expenditures for power generation |

**Policy relevance**

**(a) Purpose:** This indicator assesses the amount of funds a government allocates to the energy sector in a fiscal year.

**(b) Relevance to nuclear power development:** By considering the amount of money currently spent on energy, this indicator helps explore the energy–economy context for financially supporting the development of an NPP without marked increases in spending. Direct and indirect financial assistance by the government is designed to overcome investor uncertainties about the risks associated with the construction of new NPPs. It includes various forms of loan guarantees, risk insurance and production tax credits to facilitate financing of nuclear power projects [25, 26].

**(c) Relevance to sustainable development:** How much a government allocates to energy spending is relevant to sustainable development because of the key role energy plays in long term economic growth and competitiveness. Although the private sector often plays an essential role in the expansion of the energy sector, adequate levels of government support for energy sector development are a prerequisite to ensuring provision of reliable and affordable energy services. Specifically, investment in innovative new (clean) energy technologies as well as their deployment and long term development are crucial for enhanced environment stewardship and reduced energy and carbon intensity, and hence contribute significantly to the sustainability of economic growth and development.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** The national energy budget can be viewed in connection with the financial assistance requirements associated with the total cost of an NPP.

**(f) Links to other indicators:**
- MAC1: Gross domestic product (GDP);
- ENE1: Primary energy supply;
- ENE12: Government expenditures for power generation;
- NUC5: Estimated cost of the new NPP;
- NUC7: Public investments in nuclear power generation.

**Methodological description**

**(a) Underlying definitions and concepts:** Government spending on energy can take several forms, including subsidies for energy producers and products (e.g. grants, loans, loan guarantees or tax subsidies), energy research and development (R&D) (especially spending on innovative new energy technologies), or streamlining certain procedures (e.g. permitting processes).

**(b) Measuring methods:** Review government budget and extract expenditure items allocated to energy. To obtain the national energy budget, one should add up all expenditures in a government budget allocated to energy related activities.

**(c) Limitations of the indicator:** While this indicator gives information about the total size of the allocated funds as well as its size relative to the total budget, it does not indicate specific areas of energy investments such as R&D programmes, investment or operation subsidies, nor does it reveal the targeted energy sources and technologies.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Expenditure items in the national budget allocated to energy related activities.

**(b) National and international data availability:** The government budget is a country's annual financial statement outlining estimated revenues and spending for the forthcoming financial year. It is typically prepared by the ministry of finance. The budget breakdown is generally available from the published national budget or from statistics offices.

*ENE12: Government expenditures for power generation*

| | |
|---|---|
| Brief definition | The total government budget allocated to electricity production in a financial year |
| Units | National currency or US $ |
| Alternative definitions | National energy budget |

**Policy relevance**

(a) **Purpose:** This indicator assesses the amount of funds a government allocates to the electric power sector in a financial year.

(b) **Relevance to nuclear power development:** By assessing the amount of money currently spent on electricity, this indicator helps assess the prospects for financially supporting the development of an NPP without significantly increasing spending. It can be viewed in relation to the financial assistance requirements associated with the total cost of an NPP. Direct and indirect public financial assistance is necessary to overcome investor uncertainties about the risks associated with the construction of new NPPs. It includes various forms of loan guarantees, risk insurance and production tax credits to facilitate financing of nuclear power projects [25, 26].

(c) **Relevance to sustainable development:** Government expenditure for electricity generation is relevant to sustainable development because of the key role of electricity in long term economic growth and competitiveness. It supports humans' most basic needs (e.g. cooking, lighting, refrigeration or water pumping), and it is more flexible and convenient compared with other forms of energy. Electric power is vital for certain applications such as information and communications technology. Inadequate investment in power supply therefore perpetuates poverty and deprivation [61]. Investments in innovative new clean electricity technologies, in their deployment and long term development are crucial for improved environmental stewardship and reduced energy and carbon intensity, and hence contribute significantly to the sustainability of economic growth and development.

This indicator captures the magnitude of the government's financial support for the electricity sector. It can be used to identify and address possible funding gaps and to inform the design of policy tools to incentivize more adequate financial flows in support of sustainable development.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** The expenditures on energy for power generation can be viewed in connection with the financial assistance requirements associated with the total cost of an NPP.

(f) **Links to other indicators:**
- ENE2: Final energy demand;
- ENE11: National energy budget;
- NUC5: Estimated cost of the new NPP;
- NUC7: Public investments in nuclear power generation.

**Methodological description**

(a) **Underlying definitions and concepts:** Government spending on electricity can take several forms, including direct and indirect financial support for power producers and products (e.g. grants, loans, loan guarantees and tax subsidies), funds for R&D (e.g. spending on innovative new technologies) or streamlining certain procedures (e.g. permitting processes).

(b) **Measuring methods:** Review government budget and extract expenditure items allocated to the electricity sector. To obtain the national electricity budget, one should add up all expenditures in a government budget allocated to electricity related activities.

(c) **Limitations of the indicator:** This indicator provides information about the total size of the allocated funds as well as their size relative to the total budget. However, it does not indicate specific areas of the power sector expenditures, such as R&D programmes or investment and operational subsidies, nor does it reveal the targeted sources and technologies of electricity generation (e.g. nuclear energy).

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Expenditure items in the national budget allocated to electricity related activities.

**(b) National and international data availability:** The government budget is a country's annual financial statement outlining estimated revenues and spending for the forthcoming financial year. It is typically prepared by the ministry of finance. The budget breakdown is generally available from the published national budget or from statistics offices.

*ENE13: Share of imported fossil fuels in power generation*

| | |
|---|---|
| Brief definition | The proportion of imported fossil fuels used in electricity generation |
| Units | % |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To determine the extent to which power generation is dependent upon imported fossil fuels.

**(b) Relevance to nuclear power development:** This indicator helps assess the extent to which a country's power sector is dependent on imports of fossil fuel to generate electricity. For countries relying on large shares of imported fossil fuels, the introduction of nuclear power could help strengthen energy independence and security as well as reduce import bills.

Fossil fuel purchases can constitute a major component of total imports for import dependent countries. Reducing this import dependence by constructing an NPP can help alleviate the strain on the current account balance and the balance of trade.

**(c) Relevance to sustainable development:** Reduced imports of fossil fuels can alleviate pressure on budgets and the balance of trade, thereby freeing up funds and foreign currency for other uses. This can help boost growth and promote human development. Similarly, reducing risks associated with fuel price volatility can decrease the exposure of businesses and households to price shocks and thereby lead to a more stable cost environment, which is more conducive to investments, employment creation and growth.

Reducing the consumption of fossil fuels in general will also lower the amount of GHGs released into the atmosphere and thus address climate change, one of the main challenges to sustainable development. Replacing fossil fuels with clean energy sources such as renewables and nuclear is also likely to reduce local air pollution.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** There are no explicit targets or standards but a more diversified fuel mix that is less reliant on imported fossil fuel also helps mitigate a range of risks. Reduced reliance on fossil fuel imports can limit exposure to fuel price risks, as fossil fuel prices in international markets tend to be volatile and unpredictable. Fossil fuels, in particular oil and gas, have also been used as a tool in foreign policy and reducing imports can therefore help alleviate political and strategic risks and make the importing country less constrained in its own foreign policy. Other market and supply risks also tend to be lower with a more diversified portfolio of energy sources.

**(f) Links to other indicators:**

- MAC3: Current account balance;
- ENE8: Cost of electricity generation;
- ENE14: Diversification of energy sources in electricity supply;
- ENE19: Export and import prices of fuels used in electricity generation.

**Methodological description**

**(a) Underlying definitions and concepts:** Fossil fuels are buried organic matter formed by geological processes over millions of years. These hydrocarbons have a high density of energy that is released during combustion. This property makes fossil fuels convenient and valuable as a source of energy. Fossil fuels are typically grouped into coal, oil and natural gas.

Fossil fuels provide the bulk of global energy needs (roughly 82% of total primary energy supply in 2012 [15–18] and are indispensable for any modern economy. Since different world regions and countries have vastly different endowments of fossil fuels, those with insufficient domestic resources are forced to import from countries with more abundant resources. Given the crucial importance and high value of fossil fuels, such dependence can be a significant economic burden as well as affect a nation's foreign policy.

**(b) Measuring methods:** The share of imported fossil fuels can be derived from energy statistics. In many cases, a particular fuel is also used for purposes other than power generation. The fungible nature of fuels such as natural gas means that one cannot determine the exact source of any given unit. In such cases, the share of imports of the fuel for power generation can be assumed to be equal to the share of imports in total supply of the fuel in question. The shares for each fuel then need to be applied to the corresponding electricity production, summed over all fossil fuels and compared with total electricity generation.

**(c) Limitations of the indicator:** The share of imported fossil fuels in power generation only assesses the level of import dependence; it does not directly measure the energy security risk. If the fuel is bought in an open market and can be obtained from a variety of sources, high import dependence may not pose a major risk. However, dependence on a single source (e.g. country or infrastructure assets such as a single pipeline) could constitute a severe risk even at lower levels of dependence. Furthermore, this indicator does not capture the level of price risks associated with fossil fuel imports.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** The quantity of fossil fuel of each type used for power generation in a given measuring period, typically a year; the quantity of imported fossil fuel of each type and the fraction of each type of imported fossil fuel used by each relevant generation technology.

**(b) National and international data availability:** Data for quantifying import dependence can usually be derived from national energy statistics that contain information on sources of primary energy supply and fuel use in the power sector. These statistics are normally available from national statistics offices or energy departments. Data is also available from international organizations such as the IEA that publish annual statistics for many (but not all) countries [15–18] and the World Bank [24].

*ENE14: Diversification of energy sources in electricity supply*

| | |
|---|---|
| Brief definition | Shares of electricity generated from different energy sources |
| Units | % |
| Alternative definitions | Shannon–Wiener or other diversity index |

**Policy relevance**

**(a)** **Purpose:** To measure the diversity of electricity generation as an indicator of supply security and supply risk.

**(b)** **Relevance to nuclear power development:** One of the main strategies for strengthening energy security is diversifying types of resources, i.e. broadening the natural resource base used for energy production. This indicator is relevant to nuclear power development because nuclear energy facilitates this strategy by diversifying the portfolio of fuels and technologies in the electricity generation mix.

The introduction of nuclear power will increase the number of supply sources. There is a comprehensive and well functioning market for uranium with a diverse set of producer countries, minimizing the risk of supply interruptions for countries depending on uranium imports. In addition, uranium and fuel cycle services can be, and generally are, bought under long term contracts, effectively eliminating the risk of fuel price volatility [77]. Introduction or expansion of nuclear power can thus be a means to diversify the energy portfolio and mitigate supply risk.

**(c)** **Relevance to sustainable development:** Overreliance on any single fuel source or technology for electricity generation can pose significant risks. For example, reliance on hydro for most generation leaves electricity systems and the economies (factories, hospitals, schools, homes, etc.) that rely on them at the mercy of seasonal fluctuations in the availability of hydro resources. During droughts, electricity demand may easily outstrip generation, leading to blackouts, economic losses and social distress. Natural gas generation relies on a steady flow of natural gas, in many cases through long pipelines that are subject to weather related, technical, accidental and political disruptions. NPPs are subject to safety shutdowns in the wake of natural disasters and are, along with other thermal power plants, at the risks of extreme weather events that may affect the availability and temperature of cooling water to the extent that operation must be curtailed or shut down completely. Every technology and fuel is therefore subject to some level of risk, and diversity of supply can be an effective strategy to manage such risks.

Different fuels and generating technologies have different economic characteristics (investment vs. operating costs, for example) and environmental impacts. Hydro resources require large upfront investments and low operating costs, while natural gas technologies involve lower upfront investments and higher operating costs. A diversity of resources and technologies leads to a diverse and more stable cost structure compared with a portfolio in which electricity is provided by one or a few resources and technologies. Similarly, a diverse mix of electricity generation is likely to have fewer impacts on the environment than a power mix dominated by coal based generation, for example.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** International targets: Regional economic associations and many countries have established targets for the fraction of renewable sources in their energy supply. However, the main motivation behind such targets is usually not diversification of supply, but rather promotion of clean energy and reduction of GHG emissions.

Recommended standards: While there are no clear criteria for a desirable level of supply mix, diversification is a sound strategy for mitigating supply risks. Greater diversity is therefore preferable. Countries with low supply diversity are likely to benefit significantly more in terms of supply security from the introduction of nuclear power than countries with an already diverse supply portfolio.

**(f) Links to other indicators:**
- ENE13: Share of imported fossil fuels in power generation;
- ENE15: Share of intermittent generation in electricity supply.

**Methodological description**

**(a) Underlying definitions and concepts:** This indicator includes the various fuels and technologies for electricity generation, namely coal, oil, natural gas, nuclear, hydro, intermittent renewables and biomass. Intermittent renewables include wind, geothermal, solar thermal, solar photovoltaic (PV), wave and tidal energy.

**(b) Measuring methods:** Measurement involves determining the contribution to the total electricity generated from each fuel source annually.

**(c) Limitations of the indicator:** This indicator is limited in scope. It does not directly assess price, political or other risks of the generation portfolio.

**(d) Alternative definitions/indicators:** A further step in assessing supply diversity in power generation could be to apply a diversity index (e.g. the Shannon–Wiener index). Such indices provide a quantitative measure of diversity with a higher value typically implying greater diversity. More diversity implies a greater number of sources of electricity supply as well as a more even distribution of generation across these sources. The Shannon–Wiener index, for instance, is calculated by multiplying the share of each generation source by the natural logarithm of that share and summing across all sources and multiplying by negative one (to produce a positive value for the index).

**Assessment of data**

**(a) Data needed to compile the indicator:** Data for electricity generation by fuel and technology and the total generation in any one year.

**(b) National and international data availability:** The data required can usually be extracted from national energy and electricity statistics published by the relevant national authority (e.g. statistical agency or ministry of energy). They can also be accessed through international publications from the World Bank [13] and the IEA [15–18].

*ENE15: Share of intermittent generation in electricity supply*

| | |
|---|---|
| Brief definition | Percentage of total power supply from sources with intermittent availability |
| Units | % |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To ascertain the share of total electricity production generated from power sources for which availability and output are not determined by operators but by factors beyond their control (e.g. wind, sun or tides).

**(b) Relevance to nuclear power development:** This indicator measures the extent to which a power system relies on intermittent power sources, mainly renewables, for its electricity supply. The fluctuating output from renewable sources increases the need for flexible operation[1] from the rest of the power system and therefore needs to be paired with flexible, stable and reliable sources of power to ensure grid stability and security of supply.

NPPs are typically designed to operate in baseload mode, with steady production at or near full capacity. There is some degree of flexibility in the operation of NPPs. They can follow a predetermined daily pattern or be scheduled to operate at partial power according to grid requirements (scheduled load following plants). However, operating NPPs in a load following mode exposes plant components to multiple thermal stress cycles and requires more sophisticated instrumentation and control systems. Operating NPPs in both scheduled and arbitrary load following modes therefore adds significantly to costs [78]. The choice of mode of operation for the envisaged NPPs is crucial, as the switch of an NPP previously operated as a baseload unit to flexible operation entails various engineering, environmental, financial and commercial implications (e.g. modification of control systems to support frequency control and load following operations, adaptation of safety analysis and licensing basis changes) as a result of adjusting to new, less predictable operating patterns [78, 79]. Furthermore, not every country's nuclear legislation allows for flexible operation of NPPs. In addition, the high capital and low running costs of NPPs makes operation at lower load factors highly detrimental to their economic performance.

**(c) Relevance to sustainable development:** A large share of intermittent generation may pose risks to the security of supply and increase the chance of voltage fluctuations or even power failure. Furthermore, renewable generation tends to be more expensive than conventional thermal power sources and typically leads to an increase in the price to consumers.

On the other hand, intermittent generation is typically based on renewable energy flows which drive low carbon technologies. Support and promotion of investments in these technologies is a key part of the decarbonization of the power system. A high and growing share of intermittent renewable generation is therefore usually an indication of a power system in transition away from carbon intensive sources.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** There are no explicit targets or standards but NPPs may not be compatible with a very high share of intermittent generation as highly flexible units (e.g. gas turbines) are better suited to balance the system. In the case of a moderate penetration of intermittent generation, the stable and reliable electricity supply from nuclear power may be a good complement to renewable sources in a clean electricity portfolio.

**(f) Links to other indicators:**

- ENE3: Electricity generation;
- ENE4: Total installed capacity;
- ENE14: Diversification of energy sources in electricity supply;
- ENV6: Power density;
- ENV7: Water use in electricity generation.

**Methodological description**

**(a) Underlying definitions and concepts:** Most conventional generating technologies such as nuclear, combined cycle gas turbines or coal are to a large extent dispatchable meaning that their output can be controlled in response to changes in electricity supply and demand. They can be ramped up and down or shut down completely depending on the need for electricity supply and network reliability services. Output from dispatchable generators are typically scheduled according to their marginal generation costs or bid offer

[1] Flexible operation includes load following, frequency control and other actions that change the output of a power generation unit.

prices, starting with the lowest bidder and moving towards generators with higher marginal costs and bid prices until demand for electricity is satisfied in real time [80]. These mechanisms are necessary because electricity production and demand need to be balanced in real time. System operators must therefore dispatch generation to follow minute-to-minute changes in load and generation output. Because of their physics, bulk power electric systems would be highly unreliable and prone to frequent and severe outages in the absence of such real time balancing [81].

Intermittent sources, however, are not continuously available. Their output is determined by the natural variability of the energy sources rather than dispatched according to price signals or system requirements. Intermittent output typically results from direct, non-stored conversion of naturally occurring energy fluxes such as insolation, windiness or energy of free flowing rivers [63]. Although some intermittent sources can be quite predictable, they cannot be dispatched to meet the demand of a power system. When available, intermittent sources are either used to replace power from fossil fuelled generation units or stored in various forms.

**(b) Measuring methods:** The share of intermittent generation is calculated by adding up the generation of individual plants using intermittent sources such as wind, solar PV and wave power and dividing the sum by the total electricity generation in the power system in a given time period (e.g. one year).

**(c) Limitations of the indicator:** This indicator does not directly address balancing needs and the demand for dispatchable generation.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Total generation from intermittent sources (solar, wind, tidal and ocean) and total generation from all sources.

**(b) National and international data availability:** Data on electricity generation of power plants are typically available at national statistical offices, power companies or national energy ministries. The EIA [9] and the IEA [82] maintain the most comprehensive datasets of total electricity consumption and supply by production technologies across countries, based primarily on published national data and data collected from national energy ministries and reputable regional agencies.

*ENE16: Capacity of transmission lines*

| | |
|---|---|
| Brief definition | The maximum amount of power that can be transported over a transmission line or transmission network |
| Units | MW or other unit of power |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** The purpose of this indicator is to measure the maximum amount of electric power that can be sent over a system of transmission lines that are cross-connected in a way that permits multiple power supply to any principal point [63].

(b) **Relevance to nuclear power development:** The capacity of transmission lines can be used to help determine if an envisaged NPP can be effectively integrated into a transmission network. NPPs are usually very large generators (i.e. high installed capacity) and it is essential to ensure that the capacity of the transmission grid is sufficient to handle the planned amount of additional power flows coming on-line [78]. Alternatively, an SMR might be considered, having an equivalent electric power of less than 700 MW(e) or even less than 300 MW(e) that might be more convenient in small power grids.

The transmission system needs to have sufficient capacity to transfer electricity from power stations to load centres under any plausible demand and supply conditions. It needs to be able to accommodate power from large generators such as NPPs when operating at full capacity as well as to meet all load requirements when these generators are out of service (e.g. for refuelling or scheduled maintenance). This applies both to static conditions (e.g. ability to manage extreme circumstances in demand and unit availability) as well as dynamic changes (e.g. ability to handle sudden loss of units or spikes in demand).

(c) **Relevance to sustainable development:** No direct relevance to sustainable development.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** There are no explicit targets or standards but the capacity of transmission lines should be evaluated in relation to the estimated size of a new NPP.

(f) **Links to other indicators:**
- ENE4: Total installed capacity;
- ENE5: Peak electricity demand;
- ENE17: Reliability of the transmission and distribution system;
- NUC1: Installed nuclear power capacity;
- NUC6: Estimated size of the new NPP.

**Methodological description**

(a) **Underlying definitions and concepts:** A transmission network's capacity is the potential maximum quantity of electric power that can be sent via a system of transmission lines that are cross-connected in a way that permits multiple power supply to any principal point. Transmission capacity can be determined either by a line's thermal capacity, i.e. its capability to withstand heat generated by line loss, or by its stability limit, which depends on factors such as voltage class, line length and network configuration [83].

A transmission line consists of a combination of structures, wires, insulators and associated equipment through which large quantities of power are moved at high voltage typically over long distances between a generating point and major substations or delivery points. Changes in generation and transmission at any point have significant consequences for loads on the transmission system. The consequences of load exceeding capacity are particularly severe because they can cause overheating, leading to sagging overhead lines or electrical flashover to trees or the ground or, in the case of underground cables, to damage to the insulation. Excess load can also create power supply instability such as phase and voltage fluctuations. Such changes are difficult to control and are often major contributing factors to a grid collapse. This is why the quantity of power flowing through each transmission line must not reach the line's full capacity [63, 78].

(b) **Measuring methods:** This indicator is computed by adding up the capacities of individual transmission lines in a power system to obtain the total capacity of the network transmission. There are multiple factors such as thermal capacity, voltage class, line length and network configuration that determine how much power a given transmission line can potentially carry. Transmission capacity is expressed in terms of electric power, generally in MW or GW [83, 84].

**(c)** **Limitations of the indicator:** While capacity can be ascribed to individual transmission lines, it cannot be used to determine the actual transfer capability of a transmission path within an electric system or between multiple systems. Since a single transmission line is operated as part of an interconnected network, the physical relationship of that line to other elements of the transmission network plays a key role in its ability to transfer electric power. In fact, the aggregated capacity of transmission lines is often greater than the actual transfer capability. If known, the latter may be used as an indicator instead [84].

**(d)** **Alternative definitions/indicators:** Transfer capability.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Capacities of individual transmission lines within a transmission network.

**(b)** **National and international data availability:** Transmission line capacities can be obtained from transmission system operators or organizations responsible for national energy statistics.

*ENE17: Reliability of the transmission and distribution system*

| | |
|---|---|
| Brief definition | The extent to which an electricity network is affected by power outages |
| Units | Number, magnitude (MW·h) and duration (hours) of outages |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To assess the ability of a transmission and distribution network to meet electricity demand in the event of equipment failure or other sudden disturbances.

**(b)** **Relevance to nuclear power development:** A stable and reliable electricity grid is essential to support an NPP. While any new NPP will be built with robust on-site backup power source, it is desirable to maintain uninterrupted grid supplied power to plants in case a sudden shutdown is required for safety reasons. Unreliable grids experiencing frequent disruptions and failures need to be upgraded to be suitable for nuclear power.

**(c)** **Relevance to sustainable development:** Electric power is essential for the provision of basic services such as cooking, lighting and heating as well as more sophisticated services required for powering appliances and machinery. A stable and reliable transmission and distribution network is therefore essential for the reliable functioning of a power grid that in turn plays a major role in support of sustainable development. Inadequate provision of electricity could perpetuate poverty and deprivation by negatively impacting human resources as well as the viability and competitiveness of businesses. Voltage fluctuations and system trips can damage electrical equipment and disrupt production or services and increase costs for businesses and households.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** The grid needs to be designed and operated in a way that protects plant performance from common faults and minimizes consequences of unusual or severe events. IAEA Member States with a deregulated electricity system generally have published codes or standards to regulate the electricity system. They stipulate the required performance of the grid (e.g. acceptable frequency and voltage range) as well as planning and operation requirements that ensure grid reliability.

Regulations may also define requirements for system studies, technical requirements for generating units, and so on. Compliance is enforced by a government agency. In Member States with a regulated electricity system, grid reliability requirements, although in place, do not necessarily exist in the form of a published code or standard [53].

**(f) Links to other indicators:**
- ENE16: Capacity of transmission lines;
- NUC1: Installed nuclear power capacity;
- NUC6: Estimated size of the new NPP.

**Methodological description**

**(a) Underlying definitions and concepts:** While NPPs supply large amounts of electricity to the grid, they also rely on it for power consumption during crucial safety operations, especially during emergency conditions. The safe startup, operation and shutdown of NPPs require reliable and stable power supply from the electric grid called off-site power[2]. In particular, the grid plays a key role for safety by providing a reliable source of electricity to power the NPP's cooling system to keep nuclear fuel at low temperatures after a reactor has been shut down. Sufficient reliable power is also needed to sustain the coolant system, vital safety related instrumentation, control, monitoring and surveillance systems, as well as heating, ventilation and air conditioning systems to maintain operable environments for equipment and personnel. In addition to power requirements during safety operations, NPPs also require a stable and reliable grid to minimise the number of unplanned trips from power caused by grid faults and to achieve a high load factor without constraints due to grid restrictions [53, 78].

The grid supply should have appropriate quality. The safety systems of an NPP are designed for continuous operation with limited variations in voltage and frequency from nominal values. Increased variation has potentially negative implications for nuclear safety and the lifespan of the plant by accelerating the ageing of plant components such as electric motors or diminishing the functionality of components. Coolant pumps, for example, might operate too slowly in the event at below-minimum frequency. It is therefore essential for voltage and frequency of power supply to be tightly controlled within a defined narrow range [53, 85].

**(b) Measuring methods:** To obtain a measure of grid reliability in terms of the degree to which the grid can maintain uninterruptible power supply to an NPP site, the following aspects are important: the number of power outages, average magnitude of power outages (i.e. lost load) and the average duration of power outages (e.g. number of hours).

**(c) Limitations of the indicator:** This indicator does not take into consideration variations in voltage and frequency of grid supply that are equally important to grid reliability for NPPs.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Number, magnitude and duration of power outages, variation of voltage and frequency of grid supply.

**(b) National and international data availability:** Data on power outages are mostly available from grid operators, national (energy) statistics bodies as well as from various international sources, including the World Bank.

[2] Off-site power is the primary (preferred) source of power for NPPs during normal and emergency shutdowns rather than on-site power sources such as batteries and backup generating units such as diesel generators or small gas turbines.

*ENE18: Power generation plant vintage*

| | |
|---|---|
| Brief definition | An electricity system's current stock of power generation capacities by age |
| Units | Capacity (GW, MW) in cohorts of years of operation |
| Alternative definitions | Capacity (GW, MW) in cohorts of expected remaining years of operation |

**Policy relevance**

**(a)** **Purpose:** To assess the age distribution of the current stock of electricity generation plants in a power system and identify likely retirements of power generation assets.

**(b)** **Relevance to nuclear power development:** The upcoming retirement of old power stations can be an indicator of future investment needs. If substantial retirement of existing capacity is planned for a specific time period, say in the next 10–15 years, then this could represent an opportunity to add an NPP to the generation fleet. NPPs tend to be very large and the incremental demand growth may not be sufficient to support a new NPP in small or medium sized systems [53]. However, if the addition of an NPP coincides with the retirement of existing plants, it is more likely that the plant could be accommodated without expensive reductions in overall asset utilization.

**(c)** **Relevance to sustainable development:** A large share of old plants can be an indication that the power system is dominated by ageing and inefficient plants, resulting in higher electricity prices and lower security of supply. It may also be an indication of high levels of GHG emissions produced by the power system due to the old age and low efficiency levels of existing assets.

At the same time, a large share of old plants in the generation fleet is the sign of a system with a significant amount of generation capacity likely to be retired in the near future. This indicates scope for a more rapid transition to cleaner electricity supply than would be the case with a younger fleet of plants that would be locked in with the current asset base for a longer period of time.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** No specific targets or standards exist but a younger fleet of modern and efficient plants is generally desirable. Countries with an older fleet of plants could have greater benefits from the introduction of an NPP.

**(f)** **Links to other indicators:**

- ENE4: Total installed capacity;
- NUC6: Estimated size of the new NPP;
- ENV1: $CO_2$ emissions intensity of power production;
- ENV2: Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates).

**Methodological description**

**(a)** **Underlying definitions and concepts:** In the past, existing electricity generation facilities were built and commissioned over a long time period. It is important to keep track of their ageing in order to manage their timely renewal or replacement. By sorting existing capacities into age groups, one can get a good overview of the current age structure of the generation fleet.

**(b) Measuring methods:** A power system's generation plant vintage can be measured by calculating the number of years of operation of individual power plants and identifying their respective generating capacity, then assembling them into groups according to the number of years they have been in operation, for example, less than 10 years, 11–20 years, 21–30 years, and so on.

**(c) Limitations of the indicator:** This indicator does not take into account the remaining years of operation of existing generation capacity or planned future capacity additions.

**(d) Alternative definitions/indicators:** If the retirement dates of individual power plants are known, this indicator can be calculated based on remaining years of operation. This would provide an overview of current as well as future generation capacity of existing power plants for a particular timeframe (e.g. expected lifespan of an envisaged NPP).

**Assessment of data**

**(a) Data needed to compile the indicator:** Age and generation capacity of all power plants connected to an electricity system.

**(b) National and international data availability:** Data on age and generation capacity of power plants can usually be obtained from national energy statistics bodies or from utilities directly. The age and operational history of NPPs is available from the PRIS database maintained by the IAEA [4].

*ENE19: Export and import prices of fuels used in electricity generation*

| | |
|---|---|
| Brief definition | Export price: the price at which respective energy resources sourced or produced in the home country can be sold on international markets<br>Import price: the price to be paid when importing energy resources from a foreign country |
| Units | Local currency or US $/gigajoule (GJ) of energy |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** The export price shows the price that a supplier of respective energy resources (e.g. oil, gas, coal, uranium, electricity) can receive for selling outside the boundaries of the home country. The import price indicates the price that a buyer of respective energy resources originating from a foreign country must pay to procure it.

**(b) Relevance to nuclear power development:** Export prices of fuels used in electricity generation are relevant to nuclear energy development because nuclear power could displace generation from expensive fuel sources such as oil and gas, and therefore free up more of these resources for export. Fossil fuel income raises national savings, facilitates capital accumulation, has a positive impact on the overall fiscal balance and potentially boosts the amount of capital available for the government to provide some form of financial support to the development of a nuclear power programme. In addition, fuel exports increase foreign exchange reserves that helps countries self-insure themselves against foreign exchange market turbulence. This makes export prices of power generating fuels particularly relevant to NPP construction in countries that import nuclear technology or reactors as well as foreign experts [25, 26]. Import prices of power generation fuels, in contrast, are relevant to nuclear power development because nuclear generation potentially reduces or even eliminates the need for imports, decreases energy expenditure and thereby preserves national savings, strengthens energy security and saves foreign exchange reserves.

In general, this indicator serves as an important economic parameter for assessing electricity generation investments. Comparison of import and export prices of fuels used in the power generation mix can help determine the viability of the envisaged NPP. Fossil fuel price volatilities and steady increases, for instance, make nuclear power an attractive alternative to fossil based power generation for importers of fossil fuels. As global oil demand becomes increasingly insensitive to prices, the potential impact of supply disruptions resulting from political unrests, conflicts and trade embargoes, for example, on international oil prices is increasing [7].

**(c) Relevance to sustainable development:** Power supply is an essential input for any economic activity. The import price of fossil fuels have an impact on power production cost and consequently on electricity prices (though there may be some lag in the transfer of the impact to the consumers). The higher the overall import bill, the higher the strain on budgets and the balance of payments. Fuel imports also make a nation more vulnerable to price shocks. Import price fluctuations of fossil fuels directly impact the economic pillar of sustainable development, such as household needs or industrial growth. Note that the degree of vulnerability of a power system or an economy to changes in import prices varies with the level of dependence on individual fossil fuels [75].

Fossil fuel exporting countries are equally vulnerable to sudden price decreases, even more so when fuel exports generate the overwhelming share of an economy's export revenues. In this case, there is a close link to the overall fiscal status and the balance of payments. Fluctuations in global output and fossil fuel prices are strongly linked to the fiscal position of fossil fuel exporters. This in turn has a significant impact on economic growth, macroeconomic stability, inflation and therefore on sustainable economic development [7, 86].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** There are no explicit targets or standards but export and import prices should be viewed in conjunction with the prospects for increasing exports or reducing imports as a consequence of introducing nuclear power.

**(f) Links to other indicators:**

- ENE7: End user price of electricity;
- ENE8: Cost of electricity generation;
- ENE9: Levelized cost of electricity;
- ENE10: Fuel price increase sensitivity;
- ENE13: Share of imported fossil fuels in power generation;
- NUC4: Production of fissile material (uranium).

**Methodological description**

**(a) Underlying definitions and concepts:** Import prices affect the economic viability of power projects and thus the relative amount of each fuel used in the energy mix as well as the choice of power generating technologies deployed in fuel importing economies. Prices received by exporters, on the other hand, affect production and investment decisions in exporting countries that, in turn, have an impact on future fuel production quantities.

The wide range of prices for various energy resources and fuels reflect large differences in costs, taxes and subsidies across countries. The import price, i.e. the delivered ex ship price, is the price the buyer pays for the goods delivered by the seller to a specified port of destination. It includes all costs and risks associated with transportation of the goods to its point of destination [87]. Import prices contain elements specific to the market and depend on a number of factors that could lead to significant variations such as dates of landing and foreign exchange acquisition. The agency in charge of price control estimates the costs of storage and transport in order to determine what would be a reasonable margin along the supply chain [88].

The export price of a fuel, i.e. the free on board price, is the price the seller receives for fuel delivered to the port of shipment, including loading costs [87]. It may contain an export tax. Governments often use export taxes in order to safeguard domestic supplies, e.g. in the case of fuel shortages, thereby lowering domestic prices. In general, the fuel export price more or less follows international fuel prices, with differences in contractual arrangements and the quality of the fuel leading to some price variations for individual countries [75, 88].

(b) **Measuring methods:** Import (delivered ex ship equivalent) and export (free on board equivalent) prices of power generation fuels are registered in transaction data for customs and foreign trade statistics.

(c) **Limitations of the indicator:** None.

(d) **Alternative definitions/indicators:** None.

**Assessment of data**

(a) **Data needed to compile the indicator:** Export and import prices of fuels in power generation such as oil, gas, coal, uranium or the price of electricity itself.

(b) **National and international data availability:** Export and import prices of fuels in power generation are generally available nationally from national energy statistics offices and ministries of foreign trade or their statistics branches. International sources include organizations such as the IEA [66], the IAEA [20] and the EIA, although availability of price data can vary from country to country.

*ENE20: Reserve to production ratios for various fuels*

| | |
|---|---|
| Brief definition | Number of years for which the current level of production of any non-renewable energy resource can be sustained by current reserves |
| Units | Years |
| Alternative definitions | Total reserves, depletion rate of reserves |

**Policy relevance**

(a) **Purpose:** To assess the abundance and future availability of non-renewable energy resources by calculating the reserves to production ratio (RPR) as the length of time that proven reserves of a resource would last at continued current levels of production.

(b) **Relevance to nuclear power development:** This is an indicator of the remaining lifetime of a resource measured by the number of years for which the current level of production of can be sustained by currently known reserves. It thus helps assess the ability to maintain and expand the supply of fuels currently used in power generation. This has implications for the development of an envisaged NPP as the introduction of nuclear power could potentially slow the depletion of other energy resources such as coal or natural gas. The number of years of remaining reserves can also be an indicator of possible future price developments. If reserves are running low, future supplies may have to come from lower quality deposits or imports that might lead to higher prices.

**(c) Relevance to sustainable development:** Energy is required for virtually any human endeavour including productive uses, public services or personal needs. A safe and secure supply of affordable energy is required to support human development. Effective management of energy resources is therefore crucial for achieving a sustainable supply of energy. This indicator gives an assessment of the availability of a resource. A low ratio indicates that reserves will have to be expanded (through exploration, technological improvements or price increases) if the level of production is to be maintained or increased. Failure to do so would lead to declining production and the need to switch to other energy sources as a replacement.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** Although a range of issues influence the prospects for future domestic fuel extraction, a high RPR is clearly preferable. Countries where the ratio is low or falling could alleviate depletion risks by introducing an NPP.

**(f) Links to other indicators:**
- NUC4: Production of fissile material (uranium);
- NUC6: Estimated size of the new NPP.

**Methodological description**

**(a) Underlying definitions and concepts:** The RPR indicates the number of years for which the current level of production of any non-renewable energy (or mineral) resource can be sustained by its current reserves. Reserves are the amount of resources that can be recovered with reasonable certainty under current economic conditions using existing technologies based on geological and engineering information. The inverse of the RPR is the share of total reserves produced in a year. For some minerals such as uranium ore and coal, a steady level of production can generally be maintained over a long period of time. This helps obtain a reasonable measure of the number of years the production level can be supported by existing proven reserves. The production from an oil or gas field, however, typically ramps up rapidly in the early phases of production and then declines gradually over the lifetime of the field. When production levels fall too low to cover the costs of continued operation, the wells are plugged and the field is decommissioned. The RPR is therefore not a good indicator of the number of years for which production of the given resource at the specific location is likely to continue.

**(b) Measuring methods:** The RPR is calculated by dividing the remaining proven reserves in a country at the end of the year by the production in that year.

**(c) Limitations of the indicator:** Owing to differences in classification and methods of estimation of reserves, comparison of the magnitude of RPR across different countries might be problematic. Moreover, the magnitude of the RPR is strongly influenced by political, technological, economic and environmental circumstances. For example, an oil field with proven reserves might not be in production or there might be limits deliberately imposed on the level of production owing to strategic or political reasons such as quotas for oil exports [89].

**(d) Alternative definitions/indicators:** Alternative indicators include total reserves and the depletion rate of reserves.

**Assessment of data**

**(a) Data needed to compile the indicator:** Data on proven energy reserves and production of a particular energy resource in a given year.

**(b) National and international data availability:** National sources of data on proven fossil energy reserves are typically geological surveys and energy statistics organizations. International data sources include the WEC's World Energy Resources [19] as well as international oil and gas companies (e.g. BP Statistical Review of World Energy [58]). Data on uranium resources can be obtained from Uranium: Resources, Production and Demand, a biennial publication by the joint IAEA/NEA Uranium Group [20].

*ENE21: Rate of return on investments in the power sector*

| | |
|---|---|
| Brief definition | Profitability of investments in power generation |
| Units | % |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To measure the return on investments in the power sector over a period of time and to help determine whether the sector offers attractive opportunities for investors.

**(b) Relevance to nuclear power development:** The rate of return in the power sector helps assess the extent to which investments in the sector offer attractive returns. Investors respond to the trade-off between risks and returns. A sector's attractiveness is thus partly a reflection of the level of risk associated with investments. The nature of risks for different types of generation technologies affects the expected return on investment and may therefore influence the choice of technologies. Different risks affect generating technologies in different ways. For a new NPP, uncertainty about future electricity prices is a major factor affecting the value of investments in liberalized electricity markets as it creates a risk for the investor. In addition, foreign investors need to adjust for risks associated with exchange rate fluctuations. The flow of capital to the power sector is affected by the expected returns and the project horizon, which tends to be relatively long for power projects in general and nuclear power projects in particular because NPPs typically have a long lead and construction time [69, 90].

In regulated markets, on the other hand, there is no market risk. In view of a guaranteed rate of return, utilities can finance their investments with a relatively low share of equity and borrow at interest rates close to government debt yields. The risks are limited to the impacts of unfavourable regulatory decisions and cost overruns due to bad project management. Therefore, investors can depend on steadiness as they will be able to make fairly constant and substantial returns irrespective of the state of the economy or the power generation company [91].

**(c) Relevance to sustainable development:** The rate of return on investments in the power sector is relevant to sustainable development because electricity is of key importance to economic growth and development. The more attractive the sector for investors, the higher the likelihood of the availability of sufficient capital for investments to provide a reliable electricity supply to power economic activity over the long term.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** In regulated markets, there is generally a target rate of return allowed by the regulator. The same rate is likely to apply to nuclear power investments. In competitive markets, the rate of return should be compared with those in other economic sectors.

**(f) Links to other indicators:**

- ENE7: End user price of electricity;
- ENE8: Cost of electricity generation;
- NUC8: National and foreign direct private investments in nuclear electricity generation.

**Methodological description**

**(a) Underlying definitions and concepts:** The rate of return on investments shows the compensation providers of capital require or expect in return for their investments. As in any sector, investors in the power sector respond to the trade-off between risks and returns. They seek returns corresponding to the risk. The power sector competes for capital with other economic sectors that may offer attractive returns with shorter project horizons and relatively acceptable risk profiles.

In a regulated power market, returns on investments are subject to regulatory oversight and energy utilities are able to pass on costs to energy consumers. The government or regulator thereby ensures that regulated utilities are able to finance their operations and the investments to ensure a continued reliable power supply. In the case of a regulated market, this indicator is easy to use as the rate of return is guaranteed. In liberalized markets, in contrast, the regulatory risk shield is removed, exposing investors to various risks. Electricity charges are largely determined by market forces on the basis of a supply–demand mechanism and generators are no longer guaranteed either total cost recovery from power consumers or future price levels. In this case, data on rates of return on investments needs to be gathered from company financial reports [69, 90].

**(b) Measuring methods:** The rate of return can be calculated over a single period (typically a year) or over the entire lifetime of the project, consisting of multiple sub-periods. To obtain the rate of return on an investment for a single period of one year, one should divide the amount of money gained or lost on an investment during that period (i.e. interest, profit/loss, net income/loss) by the amount of money invested (i.e. asset, capital, principal). The result is called annual return [92].

There are various methods to calculate the rate of return over a number of sub-periods, including the annualized arithmetic mean, the annualized geometric mean and the compound return (internal rate of return of actual cash flows):

*Annualized arithmetic mean*: $\frac{\sum(r_1+\ldots+r_n)}{n}$

where $r_i$ are the returns over $n$ successive sub-periods;

*Annualized geometric mean*: $(\prod_{i=1}^{n}(1+r_i))^{\frac{1}{n}}-1$

where $r_i$ are the returns over $n$ successive sub-periods;

*Compound return* is the rate $r$ that solves for the equation $\sum_{n=0}^{N}\frac{C_n}{(1+r)^n}=0$

where

$n$ is a period;
$C_n$ is the cash flow for that period;

and $N$ is the total number of periods.

This method takes into consideration the time value of money [92].

**(c) Limitations of the indicator:** The rate of return is a key metric for assessing investments in assets, but it needs to be seen in the context of other factors such as perceived risks. Historical rates may have limited relevance if there have been significant changes in regulations, institutional settings or market conditions. The IAEA energy planning tool Model for Financial Analysis of Electric Sector Expansion Plans (FINPLAN) can be used for an in-depth financial analysis of electricity generation projects by taking into account financing sources, expenditures, revenues, taxes, interest rates and other relevant factors (Ref. [56], p. 4).

**(d) Alternative definitions/indicators:** Alternative indicators include the profit rate and the return on capital of power sector investments.

**Assessment of data**

**(a) Data needed to compile the indicator:** Rate of return on investments in power generation by individual power companies, most often stated for a calendar or fiscal year.

**(b) National and international data availability:** In regulated electricity sectors, the rate of return is permitted (and guaranteed) by the relevant regulatory body (or government). In liberalized power markets, data on the rate of return on investments can be obtained from company financial reports.

## 3.3. NUCLEAR DIMENSION

*NUC1: Installed nuclear power capacity*

| | |
|---|---|
| Brief definition | The sum of net maximum electric output that nuclear power generators connected to a grid can produce under specific conditions |
| Units | GW(e) or MW(e) |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** This indicator measures the size of a country's nuclear power generating capacity and can be used to assess the capability to expand nuclear generation.

**(b) Relevance to nuclear power development:** This is an indicator of the current state of the nuclear power industry in the country. A large fleet of reactors is an indication of extensive experience with nuclear power and is a sign of a mature industry with well established institutions, operational experience and a large workforce with the necessary skills and knowledge to manage and expand the nuclear power programme.

The complexity of nuclear technology requires highly educated, specifically trained and experienced workers. While nuclear newcomers are likely to depend primarily on their technology supplier to help train qualified people for construction, licensing and startup as well as to develop required national capabilities and domestic training programmes, the challenge in countries with existing installed capacity and expanding nuclear power programmes is to scale up existing education and training in order to have the required qualified workforce ready when needed [93, 94].

**(c) Relevance to sustainable development:** By assessing the state of the nuclear power industry in a country, this indicator can help measure a power system's alignment with sustainable development goals. The larger the share of nuclear power capacity in the total installed capacity, the larger the share in electric power production supporting environmental preservation by low air pollutant and GHG emissions. Nuclear power is one of the energy sources and technologies available today with significant potential to help meet the climate–energy challenge [95].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** There is no target or standard for installed nuclear capacity. In general, countries with existing nuclear reactors have fewer obstacles to further investments in nuclear power than countries with no existing nuclear plants.

**(f) Links to other indicators:**

- ENE3: Electricity generation;
- ENE4: Total installed capacity;
- ENE16: Capacity of transmission lines;
- ENE17: Reliability of the transmission and distribution system;
- NUC2: Nuclear power reactors in operation;
- NUC3: Planned nuclear power investments and retirements;
- ENV3: Production of low level radioactive waste;
- ENV4: Production of spent fuel and high level radioactive waste.

**Methodological description**

**(a) Underlying definitions and concepts:** An NPP's electricity generation capacity is its potential to deliver power and is measured in MW(e) or GW(e). It is the maximum net electric output that the plant can produce. Total installed nuclear power capacity is the sum of all individual nuclear power reactors' generating capacities.

**(b) Measuring methods:** This indicator can be computed by adding up installed capacities of all NPPs (measured in MW(e)) in a country.

**(c) Limitations of the indicator:** This indicator only measures the total capacity at currently operational power reactors, but it does not provide information about the quantity of nuclear electricity produced. There can be institutional and human resource challenges for nuclear power development even if a number of reactors are already in operation.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Installed nuclear plant (nameplate) capacity of all individual nuclear power generators connected to the national grid.

**(b) National and international data availability:** Data on individual plant installed capacity as well as total electricity installed capacity are usually available from national energy statistics bodies as well as from various international sources. The IAEA PRIS database [4] provides the up to date status of installed nuclear capacities in all countries.

*NUC2: Nuclear power reactors in operation*

| | |
|---|---|
| Brief definition | Number of nuclear power reactors in operation in a power system |
| Units | Number |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To measure the size and state of the nuclear power industry in a country.

**(b)** **Relevance to nuclear power development:** This indicator has direct relevance because it shows the state of the nuclear power industry in the country. The number of operating reactors can be used to help assess a country's capability to develop or further expand a nuclear programme.

Countries with a significant number of operational nuclear plants are more likely to have the necessary conditions, including strong institutions and a qualified and experienced workforce to facilitate the development of additional NPPs. The development of competent national human resources with the required knowledge and safety culture needed in the nuclear power industry is crucial for the introduction of a nuclear development programme. While nuclear newcomer countries face a significant challenge as they will need to rely heavily on support from vendor countries for education and training for their first NPPs [96], countries with nuclear power reactors in operation are mainly concerned with bridging the experience gap as the workforce renews and expands to ensure a sufficient number of qualified individuals available to replace experienced individuals who retire. It is generally expected that the future expansion of nuclear power globally will be largely driven by countries that already have nuclear power [93].

**(c)** **Relevance to sustainable development:** This indicator can help assess a power system's alignment with sustainable development goals. The more nuclear power reactors in operation, the higher the share of power produced with low GHGs emissions. Nuclear power is an attractive option to meet growing energy demand with increased supply resiliency while at the same time helping preserve the environment by reducing air pollution and GHG emissions [93, 95].

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** There is no target for the number of reactors. In general, countries with existing nuclear reactors will have fewer obstacles to the expansion of nuclear power than countries with no existing nuclear plants.

**(f)** **Links to other indicators:**

- ENE4: Total installed capacity;
- NUC1: Installed nuclear power capacity;
- NUC3: Planned nuclear power investments and retirements;
- ENV3: Production of low level radioactive waste;
- ENV4: Production of spent fuel and high level radioactive waste.

**Methodological description**

**(a)** **Underlying definitions and concepts:** A reactor is classified as operational or in operation from its first grid connection to its permanent shutdown. Therefore, even when a reactor is experiencing outages, i.e. temporarily not producing electric power, it still counts as operational. Reasons for (planned) outages include refuelling, maintenance, repair, large refurbishment or a political decision. This category, however, does not include reactors whose status is declared as long term shutdown, even those that have not yet reached permanent shutdown [4].

**(b) Measuring methods:** To calculate this indicator, it is necessary to add up all operational NPPs in a country.

**(c) Limitations of the indicator:** The indicator only measures the number of NPPs currently in operation in a country, but it does not provide information about the quantity of nuclear power produced. Similarly, there can be institutional and human resource challenges for nuclear power development even if a number of reactors are already in operation.

**(d) Alternative definitions/indicators:** Installed nuclear power capacity.

**Assessment of data**

**(a) Data needed to compile the indicator:** Total number of operational NPPs in a country.

**(b) National and international data availability:** National sources include NPP operators and national energy statistics organizations. An international source is the PRIS database maintained by the IAEA [4].

<u>NUC3</u>: *Planned nuclear power investments and retirements*

| | |
|---|---|
| Brief definition | Installed capacity of planned new NPPs (including those under construction) and of planned NPP retirements |
| Units | GW(e) or MW(e) |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** To assess prospects and plans for nuclear power in a country.

**(b) Relevance to nuclear power development:** This is an indicator of a country’s expressed interest in nuclear power. It summarizes the plants under construction, foreseeable plans for new NPPs to be built as well as existing ones to be shut down. In general, future expansion of nuclear power globally is expected to partly come from countries already generating nuclear power. In its high nuclear power estimates, the IAEA projects the majority of additions to occur in countries such as China, India, the Russian Federation and other countries in Europe and North America — all countries already operating NPPs [4, 97]. In this group of countries, some intend to phase out nuclear energy by a specified date or once the end of the current licensing period or a certain cumulative power output of the NPPs is reached. Thirteen countries had new plants under construction as of early 2015; some of them are building their first reactors. Planned retirements may indicate a need to build new NPPs to replace retired ones.

**(c) Relevance to sustainable development:** Concerns about energy supply security and environmental conservation — two important aspects of sustainable development — are significant reasons for introducing or expanding nuclear programmes. The link to supply security is based on the ability of nuclear power to further increase supply diversity and resiliency because uranium is available from diverse producer countries, it is required in small volumes and it is easy to establish strategic reserves if needed. Nuclear power is a low carbon technology and does not emit pollutants detrimental to local air quality, and so neither causes regional acidification nor contributes to climate change [93].

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** None.

**(f) Links to other indicators:**

- ENE4: Total installed capacity;
- NUC1: Installed nuclear power capacity;
- NUC2: Nuclear power reactors in operation;
- NUC4: Production of fissile material (uranium);
- NUC6: Estimated size of the new NPP.

**Methodological description**

**(a) Underlying definitions and concepts:** A nuclear reactor is considered under construction from the date when first major pour of concrete is completed (typically for the base mat of the reactor building) to the date when the reactor is handed over by the contractors to the owner and declared officially in commercial operation [4]. The majority of nuclear plants currently under construction are in Asia, a region with fast growing economies and rapidly rising electricity demand. A combination of energy security concerns, GHG emissions constraints and the economics of nuclear power are making it an attractive option for new capacity in many countries.

A reactor is considered to be planned when approvals, funding or other major commitments are in place. Planned reactors are mostly expected to be in operation within 8–10 years.

A nuclear reactor is considered permanently shut down from the date when it is officially declared by the owner to be taken out of commercial operation and shut down permanently. Early nuclear plants were designed to operate for about 30 years while newer plants are designed for an operating life of between 40 and 60 years. At the end of its operation, a power plant needs to be decommissioned, decontaminated and demolished in order to make the site available for other uses. This process includes cleanup of contamination and progressive dismantling of the plant. Other reasons for retirement include accidents or serious incidents, political decisions or regulatory impediments [98].

**(b) Measuring methods:** To quantify this indicator, it is necessary to add up the total net electric capacity of all NPPs under construction and planned, on the one hand, and the total net electric capacity of plants to be retired within a certain timeframe.

**(c) Limitations of the indicator:** None.

**(d) Alternative definitions/indicators:** The number of reactors planned and under construction, and the number of reactors to be shut down.

**Assessment of data**

**(a) Data needed to compile the indicator:** Total net electric capacity of all NPPs under construction and planned in a country and the total net electric capacity of all NPPs planned for retirement.

**(b) National and international data availability:** National sources include utilities building, planning or operating NPPs as well as national energy statistics or nuclear energy regulation agencies. The principal international data source is the IAEA's PRIS [4] comprehensive database covering NPPs worldwide and containing information on power reactors in operation, under construction and permanently shut down.

*NUC4: Production of fissile material (uranium)*

| | |
|---|---|
| Brief definition | Amount of uranium produced |
| Units | Tonnes of uranium (t U) |
| Alternative definitions | Uranium resources |

**Policy relevance**

**(a)** **Purpose:** This indicator measures the amount of uranium produced in a country in a given year.

**(b)** **Relevance to nuclear power development:** This indicator helps determine whether an NPP could be supported by domestic uranium production. Countries using uranium in commercial NPPs typically need to import a large share of their uranium demand. As of 2010, only two nuclear power generating countries — Canada and South Africa — produced uranium in sufficiently large quantities to meet domestic requirements [20].

A country's uranium production can also be used to assess the international status of the domestic nuclear industry, not only relative to domestic production in previous periods but also in comparison with world uranium production [20].

**(c)** **Relevance to sustainable development:** Uranium production is linked to sustainable development as it contributes directly to job creation. This includes employment directly related to production such as exploration, mining, milling and processing related activities, head office, laboratory, mining emergency services, and so on. The joint IEA and IAEA publication [20] reports employment figures related to uranium production and productivity.

**(d)** **International conventions and agreements:** Uranium is sold only to countries that are signatories to the IAEA's Nuclear Non-Proliferation Treaty and allow international inspection to verify that the uranium they import is used only for peaceful purposes [99].

**(e)** **International targets/recommended standards:** The Nuclear Non-Proliferation Treaty seeks to prevent diversion of fissile material from peaceful uses to nuclear weapons or other nuclear explosive devices.

**(f)** **Links to other indicators:**
- ENE19: Export and import prices of fuels used in electricity generation;
- ENE20: Reserve to production ratios for various fuels;
- NUC3: Planned nuclear power investments and retirements.

**Methodological description**

**(a)** **Underlying definitions and concepts:** Uranium is produced by using open pit and underground mining techniques. It is processed by conventional uranium milling, in situ leaching, co-product or by-product recovery from copper, gold and phosphate operations, heap leaching and in-place leaching. Although historically uranium was mostly produced in open pit and underground mines, in situ leaching — involving the use of acid or alkaline solutions to extract uranium directly from its deposit — has become increasingly important over the past 20 years [20].

In the last two decades, the largest source of uranium has been primary production, meeting around 50–85% of world demand. The rest has been derived from secondary sources such as stockpiles of natural and enriched uranium, reprocessing of spent fuel, re-enrichment of depleted uranium tails and down-blending of weapons grade uranium [20].

**(b) Measuring methods:** Uranium resources and production quantities are expressed in t U. Uranium production denotes the amount of uranium output from an ore processing plant or production centre in t U contained in concentrate (with milling losses deducted) [20].

**(c) Limitations of the indicator:** The indicator does not provide information about how much, if any, of the uranium produced is consumed locally. It also does not indicate the source of uranium (e.g. primary or secondary).

**(d) Alternative definitions/indicators:** Uranium resources can be used as an alternative indicator to current production levels. While data on current production are useful to assess the capacity of domestic mining industries to meet local demand for uranium at present, total uranium resources indicate the prospects for domestic self-sufficiency in the long run.

**Assessment of data**

**(a) Data needed to compile the indicator:** Total amount of uranium produced in a country in a given year.

**(b) National and international data availability:** National data sources include national geological surveys and services, and national statistical offices. Internationally, the IAEA/NEA Uranium Group's biennial production Uranium: Resources, Production and Demand (The Red Book) is the primary reference source for world uranium supply. It presents data on estimates of uranium resources in several categories of assurance based on existence and economic attractiveness for reporting Member States [20].

*NUC5: Estimated cost of the new NPP*

| | |
|---|---|
| Brief definition | Total of direct and indirect costs of the complete envisaged nuclear power unit |
| Units | National currency or US $, national currency or US $/kilowatt (electrical) (kW(e)) |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** The purpose of this indicator is to assess the capital requirements for the development of a new nuclear reactor unit.

**(b) Relevance to nuclear power development:** This indicator can be used to assess whether or not an NPP can be built at an acceptable cost in a given country and context. It includes all direct and indirect costs of the complete power unit and forms the basis of comparison with a number of other indicators. Comparing the estimated cost of a new NPP with a country's GDP, for example, helps assess the magnitude of the envisaged investment relative to the size of the national economy. Similarly, the indicator can be used in conjunction with the national energy budget or government expenditures on power generation to assess the required financial support for the development of a new NPP. The estimated cost components can also be used for assessing the LCOE (also accounting for fuel, operation and maintenance, and other costs) of a new NPP that can be compared with the overall cost level in the power sector to determine whether existing electricity prices would be sufficient to pay for the plant.

**(c) Relevance to sustainable development:** Access to affordable electricity is a key driver for growth and development. If electricity can be provided at low prices, it is a boon to businesses and households. A lower investment cost for an NPP is a pre-condition to lower electricity prices for consumers. Furthermore, the lower the cost of a new NPP relative to the cost of other generation options, in particular other low carbon sources, the lower the costs of reducing carbon emissions in the power sector.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** There are no specific threshold values, but lower costs are preferable.

(f) **Links to other indicators:**

- MAC1: Gross domestic product (GDP);
- MAC6: Large scale projects financed in the past ten years (in excess of US $250 million);
- ENE11: National energy budget;
- ENE12: Government expenditures for power generation;
- NUC8: National and foreign direct private investments in nuclear electricity generation.

**Methodological description**

(a) **Underlying definitions and concepts:** This indicator shows the total cost of building an NPP and bringing it into commercial operation. It can be broken down into two broad categories. Overnight costs include the engineering, procurement and construction costs and owner's costs (e.g. transmission upgrades, administrative systems, project management, permits, tax, legal and staffing costs). They represent the costs of building an NPP if it could be constructed overnight, i.e. they exclude financing costs, cost escalation and inflation. Financial costs include interest during construction and other financial charges. This breakdown is important because a failure to distinguish between estimates including versus excluding financial costs can lead to confusion in the comparison of published capital cost figures in case of delay in the construction schedule. Financing costs can constitute a major component of the total project costs. In an assessment of a range of potential projects, interest during construction ranged from 18 to 53% of the overnight costs for a new NPP [70]. Financing costs depend on a number of factors such as interest rate, project leverage and whether the plant is built as part of a regulated entity's rate base or as a merchant plant. Some projects may obtain more favourable financing terms through government loan guarantees or policies to recover carrying costs through rates during construction [100].

Reported overnight investment costs vary widely between sources even when they are presented on a per kW(e) basis. It is likely that these differences are due to factors reflecting differences in local market conditions and/or technology choices, in accounting methods and deviations in exchange rate values. Furthermore, the market for NPP technologies is far from transparent and the availability of data on actual recent costs of building nuclear power stations is limited. Moreover, construction cost data supplied by vendors may be optimistic, especially ahead of contractual commitments, and not subject to independent evaluation. In the IEA's New Policies Scenario, the assumed overnight costs of new NPPs are in the range of US $2000 to US $4600/kW(e). This wide range reflects differences in local conditions, including the structure of the nuclear industry [7].

(b) **Measuring methods:** Total investment costs are the costs of building the NPP and bringing it into commercial operation. They make up around three quarters of the total cost of generating electricity from nuclear power [101]. In the IAEA Account System, overnight costs comprise accounts 21 to 54 and 70, and the financial cost component can be broken down into escalation costs (account 60), interest during construction (account 61) and fees (account 62) [102].

(c) **Limitations of the indicator:** Capital cost estimates can be misleading unless the underlying assumptions are clearly stated. For example, they may or may not include contingencies, taking into account factors such as project complexity, design status, market conditions, or first of a kind technologies. Cost estimates could also represent the cost for more than one unit. Variations in these and other assumptions may cause differences of the order of hundreds of millions of US dollars [100].

(d) **Alternative definitions/indicators:** Cost of power generation by the new NPP.

**Assessment of data**

(a) **Data needed to compile the indicator:** All direct and indirect cost components of an NPP should be collected and accounted for. They can be sorted into two main groups: capital costs (equipment, materials and labour required to build the plant) and financing costs [100].

(b) **National and international data availability:** Reliable data on estimated costs of new NPPs are difficult to obtain. Vendors and project sponsors know these data best but would usually not reveal them for commercial reasons. Secondary sources include the NEI [100] and the IEA/NEA [70].

*NUC6: Estimated size of the new NPP*

| | |
|---|---|
| Brief definition | Maximum electric power that a new nuclear unit can export to the transmission system |
| Units | GW(e) or MW(e) |
| Alternative definitions | Installed capacity of a new nuclear unit |

**Policy relevance**

(a) **Purpose:** This indicator shows the size of an envisaged NPP that can be compared with the capacity of the power grid and the demand for electricity.

(b) **Relevance to nuclear power development:** This is an important indicator for determining whether the size of an envisaged NPP is suitable for the local grid and the economy. A new NPP might be among the largest single generating units on the grid and significant challenges could arise when operating it on a relatively small grid. A single nuclear unit could represent a large percentage of the installed generation capacity. It would require the availability of sufficient generation capacity to meet power demand during periods when the nuclear plant is shut down (planned or unplanned) or otherwise unable to deliver power to the grid. Hence, there is a practical limit to the size of the generating unit that can be installed in an electric grid to ensure stability when it is disconnected [53]. Alternatively, an SMR might be considered, having an equivalent electric power of less than 700 MW(e) or even less than 300 MW(e) [103]. This would mitigate the problems associated with the integration of a unit with large capacity.

(c) **Relevance to sustainable development:** No direct relevance.

(d) **International conventions and agreements:** None.

(e) **International targets/recommended standards:** No standards or thresholds are defined but the estimated size of the new NPP needs to be seen in the context of other indicators listed under (f) below.

(f) **Links to other indicators:**
- ENE1: Primary energy supply;
- ENE2: Final energy demand;
- ENE3: Electricity generation;
- ENE4: Total installed capacity;
- ENE16: Capacity of transmission lines;
- ENE17: Reliability of the transmission and distribution system;

- ENE18: Power generation plant vintage;
- ENE20: Reserve to production ratios for various fuels;
- NUC3: Planned nuclear power investments and retirements;
- ENV6: Power density.

**Methodological description**

**(a)** **Underlying definitions and concepts:** The size of an NPP refers to the maximum electric power it can export to the transmission system. Over the years, there has been a steady increase in the size of new reactor designs offered by vendors. Currently available reactors have a capacity of no less than 1000 MW(e). Even though designs for SMRs are under development, they are unlikely to become available for commercial use for a number of years [53].

If the current or future electricity demand of a nuclear newcomer country is too small relative to the size of an envisaged NPP and if there is a lack of strong grid connections to neighbouring countries, it may be a challenge to introduce nuclear power until smaller units become available [53]. Overall grid capacity can be increased by establishing interconnections with other grids [93].

**(b)** **Measuring methods:** A generator's power generation capacity is the maximum electric output it can technically produce as designated by the manufacturer. Installed generating (nameplate) capacity is typically expressed in MW(e) [63].

**(c)** **Limitations of the indicator:** The prospects for effective integration of an NPP into a power grid depend on a range of variables other than the generator size. It is impossible to make exact statements about the impacts on system performance or reliability based solely on the reactor size.

**(d)** **Alternative definitions/indicators:** None.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** This indicator requires information about the size, i.e. the maximum electric output, of the envisaged NPP.

**(b)** **National and international data availability:** Data on the estimated size of a new NPP may be obtained from relevant project owners or reactor vendors.

*NUC7: Public investments in nuclear power generation*

| | |
|---|---|
| Brief definition | Government funds dedicated to nuclear power generation |
| Units | National currency or US $ |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To measure public financial commitments to nuclear power production.

**(b)** **Relevance to nuclear power development:** This is an indicator of the government's current financial commitment to nuclear power development in addition to any supportive policy, legal and regulatory framework that a government may have put in place. Public investment in nuclear power generation plays a significant role in reducing uncertainties for potential investors about the risks associated with the construction of a new NPP, especially in the case of first of a kind plants. Specifically, government investments (e.g. in the form of debt guarantees), significantly reduce the risk of non-payment and hence the cost of debt. This in turn affects favourably the creditworthiness of a nuclear power project, the cost of the loan and the risk–return ratio of the interest offered to the creditor [25].

**(c)** **Relevance to sustainable development:** This indicator is relevant to sustainable development to the extent that it reflects public commitment to low GHG emitting power generation with a positive impact on climate change mitigation and environmental preservation.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** There are no explicit targets or standards but government support of some kind is usually required to realize NPP projects, and government spending on nuclear power is therefore conducive to further nuclear programme development.

**(f)** **Links to other indicators:**

- MAC1: Gross domestic product (GDP);
- ENE11: National energy budget;
- ENE12: Government expenditures for power generation;
- NUC8: National and foreign direct private investments in nuclear electricity generation.

**Methodological description**

**(a)** **Underlying definitions and concepts:** Governments that want to encourage or expedite a new phase of nuclear construction involving private investments have a range of tools available to support potential investors. These include direct financial assistance such as asset ownership or equity participation as well as indirect financial assistance through the provision of various incentives such as loan guarantees for a set share of the total project costs, risk insurance for construction delays or production tax credits for the plant's output in the first years of its operation [25, 26].

**(b)** **Measuring methods:** To obtain the total amount of public funds dedicated to nuclear power generation, one needs to add up all government spending on energy.

**(c)** **Limitations of the indicator:** Not all government support can be clearly monetized. Regulatory arrangements favouring nuclear investments tend to reduce financial risks and thus the risk premium and the cost of capital but this cannot be characterized as a dedicated government fund.

**(d)** **Alternative definitions/indicators:** None.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Total amount of public funds in the national budget dedicated to nuclear power generation.

**(b)** **National and international data availability:** The government budget is a country's annual financial statement outlining estimated revenues and spending for the forthcoming financial year. It is typically prepared by the ministry of finance. The budget breakdown is generally available from the published national budget or from statistics offices.

*NUC8: National and foreign direct private investments in nuclear electricity generation*

| | |
|---|---|
| Brief definition | Total national and foreign direct private investment flows in nuclear power generation |
| Units | National currency or US $ |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** This indicator measures the level of direct private investment flows, both national and foreign, in the nuclear power generation sector.

**(b)** **Relevance to nuclear power development:** This is an indicator of proven track record in attracting private capital to nuclear power development. Private investment in nuclear power is a sign that the sector is viewed favourably by investors and demonstrates that it is possible to attract financing for NPPs in the country. It implies that investments in NPPs have been expected to yield returns that are attractive relative to the perceived risks.

The viability of investments in a country's nuclear development programme depends on a number of factors such as macro- and socioeconomic conditions for evaluating a country's ability to support an investment of the size required for the construction of an NPP; energy related issues to determine the appropriate size and costs of the envisaged NPP for local economic and energy market conditions [53] and that reflect the current state of and interest in a country's nuclear power industry or the extent an NPP could be supported by local uranium production [20].

In addition, supportive policies, legal and regulatory frameworks put in place by a government and public investments in nuclear power generation also play a significant role in encouraging private investors by reducing uncertainties related to national and foreign direct investments in NPD [25, 26]. Finally, the adequate levels of private investments attracted to the construction of a new NPP depend on the project's risk profile, i.e. its creditworthiness and its price [25].

**(c)** **Relevance to sustainable development:** This indicator reflects financial flows into power generation with low GHG emissions that has a positive effect on climate change mitigation and environmental preservation.

**(d)** **International conventions and agreements:** None.

**(e)** **International targets/recommended standards:** There are no explicit targets or standards but an existing nuclear industry is conducive to further investments in nuclear power. The larger the industry, the better the prospects.

**(f)** **Links to other indicators:**
- ENE21: Rate of return on investments in the power sector;
- NUC5: Estimated cost of the new NPP;
- NUC7: Public investments in nuclear power generation.

**Methodological description**

**(a)** **Underlying definitions and concepts:** Private investments in nuclear power include the full amount of money invested in the nuclear power value chain. It is the sum of all nuclear asset finance, new equity raised in capital markets, private equity, and venture capital and private R&D spending.

(b) **Measuring methods:** To obtain total direct investment in nuclear power generation, one needs to add up all national and foreign direct private investment flows into a country's nuclear power sector.

(c) **Limitations of the indicator:** None.

(d) **Alternative definitions/indicators:** None.

**Assessment of data**

(a) **Data needed to compile the indicator:** All investments in a country's nuclear power sector from national and foreign direct private sources.

(b) **National and international data availability:** National and foreign private investment flows into a country's nuclear energy sector might be available from national sources such as national energy statistics offices but in many countries one would need to access annual reports and financial statements of individual companies to arrive at an estimate.

## 3.4. ENVIRONMENTAL DIMENSION

*ENV1: $CO_2$ emissions intensity of power production*

| | |
|---|---|
| Brief definition | The amount of $CO_2$ emitted per unit of electricity generation |
| Units | Grams of $CO_2$ per kW·h (g $CO_2$/kW·h) |
| Alternative definitions | — |

**Policy relevance**

(a) **Purpose:** To measure the specific emissions of the most important GHG from electricity production.

(b) **Relevance to nuclear power development:** Nuclear power is a low carbon technology and reducing carbon emission can be one motivation for pursuing nuclear power development. Since the nuclear fuel cycle requires only small quantities of fossil fuels, a country's net GHG emissions could be lowered significantly by the implementation of a nuclear power project [104]. The estimations of the Intergovernmental Panel on Climate Change of the GHG mitigation potential of various electricity generating technologies have shown that in the electricity sector, nuclear power has a significant mitigation potential at a low average cost.

The carbon intensity of electricity production is a measure of the extent to which nuclear power can contribute to reducing carbon emissions in power systems with high carbon intensities by replacing fossil fuel sources, especially coal. In electricity systems with low average carbon intensity (e.g. those dominated by hydropower), there is less scope for nuclear power to lower carbon emissions further and climate change concerns would therefore not be a major reason to pursue an NPP.

(c) **Relevance to sustainable development:** Reducing carbon emissions in the power sector is one of the main requirements for combating climate change. Power generation is a major contributor to GHG emissions at approximately 48% of total $CO_2$ emissions globally in 2011 [13]. It is also a part of the economy where the costs of mitigation are comparatively low.

The carbon intensity of electricity production is an indication of the degree to which the power sector contributes to climate change. High carbon intensity is a sign of an unsustainable sector with a high climate impact from every unit of electricity produced. Under such circumstances, investments in clean low carbon technologies such as renewables and nuclear power are vital. Conversely, low carbon intensity is a sign of a sector in which power generation is clean and low carbon technologies already dominate.

**(d) International conventions and agreements:** The UNFCCC provides the foundations and legal framework for climate protection globally. The Kyoto Protocol defines quantitative constraints and deadlines for reducing GHG emissions for more developed countries.

**(e) International targets/recommended standards:** International targets: Nations agreed under the Copenhagen Accord UNFCCC to reduce GHG emissions to levels that will keep the increase in global mean temperature below 2°C relative to pre-industrial levels. This corresponds to about 450 ppm concentration of $CO_2$ in the atmosphere.

There are no explicitly recommended standards for $CO_2$ intensity in the electricity sector but a lower intensity indicates a smaller impact in terms of the atmospheric concentration of GHGs and is therefore desirable.

**(f) Links to other indicators:**
- ENE1: Primary energy supply;
- ENE2: Final energy demand;
- ENE3: Electricity generation;
- ENE18: Power generation plant vintage.

**Methodological description**

**(a) Underlying definitions and concepts:** The bulk of global electricity is generated by burning of fossil fuels, which results in $CO_2$ emissions. The amount of emissions per unit of electricity generation depends primarily on two parameters: the precise nature of the fuel burned and the efficiency of converting the heat into electricity. Qualitatively, coal emits more $CO_2$ than oil, and oil emits more than natural gas (methane) per unit of energy supplied. Nuclear power, hydropower and renewables have practically no direct $CO_2$ emissions when producing electricity, but all electricity sources have some GHG emission over their full life cycle.

**(b) Measuring methods:** The $CO_2$ intensity of electricity production can be calculated by dividing the total amount of $CO_2$ emissions from power production (in grams) by the total amount of electricity generated (in kW·h).

**(c) Limitations of the indicators:** $CO_2$ intensity measures only $CO_2$ emissions and ignores all other GHG emissions from the power sector. However, $CO_2$ is the major GHG emitted from the power sector, data on other GHGs are poor and conversion to $CO_2$ equivalent is debated.

**(d) Alternative definitions/indicators:** GHG emissions intensity (accounting for all GHGs).

**Assessment of data**

**(a) Data needed to compile the indicator:** Data on $CO_2$ emissions from all power generation plants and the amount of electricity produced by them. $CO_2$ emissions can be derived from the type and quantity of fossil fuels consumed in power generation.

**(b) National and international data availability:** National sources include statistical bodies collecting energy and environmental data, ministries of energy and environment and national focal points to the UNFCCC responsible for the national submissions of emissions reports to the UNFCCC. The main international data sources are the World Bank data series [13] and the World Resources Institute [105].

*ENV2: Air pollutant emissions intensity ($SO_x$, $NO_x$, particulates)*

| | |
|---|---|
| Brief definition | The quantity of sulphur oxides ($SO_x$), nitrogen oxides ($NO_x$) and particulate matter (PM) emitted from electricity generation |
| Units | Grams of $SO_x$, $NO_x$ and PM per kW·h of electricity |
| Alternative definitions | Total amounts emitted (t), emissions per unit of GDP (t/US $), emissions disaggregated by type of fuel (t) |

**Policy relevance**

**(a)** **Purpose:** To measure the emissions of air pollutants from power production.

**(b)** **Relevance to nuclear power development:** The combustion of fossil fuels produces air pollutants that can adversely impact human health, the natural environment and damage buildings and structures. The emission of pollutants such as $SO_x$, $NO_x$ and PM can be managed by improved combustion at the power stations, by installation of control equipment, by switching fuel source (e.g. to low sulphur coal) or by investments in power sources that do not emit air pollutants. An NPP represents one such technology as it emits virtually no air pollutants during operation. An NPP replacing fossil generation could therefore significantly lower air pollutant emissions from an electric power system [104].

**(c)** **Relevance to sustainable development:** Air pollutants such as $SO_x$, $NO_x$ and PM are harmful to human health and damage ecosystems and buildings. These impacts are clearly detrimental to human development, environmental protection and economic growth. Reducing local and regional air pollution by replacing fossil power plants with high pollution intensity with NPPs therefore promotes sustainable development.

**(d)** **International conventions and agreements:** In Europe: the Geneva Convention on Long-range Transboundary Air Pollution [106] and the associated Gothenburg Protocol sets quantitative emissions limits for countries in the region.

**(e)** **International targets/recommended standards:** Critical load levels for $SO_x$, $NO_x$, volatile organic compounds and ammonia are established in the Gothenburg Protocol for most of the Northern Hemisphere.

Recommended standards: There are no specific standards, but lower emissions intensities indicate lower environmental impacts and are therefore desirable. In countries with high emissions intensities from electricity production, the potential for improving air quality and reducing acid deposition by building and operating an NPP will be higher.

**(f)** **Links to other indicators:**
- ENE1: Primary energy supply;
- ENE2: Final energy demand;
- ENE3: Electricity generation;
- ENE18: Power generation plant vintage.

**Methodological description**

**(a)** **Underlying definitions and concepts:** The bulk of global electricity is generated by burning fossil fuels, which results in emissions of $SO_x$, $NO_x$ and PM. Coal and other solid fossil fuels, especially lignite, are of particular concern. Although the oxides are gaseous, they return to the surface with precipitation and, depending on the nature of the surface environment, deposition may exceed critical levels above which direct adverse effects on receptors such as human beings, plants, ecosystems and materials may occur. Particulate matter arises especially from the combustion of solid fuels, although incomplete combustion of liquid fuels may also produce particulates. While these PM are generally non-toxic, they are a considerable nuisance (e.g. because they cause visibility degradation) and two size fractions, PM with a diameter of less than 10 µm (PM10) and of less than 2.5 µm (PM2.5), present a particular hazard for respiratory diseases.

Fossil fuels are also burned for heat generation (industrial and residential heat). In some cases, facilities cogenerate heat and power. Conventionally, emissions from combined heat and power generation are regarded as emissions from power generation.

**(b)** **Measuring methods:** Most utilities are required to keep records of their $SO_x$, $NO_x$ and PM emissions.

**(c)** **Limitations of the indicator:** Because emissions from solid fossil fuels are the greatest concern, there is very little data on emissions from other fuel types. The IAEA energy planning tool Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS) estimates and quantifies health and environmental damage costs of different electricity generation technologies (Ref. [56], p. 4).

**(d)** **Alternative definitions/indicators:** Emissions intensities (g/kW·h) are appropriate indicators of air pollution. Data are normally reported as total emissions by mass. However, for various purposes (critical load or international agreements) they may be reported as total amounts. Disaggregation of data according to types of fuels used in generation can provide guidance on the possibilities of reducing emissions by fuel switching.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Data on $SO_x$, $NO_x$ and particulate emissions from generating facilities and the annual power output of the facilities, disaggregated by fuel type.

**(b)** **National and international data availability:** Data on emissions of air pollutants and air quality is usually available from environmental agencies or departments at national or local levels. Examples include the emissions trading system of the United States Environmental Protection Agency [107] and the air pollution statistics of the United Kingdom Department of Environment, Food and Rural Affairs [108]. The European Environmental Agency publishes data and statistics including plant by plant emissions of $SO_x$, $NO_x$ and dust from large combustion plants [109]. Data on estimated health impacts of ambient air pollution is available from the World Health Organization [110].

*ENV3: Production of low level radioactive waste*

| | |
|---|---|
| Brief definition | The amount of low level radioactive waste produced by an NPP or an electric power system |
| Units | Cubic metre ($m^3$) of annual production and accumulated totals |
| Alternative definitions | — |

**Policy relevance**

**(a)** **Purpose:** To assess the amount of LLW produced by an NPP or an electric power system.

**(b)** **Relevance to nuclear power development:** Generation of LLW is relevant to nuclear power development because all parts of the nuclear fuel cycle produce some form of radioactive waste that must be disposed of in a fully contained and stable manner in order to protect people and the environment [111]. NPP operators are required to have all the necessary equipment for waste processing and monitoring the site and its environment. The implementation of a waste management programme in agreement with national policy and established regulations requires adequate technical capabilities, including equipment, installations and personnel. The development of a new NPP requires careful planning and implementation of a waste management programme. Several factors such as local availability of equipment and resources as well as adequate handling, transportation, storage and disposal of radioactive waste need to be taken into consideration. These and other aspects tend to pose significant challenges, especially in developing countries that lack a highly skilled workforce and have only limited access to highly sophisticated equipment. Minimization of radioactive waste generation — comprising source reduction, recycling and reuse of valuable by-products and treatment to reduce the volume of radioactive waste — is a vital requirement that must be addressed at all stages of the design and operation of an NPP [112].

Financial provisions also need to be made for the management of radioactive waste. The related costs represent approximately 5% of the total cost of nuclear power. The three main approaches to arranging for the necessary funds include provisions on the generating company's balance sheet, payments into a special internal fund and payments into a fund held externally. Most governments also require nuclear operators to set aside funds as a levy to cover the costs of the management and disposal of their wastes [111].

(c) **Relevance to sustainable development:** From a sustainable development perspective, it is vital that the volume of LLW to be disposed of is minimized and that the disposal is performed in a fully contained and stable manner.

(d) **International conventions and agreements:** The IAEA safety standards supporting the implementation of binding international instruments and national safety infrastructures are a keystone of the global nuclear safety regime. These standards include fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment in order to limit the likelihood of adverse consequences from radiation related events [113]. The IAEA's Radioactive Waste Safety Standards Programme (RADWASS) provides guidance to Member States on the safe management of spent fuel and all types of radioactive waste, with the objective of helping ensure that they are managed safely to protect humans and the environment [114].

(e) **International targets/recommended standards:** It is prudent to formulate appropriate policies and strategies to ensure the safe, technically optimal and cost effective management of spent fuel and radioactive waste. A policy for spent fuel and radioactive waste management is typically established by the national government or a designated governmental organization and may become codified in the national legislative system. It should include a set of goals and requirements to ensure the safe and efficient management of spent fuel and radioactive waste in the country and may be expanded into several different strategy components (normally established by the relevant waste owner or nuclear facility operator) [115]. A requirement for LLW is robust isolation and containment for up to a few hundred years. It is common practice to dispose of such waste in engineered near surface facilities. LLW is processed by treatment and conditioning in preparation for transport, storage and disposal, depending on the planned storage and disposal methods [116].

(f) **Links to other indicators:**
- NUC1: Installed nuclear power capacity;
- NUC2: Nuclear power reactors in operation.

**Methodological description**

(a) **Underlying definitions and concepts:** LLW is generated in most facilities involved in nuclear power production, but it is also a by-product of using radioactive materials in medical diagnosis and treatment, biomedical and pharmaceutical research, and manufacturing [117]. LLW is above clearance levels but contains only limited amounts of long lived radionuclides[3]. Examples include paper, rags, tools, clothing, filters and other material used in cleaning the reactor's cooling systems and fuel storage ponds, decontamination

[3] A radionuclide is a radioactive isotope of a particular element. Different isotopes of a given element have different numbers of neutrons but the same number of protons; hence isotopes of the same element share atomic numbers but not mass numbers.

of equipment as well as filters and metal components that have become radioactive as a result of their use in or in close proximity to the reactor [111].

LLW includes a broad range of waste, from short lived radionuclides with higher levels of activity concentration to long lived radionuclides at only relatively low levels of activity concentration [116]. It contains about 90% of the total volume but only 1% of the total radioactivity of all radioactive waste [111].

**(b) Measuring methods:** It is necessary to add up the volume of LLW produced by individual nuclear power units connected to the grid over the period under consideration (e.g. one year).

**(c) Limitations of the indicator:** None.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** The total volume of LLW produced by individual reactors in a power system over the period under consideration (e.g. one year).

**(b) National and international data availability**: NPP operators and national nuclear regulators keep track of the amount of LLW produced in their plants and country, respectively. The IAEA's NEWMDB is an on-line information source on radioactive waste management. It contains information about radioactive waste inventories and national radioactive waste management programmes, disposal, relevant laws and regulations, policies, plans and activities. Data in the NEWMDB are supplied by designated government representatives [118].

*ENV4: Production of spent fuel and high level radioactive waste*

| | |
|---|---|
| Brief definition | The amount of SF&HLW produced by an NPP or an electric power system |
| Units | $m^3$ of annual production and accumulated totals |
| Alternative definitions | — |

**Policy relevance**

**(a) Purpose:** This indicator is used to assess the amount of SF&HLW produced by an NPP or in an electric power system.

**(b) Relevance to nuclear power development:** Generation of SF&HLW is relevant to nuclear power development because such waste is produced in the process of burning uranium fuel in a nuclear reactor and it is a core aspect of the design of the disposal facility for SF&HLW. See also ENV3.

**(c) Relevance to sustainable development:** From a sustainable development perspective, it is vital that the volume of SF&HLW to be disposed of is minimized and that the disposal is performed in a fully contained and stable manner.

**(d) International conventions and agreements:** The IAEA safety standards supporting the implementation of binding international instruments and national safety infrastructures are a keystone of the global nuclear safety regime. These standards include fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment in order to limit the likelihood of adverse consequences from radiation related events [113]. The IAEA's Radioactive Waste Safety Standards Programme (RADWASS) provides guidance to Member States on the safe management of spent fuel and all types of radioactive waste, with the objective of helping to ensure that they are managed safely to protect humans and the environment [114].

**(e) International targets/recommended standards:** The generally recognized option for the disposal of SF&HLW is disposal in deep, stable geological formations several hundred metres below the earth's surface [116]. A policy for SF&HLW management is typically established by the national government or a designated governmental organization and may become codified in the national legislative system. It should include a set of goals and requirements to ensure the safe and efficient management of SF&HLW in the country and may be expanded into several different strategy components (normally established by the relevant waste owner or nuclear facility operator) [115]. A requirement for SF&HLW is safe isolation and containment for hundreds of thousands of years.

**(f) Links to other indicators:**

- NUC1: Installed nuclear power capacity;
- NUC2: Nuclear power reactors in operation.

**Methodological description**

**(a) Underlying definitions and concepts:** SF&HLW have activity concentrations at sufficiently high levels to generate a significant amount of heat from the radioactive decay process and large amounts of long lived radionuclides. They contain fission products and transuranic elements generated in the reactor core. They are highly radioactive and very hot and therefore require shielding and cooling . These aspects need to be taken into consideration in the design of the disposal facility [116].

SF&HLW contain over 95% of the total radioactivity generated in the process of nuclear power production. Nuclear power facilities worldwide produce about 10 000 $m^3$ of SF&HLW per year [111]. They comprise both short and long lived components, their longevity depending on the length of time necessary for the radioactivity of particular radionuclides to fall to non-hazardous levels. This distinction becomes relevant in the management and disposal of SF&HLW when short lived products can be separated from long lived components [111].

**(b) Measuring methods:** Measuring and adding up the volumes of SF&HLW produced by individual nuclear power units connected to the grid over the time period under consideration (e.g. one year).

**(c) Limitations of the indicator:** None.

**(d) Alternative definitions/indicators:** None.

**Assessment of data**

**(a) Data needed to compile the indicator:** Total volume of SF&HLW produced by a power system over the period under consideration (e.g. one year).

**(b) National and international data availability:** NPP operators and national nuclear regulators keep track of the amount of SF&HLW produced in their plants and in their country, respectively. The IAEA's NEWMDB is an on-line information source on radioactive waste management. It contains information about radioactive waste inventories and national radioactive waste management programmes, disposal, relevant laws and regulations, policies, plans and activities. Data in the NEWMDB are supplied by designated government representatives [118].

*ENV5: Solid waste generation from electricity production*

| | |
|---|---|
| Brief definition | The mass of ash and solids from flue gas treatment produced in electricity generation |
| Units | Tonne (t) |
| Alternative definitions | The specific mass expressed as per MW·h electricity generated or disaggregated according to fuel types |

**Policy relevance**

**(a)** **Purpose:** To measure the amount of non-hazardous solid waste from electricity generation.

**(b)** **Relevance to nuclear power development:** This indicator quantifies the amount of solid waste produced in power generation. It has important implications for nuclear power development because the weight and volume of radioactive wastes produced by nuclear power generation is very small relative to amount of wastes produced in fossil fuel electricity generation. An envisaged NPP therefore has the potential to significantly lower the solid waste generation in the power sector. Power generation from a typical 1000 MW(e) NPP produces approximately 300 $m^3$ of low and intermediate level waste and some 30 t of SF&HLW annually [119]. In comparison, a coal plant of similar capacity produces about 300 000 t of ash per year that also includes radioactive material and heavy metals [120]. Nuclear power is the only large scale power generating technology that takes full responsibility for its wastes and fully incorporates the related costs into the electricity cost [111].

**(c)** **Relevance to sustainable development:** Non-hazardous solid wastes generally present few opportunities for reuse and must be disposed of in landfills. It is desirable that the volume be minimized and the disposal fully contained and stable.

**(d)** **International conventions and agreements:** None

**(e)** **International targets/recommended standards:** There are no specific targets or standards but a lower amount of waste generation is desirable. In countries with a high volume of solid waste generation in the power sector, the mitigation potential from the introduction of an NPP is higher.

**(f)** **Links to other indicators:**
- ENE1: Primary energy supply;
- ENE3: Electricity generation;
- ENE18: Power generation plant vintage.

**Methodological description**

**(a)** **Underlying definitions and concepts:** The primary solid waste arising in power generation is ash from the combustion of coal. The finest fraction, referred to as fly ash, has some value as an additive to cement and much fly ash is disposed of in this way. The coarser fractions have little or no use and are disposed of in landfills designed for this purpose. The ash contains some carbon and it is usually measured as it gives a guide to the overall efficiency of combustion. As the ash is the result of high temperature combustion, it is relatively stable and contains a very small leachable fraction; therefore, the design of disposal for long term retention does not raise problems. Compaction may sometimes be necessary to minimize the stored volume but the density can then approach the level suitable for construction, so the impact even in terms of land use can be mitigated. A waste stream of lesser volume arises from flue gas desulphurization if the primary fuel is coal, although some fuel oils contain enough sulphur to make desulphurization mandatory. Sulphur oxides are adsorbed by an alkaline material, generally lime. The product is primarily calcium sulphite but in most cases secondary oxidation is applied to convert it into calcium sulphate (gypsum) for which there is a reasonable market. The desulphurization process may be wet, in which case the product is a sludge that must be dried before sale. Dry scrubbing is less efficient but produces a dry product directly. Some of the sludge or dry product may not be marketable and must be dumped in landfills. In this case, special landfill construction techniques are essential to prevent soluble species migrating into the biosphere.

The remaining solid wastes from power generation are mostly normal industrial wastes: scrap metal, insulation materials, protective clothing, grease and cables. Some materials can be recycled. There is a slight possibility that insulation materials contain asbestos and must be handled according to the local industrial regulations. In general, however, the volume of the remaining solid waste is small relative to the first two types of waste, and systems for handling industrial waste are generally in place.

**(b)** **Measuring methods:** The mass of ash produced is normally recorded by the power station, and usually fly ash and bottom (coarse) ash are differentiated. The mass of fly ash sold is also important, as the balance may have to be added to the bottom ash as landfill. Solids arising from desulphurization are also measured and evaluated to see how much can be sold as building material and how much must be dumped, and if it is dumped, what the moisture content of the material is, because this will determine the physical stability of the dump.

**(c)** **Limitations of the indicator:** None.

**(d)** **Alternative definitions/indicators:** The amount of waste per MW·h generated or per capita or disaggregated by fuel types.

**Assessment of data**

**(a)** **Data needed to compile the indicator:** Total weight of solid waste products from power generation.

**(b)** **National and international data availability:** The required information is available at power plant operators and may be included in the environmental reports of power companies.

*ENV6: Power density*

| | |
|---|---|
| Brief definition | Electricity production capacity per unit of land or water area |
| Units | Watt per square metre (W/m$^2$) |
| Alternative definitions | Annual electricity production per unit of land, land use intensity of power production |

**Policy relevance**

**(a)** **Purpose:** To estimate and compare the land use requirements of different energy chains.

**(b)** **Relevance to nuclear power development:** Power production requires occupation and conversion of land and this can have important environmental and economic impacts if it interferes with or precludes other uses of the land. The amount of land required to support a given amount of power production (the power density) can vary by several orders of magnitude between technologies, and land use impacts can similarly vary dramatically between sources. It is customary to evaluate land impacts based on the entire life cycle (i.e. full value chain and full lifetime) that includes the use of land resources for material exploration, extraction, production, transportation, distribution and use [121]. Different technologies have different reasons for using specific land areas and have varying consequences in terms of the environmental impacts of land use [122].

This indicator is relevant to nuclear power development because nuclear energy belongs to the least land intensive power generation technologies (i.e. it has a high power density). Conventional centralized generation options such as coal and natural gas also have high power densities, while more distributed renewable sources such as solar PV or wind tend to require larger areas. Biofuel is the most land intensive category of power generation [123]. Estimates of power density can be combined with the expected capacity factor to produce energy density estimates.

**(c) Relevance to sustainable development:** Sustainable development involves equitable fulfilment of development and environmental needs of present as well as future generations. This indicator is relevant to sustainable development because it measures the efficiency of land use by energy chains. Its inverse relationship, i.e. land use intensity, evaluates the size of the displaced arable land that could otherwise be used, for example, for food production or forests.

The key issue in land use is the competition with food production, a significant issue for biofuels where energy crops often compete with food crops for valuable agricultural land. Land use versus power capacity considerations are particularly relevant in low income countries where the bulk of people's income depends heavily on the agricultural sector.

Another key aspect is the highly invasive nature of mining. Mining is often associated with the removal of large areas of vegetation and animal habitat and requires significant rehabilitation after mining is ended. Similarly, dam construction leads to flooding large areas, which disrupts habitats and potentially forces relocation of communities.

The operation of NPPs can potentially contaminate local land with toxic by-products. The storage of radioactive waste, for instance, may prohibit any further use of contaminated land for some time [122, 124]. However, this can be mitigated by proper geological disposal. On the positive side, nuclear power has one of the lowest land requirements compared with alternative power generation technologies so it is an energy option that can help nations achieve a number of their sustainable development goals.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** This indicator needs to be seen in the context of the domestic geography, demography and, in particular, land availability. In sparsely populated countries with low demand density and good availability of land suitable for a range of power generation options, power density may be of less concern. In more densely populated regions with higher commercial pressure on land, the opportunity cost of using vast land areas for power generation is higher and the value of high density power generation is greater.

**(f) Links to other indicators:**

- ENE4: Total installed capacity;
- ENE15: Share of intermittent generation in electricity supply;
- NUC6: Estimated size of the new NPP.

**Methodological description**

**(a) Underlying definitions and concepts:** This indicator provides information about the efficiency of land use of a fuel life cycle with respect to installed capacity, i.e. installed capacity per unit of land area used ($W/m^2$). In order to obtain this information, the total area of land used for the entire energy chain must be evaluated. Some of the main features to be taken into consideration for individual fuel types are presented here.

*Coal:* The size of land transformation by the coal fuel cycle varies with factors such as the coal's heating value, seam thickness (as especially in surface mining, disturbed areas are proportional to the seam's thickness), density and the mining method. In underground mining operations, the main concern is for land subsidence or slumping around coal bearing lands, including roads, dwellings and national forests. The facilities connected with the power plant itself, such as a powerhouse, switchyard, stacks, precipitators, walkways, coal storage and cooling towers also occupy land. In addition, a coal fired plant generates a considerable amount of ash and sludge, and the disposal of the solid wastes requires additional land transformation [125].

*Natural gas:* The natural gas fuel cycle consists of extracting, purifying, transporting and storing fuels, followed by power generation. While onshore extraction requires a substantial area of land, offshore extraction needs rather insignificant areas of land but a large area of water surface. For gas transmission, a designated strip of land above the pipeline is typically barred from any sort of land development for public safety reasons. Data on energy and material usage can be taken from the description of the natural gas fuel cycle by the United States Department of Energy as a reference, and can subsequently be converted into land transformation equivalence using the Ecoinvent database [125].

*Solar:* The PV fuel cycle consists of materials acquisition, module production, operation and maintenance, and eventually material disposal. For a typical ground mounted configuration, land requirements include areas for the PV module, access, maintenance and gaps to avoid shading. Unlike conventional non-renewable technologies, solar technologies produce electricity without fuel extraction and therefore require no additional land transformation [125].

*Wind:* The land area required for wind power generation varies with the configuration and spacing of the turbines. Depending on resource availability and setting, wind turbines typically use only between 1 and 10% of the wind farm areas; the rest is utilized for grazing, agriculture or recreation [125].

*Hydroelectric:* The land area needed for generating hydroelectric power varies considerably with site specific conditions. While water reservoirs in flat areas are likely to be shallow and cover large areas, deeper and smaller dams in mountainous areas occupy less land. Run-of-the-river plants occupy a smaller area than reservoir type plants [125].

*Biomass:* Power generation from biomass is becoming more widespread in response to renewable fuel targets. Cofiring in modern coal power plants or full conversion of such plants to operate with biomass fuels are the most common forms of biomass power generation in addition to industrial cogeneration in sectors where biomass is widely available as a by-product (e.g. pulp and paper industry or sugar refineries). The required land area depends predominantly on the growth rate of biomass that in turn depends on the crop species, and the soil and climatic conditions [125].

*Nuclear:* The nuclear fuel cycle consists of mining, milling, conversion, enrichment, fabrication, production and fuel disposal. Excavation may take place underground or in open pit mines. Open pit mining is typically used where deposits are close to the surface, while underground mining is used for deep deposits, i.e. more than 120 m deep. Contrary to underground mines that require a relatively small quantity of material to be removed to access the ore, open pit mines cause fairly large surface disturbance as they require large holes on the surface, greater than the size of the ore deposit itself, in order to slope the walls of the pit and prevent collapse.

Other factors determining the extent of land transformation include the area occupied by conversion facilities, fuel fabrication plants, the NPP itself and storage facilities for radioactive waste. In countries importing uranium, the land covered by NPPs accounts for the major share of land transformation and occupation.

**(b) Measuring methods:** This indicator measures the installed capacity of a fuel life cycle across a horizontal area of land (or water) surface. Life cycle land use can be measured by calculating the land area occupied and altered from its original state by the individual processes in the fuel life cycle [125]. Characteristics of land use vary considerably across fuel cycles. Relevant data on energy and materials input can be obtained from various sources (e.g. general descriptions of fuel cycles from authorities such as ministries of energy and data on specific plants obtained from individual case studies) and processed with data from the Ecoinvent database that provides land use and occupation factors associated with various materials and energy use.

**(c) Limitations of the indicator:** Key characteristics of the impacts of power production on land use go beyond the size of the area and include duration, intensity and reversibility of change [121]. This indicator does not convey information about the mode and duration of land used, nor about the damage made to the site by energy related activities [124].

Furthermore, this indicator does not address what type of land is impacted (or its value) and does not consider the extent to which the power generation impacts other land uses. For instance, rooftop solar PV panels have a very low power density, but they do not necessarily interfere much with other uses of the land. Similarly, land between individual turbines in a wind farm can usually be cultivated. Traditional large scale power stations such as coal or nuclear plants, on the other hand, usually preclude other uses of the land.

**(d) Alternative definitions/indicators:** Instead of power density, it is possible to report annual electricity production per unit area (MW·h/$m^2$. The indicator's inverse — land use intensity of power generation — can also be used as an alternative indicator. Rather than measuring the energy intensity of land use (installed capacity per unit of land area in W/$m^2$), land use intensity measures the size of the land area occupied per unit of installed capacity ($m^2$/W).

**Assessment of data**

**(a) Data needed to compile the indicator:** In order to quantify this indicator, data on total plant installed capacities and total areas of land occupied by different stages in the fuel life cycles of generation technologies are needed.

**(b) National and international data availability:** Data on individual plant installed capacities are generally available from national energy statistics bodies and energy ministries. International sources of installed capacity data include the IEA [17, 18] and the World Bank [24]. Data on land area occupied by the entire energy chain can be obtained from the Ecoinvent database containing industrial life cycle inventory data for various sectors, including energy supply [126].

*ENV7: Water use in electricity generation*

| | |
|---|---|
| Brief definition | The amount of water withdrawn and consumed in electricity generation |
| Units | $m^3$ |
| Alternative definitions | The volume of water withdrawn per unit of electricity produced ($m^3$/kW·h), per capita ($m^3$/person) or per unit of GDP ($m^3$/national currency or US $), the volume disaggregated by type of fuel or by ownership |

**Policy relevance**

**(a) Purpose:** To measure water use by different generation technologies in the power sector.

**(b) Relevance to nuclear power development:** This indicator measures the overall water use of electricity production in an electric power network. Water use in the power sector is related to two main processes: the cooling of thermal power plants and evaporation from hydroelectric reservoirs. Water withdrawals per unit of electricity generated by coal fired and NPPs range from 70 000 to 450 000 litres per MW·h (L/MW·h), compared with between 570 and 1100 L/MW·h for combined cycle gas turbines. Water requirements for non-thermal renewables (e.g. wind or solar PV) are negligible [127].

Water use in power generation is an important indicator for nuclear power programmes because the large water requirements of current cooling technologies make NPPs particularly vulnerable to water constraints. Regions suffering from water scarcity face obvious risks but regions with ample water resources can also face constraints under extreme weather events such as droughts and heat waves as well as seasonal variation and environmental regulation. A high level of water use in power generation could be an indication of a high proportion of a country's generating capacity in thermal plants (using fresh water for cooling) and/or in hydropower (evaporation). This situation makes the power system particularly exposed to fluctuations in water availability. Hence, this indicator can be used to help assess a country's situation in terms of water availability for power generation to determine the requirements for the envisaged NPP. NPPs can be equipped with different types of cooling system with rather different water withdrawal and consumption properties. Water availability at the selected site will determine the appropriate cooling system.

**(c) Relevance to sustainable development:** Water availability is a major concern in many parts of the world and is expected to impact a growing number of people as the world population grows in size and affluence and increasingly congregates in cities. Around 1.2 billion people live in areas subject to physical water scarcity and another 500 million in regions approaching this situation [128].

The amount of total water withdrawals to support energy production was estimated at 583 billion $m^3$ in 2010, corresponding to 15% of total withdrawals. Out of this amount, 66 billion $m^3$ was consumed (evaporated) and not returned to its source. The IEA projects that between 2010 and 2035, water withdrawals for energy production will increase by 20% while consumption will rise by 85% [127].

Since the power sector is a major user of water and a sector that tends to grow in importance as an economy develops, water use in this sector is of particular concern to sustainable development. Given the importance of water availability for other uses, in particular irrigation for food production, the use of water for energy purposes can have unfavourable impacts on a range of development goals and on the sustainability of economic growth. Furthermore, large interference in water flows and thermal pollution of lakes and streams can adversely impact riparian ecosystems.

**(d) International conventions and agreements:** None.

**(e) International targets/recommended standards:** There are no explicit targets or standards for water use in the power sector. Lower levels of water withdrawals and consumption represent a lower interference in waterways and ecosystems and are therefore desirable. However, this indicator needs to be seen in relation to water availability in regions where energy installations are planned. A high rate of water use may simply indicate that water is abundantly available. If water availability is not a constraint for the power plant, then this indicator implies flexibility in choosing the cooling technology. There are certain trade-offs between water withdrawal and water consumption, and limiting the volume of water withdrawals may require cooling technologies with higher water consumption.

**(f) Links to other indicators:**

- ENE3: Electricity generation;
- ENE4: Total installed capacity;
- ENE15: Share of intermittent generation in electricity supply.

**Methodological description**

**(a) Underlying definitions and concepts:** When considering water use, it is important to distinguish between water withdrawal and water consumption. Water withdrawal represents the total amount of water diverted from rivers, lakes or pumped from groundwater. Part of this water may be returned to the environment. Water consumption, in contrast, refers to the amount of water evaporated or lost for other reasons and not returned to streams or lakes. Water withdrawn and returned is available for other uses downstream but consumed water is not.

In thermal power stations, water is withdrawn from a nearby water body to cool the plant. Where water is abundant, power plants often employ a simple once-through cooling system where the cooling water is simply passed through a heat exchanger (condenser). It cools the primary working fluid of the power station before being returned to the environment (usually the same water body from which it was taken). This type of cooling system requires high water withdrawals and therefore a plentiful water supply, but relatively little water is lost to evaporation. Alternatively, recirculating cooling systems relying on cooling towers or cooling ponds use evaporation as the main means of rejecting heat to the surroundings. These systems require less water to be withdrawn, but more water is lost to evaporation [129]. Dry cooling or hybrid systems have lower water requirements and are used in some arid regions. However, these plants are more expensive to build and use a larger fraction of the electricity they produce to operate the cooling system than the other two technologies.

(b) **Measuring methods:** The amount of water withdrawn can be metered at the point of water intake. Similarly, the amount of water returned to its source can be measured before it leaves the NPP site.

(c) **Limitations of the indicators:** This indicator does not address the nature and quality of the water source and whether water availability is a concern in the relevant country or region.

(d) **Alternative definitions/indicators:** Water withdrawal and consumption are normally recorded in terms of water use by volume. However, for comparison purposes, it might be useful to calculate the volume of water used per of unit of electricity generated ($m^3/MW \cdot h$). Additional information can be obtained by disaggregating water use according to power stations cooled by once-through, recirculating and dry cooling, or hydroelectric facilities in dam vs. run-of-the-river plants.

**Assessment of data**

(a) **Data needed to compile the indicator:** Records of the amount of water diverted from and returned to its original source by generating facilities for thermal power plants and water balances (changes in the stored water volume plus inflows minus releases) for hydropower plants.

(b) **National and international data availability:** The primary data sources are power producers using water. Data availability can be poor in many countries and regions. In some jurisdictions, power producers are required to report their water withdrawals and use to regulators. In this case, data may be available from the generating companies or the pertinent environmental authorities.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| Btu | British thermal units |
| CAB | current account balance |
| $CO_2$ | carbon dioxide |
| EIA | Energy Information Administration |
| EU | European Union |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GJ | gigajoule |
| GNP | gross national product |
| GW | gigawatt |
| GW(e) | gigawatt (electrical) |
| IEA | International Energy Agency |
| IMF | International Monetary Fund |
| kW(e) | kilowatt (electrical) |
| kW·h | kilowatt-hour |
| LCOE | levelized cost of electricity |
| LLW | low level waste |
| $m^3$ | cubic metre |
| MW | megawatt |
| MW(e) | megawatt (electrical) |
| MW·h | megawatt-hour |
| NEA | Nuclear Energy Agency |
| NEWMDB | Net Enabled Radioactive Waste Management Database |
| $NO_x$ | nitrogen oxides |
| NPDI | nuclear power development indicator |
| NPP | nuclear power plant |
| OECD | Organisation for Economic Co-operation and Development |
| PJ | petajoule |
| PM | particulate matter |
| PM10 | particulate matter with a diameter less than 10 μm |
| PM2.5 | particulate matter with a diameter less than 2.5 μm |
| PRIS | Power Reactor Information System |
| PV | photovoltaic |
| RADWASS | Radioactive Waste Safety Standards Programme |
| R&D | research and development |
| RPR | reserves to production ratio |
| SF&HLW | spent fuel and high level radioactive waste |
| SMR | small or medium sized reactor |
| $SO_x$ | sulphur oxides |
| toe | tonnes of oil equivalent |
| t U | tonnes of uranium |
| TW·h | terawatt-hour |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| W | watt |
| WEC | World Energy Council |
| WNA | World Nuclear Association |

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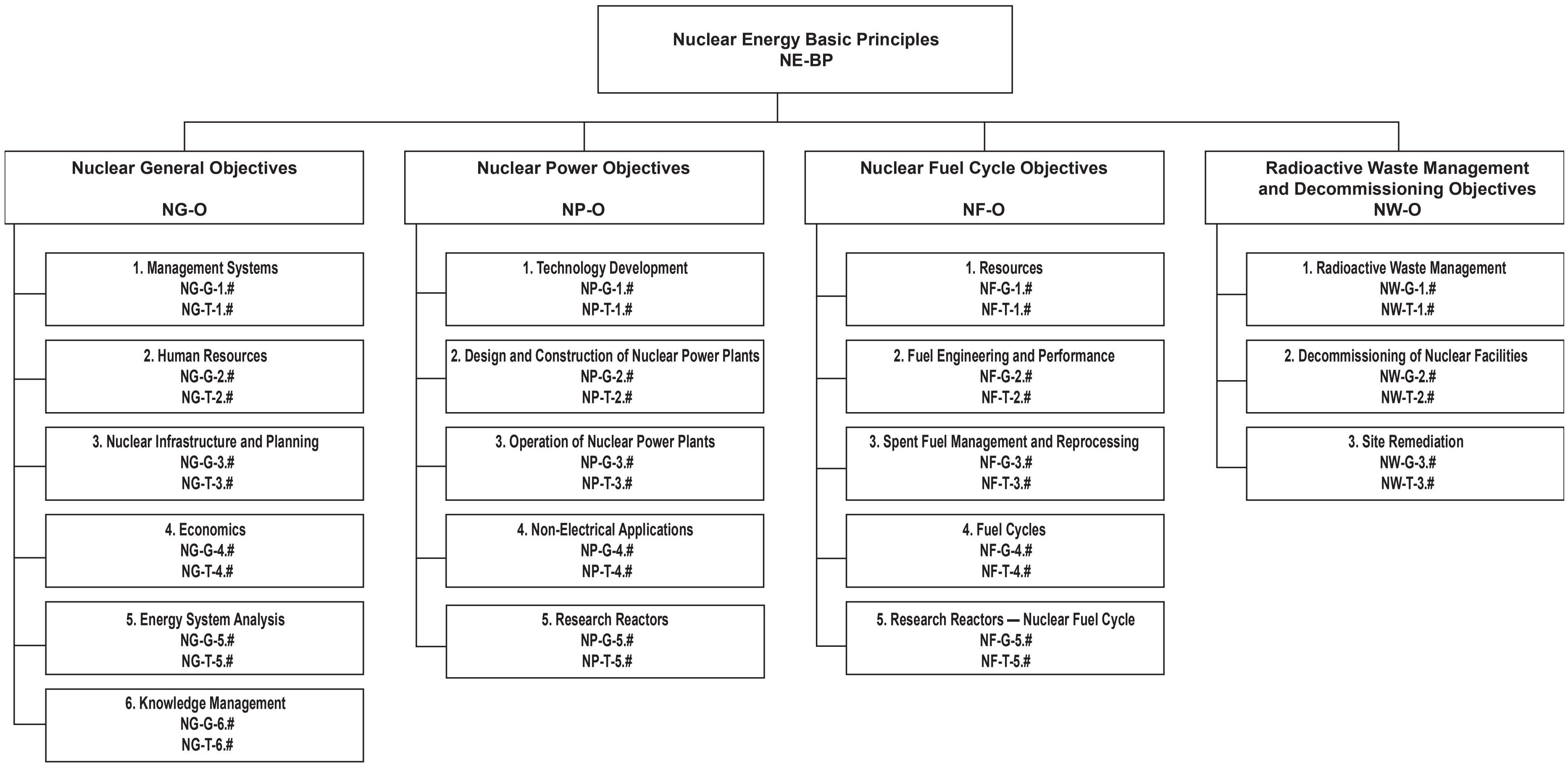
# Structure of the IAEA Nuclear Energy Series




*Key*

**BP:** Basic Principles
**O:** Objectives
**G:** Guides
**T:** Technical Reports
**Nos 1-6:** Topic designations
**#:** Guide or Report number (1, 2, 3, 4, etc.)

*Examples*

**NG-G-3.1:** Nuclear General (**NG**), Guide, Nuclear Infrastructure and Planning (topic **3**), **#1**
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