EU Socio-Economic Research on Fusion: Findings and Program

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Abstract. In 1997 the European Commission launched a Socio–Economic Research program to study under which conditions future fusion power plants may become competitive, compatible with the energy supply system and acceptable for the public. It has been shown, among others, that: 1) local communities are ready to support the construction of an experimental fusion facility, if appropriate communication and awareness campaigns are carried out; 2) since the externalities are much lower than for competitors, fusion power plants may become the major producer of base load electricity at the end of the century in Europe, if climate changes have to be mitigated, if the construction of new nuclear fission power plants continues to be constrained and if nuclear fusion power plants become commercially available in 2050. Cooperating with major international organizations, the program for next year aims to demonstrating, through technical economic programming models and global multi-regional energy environmental scenarios, that the potential global benefits of fusion power plants in the second half of the century largely outdo the RD&D costs borne in the first half to make it available. Making the public aware of such benefits through field experiences will be part of the program.

1. Introduction

Global energy consumption in 2000 have slightly exceeded 10 BToe (Billion Ton Oil Eq.; ±10%) [1]. 35% of the Total Primary Energy Supply has been used to satisfy the demand for electricity (15.4 EWh) and heat (11.8 EJ). Experts expect a growth in energy consumption of 66% to 2030 – nearly 45% to produce electricity and heat [2] - and of a factor of 4 in 2100 (40±10 BToe) [3, 4]. Energy demand projections to 2030 and 2100 are uncertain, and depend on assumptions, such as technological change, population growth, economic development, health standard, climate change mitigation, ultimate recoverable fossil resources.

Carbon dioxide emissions in 2000 from the world energy system have reached 25 GtCO2, slightly less if other calculation methods are used. According to most projection [2, 3], yearly emissions in 2030 may reach about 40 GtCO2. If emissions of CO2 from other sectors and of other major greenhouse gases (GHG) are included, the concentration of GHG is expected to grow from the present value of 370 to 450 ppm and the temperature to increase of 0.8 °C [5].

In 2100 GHG concentration and temperature will increase, with average values depending on the development of technological and economic drivers[1]. If a very rapid economic growth is associated to the use of more efficient technologies but remains fossil intensive or if economic growth and a continuous population growth is associated to a fragmented technology change (scenarios A1FI and A2 in [3]), GHG concentration reach 900 ppm CO2 equivalent and the temperature increases by 4°C. These values are reduced to about 700 ppm and 3°C if a very rapid economic growth is associated with the use of more efficient technologies balanced across all sources or if the development is oriented toward environmental sustainability and social equity, with emphasis on local and regional solutions and less rapid technological change (scenarios A1B and B2 in [3]). Only if a very rapid economic growth is associated with the use of more efficient technologies relying on non fossil fuels or if rapid changes in economic structures toward a service and information economy is are associated to reduction in material intensity and to introduction of clean and resource efficient technologies the

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[1] Projected values have an uncertainty range of the order of 30% or more, arising from some lack of definition in the very complex climate models.

concentration of GHG remains below 500 ppm and the temperature increases by about 2°C (scenarios A1T and B1 in [3]).

The cost of providing the primary fuels in 2000 has been of the order of US$T 1.5 (trillion of US dollars 2000) [1]. The additional annual cost of generating electricity and heat is of the same order of magnitude [6]. If annual costs of transmission and distribution are added, the total cost of providing economic producers and consumers with the amount of energy demanded is of the order of 10% of the global GDP, which in 2000 amounted to US$T 37.

The economic value of energy markets is expected to grow for several reasons: the quantities are going to increase although more in developing countries, the average unit supply cost of base resources should increase with the resort to unconventional fossil resources although extraction techniques could improve, the cost of supply and demand technologies should increase to comply with higher environmental standards, eventually the average price of energy should increase because the share of electricity is projected to increase. On the other side, the cost of energy cannot grow too much: as shown by previous oil shocks, a fraction of GDP much high than 10% hinder economic development.

According to most scenarios, an extrapolation of the present makes the system unsustainable. The combination of projected demographic paths and economic growth looks infeasible from the point of view of energy resources and climate, unless the technology mix changes. What economic resources are allocated to research and to make this technological change happen? The amount of R&D budget – totalling about US$B 600 [7] – that is devoted to energy has remained stable in the last decade around US$B 10[2] [8]. While the R&D effort is about 1.5 – 2% of the global GDP, the energy R&D is only about 0.3% of the value of the energy system[3]. This percentage is not higher in industry. The international industry in software & IT, health, pharmaceuticals spend in R&D more than 10% of their sales, oil & gas industries less than 1%, as beverages and tobacco industries [10]. Only 1.5% of the venture capital investments in 1998 – nearly US$B 40 – has been used by energy industries.

Why is the level of R&D investments inadequate to the needs and comparable to industries with limited innovation aspiration? Technical, economic and social reasons may provide some explanations. Energy R&D has been active for thirty years now, at a much higher level in the aftermath of oil shocks, without finding “the technological solution”. Given the scientific and technical complexity of the energy problems, perspectives of a real breakthroughs in the near future are limited. Potential developers of new technologies are discouraged also from the economic point of view. Unlike innovative sectors, where economic benefits are linked to new markets, success in the huge existing energy markets implies the displacement of giant corporations, that are ready to use all their resources to resist changes. The long time horizon of the problem weakens the social attention. While stake holders tend to be heedless, decision makers continue to allocate available resources to more urgent problem with quicker returns.

In order to maintain and possibly increase its investments in energy R&D, especially in a field with a long time horizon such as fusion [11], the European Union, launched in 1997 a Socio – Economic Research on Fusion (SERF). The program intends to provide the fusion community with a better understanding of the external conditions under which fusion power plants, once available, may become economically attractive and socially acceptable [12]. Five research

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[2] The global value is slightly higher because some countries report only governmental R&D expenditures. However private R&D funds are mostly restricted to improve commercial products, without real innovation.

[3] About 50% of energy R&D goes to nuclear, and includes around US$B 1-1.5 for fusion [9].

lines have been experimented along the years, each one using different methods: direct production cost, externalities, public attitude, ITER site studies, energy technologies systems analysis[4]. The program is developed by independent experts, making use of well established international methodologies. The budget has been around 1 M€ each years. In 6 years, the total budget has been split as follows: 27% to externalities, 23% to social studies, 23% to socio-economic ITER site studies, 17% to systems analysis and 9% to direct costs.

2. Findings

Projecting direct production cost 50 years from now is highly speculative, not only for fusion. A bottom-up approach to the costing has been developed, based on a mathematical model (PROCESS) of the engineering, physics and costing of a commercial fusion power station. For each combination of assumptions on the about eighty systems into which the plant is divided, and on general parameters, such as interest rate and assumption on availability, the total capital cost including interest during construction, the replacement costs, other operating costs payments into a decommissioning fund are combined to obtain a "levelised cost" of electricity with standard OECD methodology. If commercial power plants will be available in the second half of this century, their production cost may range from 70 to 130 mills of $1996 per kWh [13], values which are not far from other evaluation [6]. Only a few conclusions seem possible: the cost of electricity is highly uncertain, in the long term its unit level is going to increase if the environment is going to be protected, the order of magnitude of fusion base load electricity is comparable to alternatives with the same level of impact.

External costs of future fusion electricity are in the order of a few mills per kWh, twice less than present nuclear fission electricity, five to ten times less than oil and gas thermal electricity, nearly twenty times less than coal electricity [14]. The evaluation has use the ExternE methodology, previously developed for the European Commission. However, the conversion to economic values of different damages is highly uncertain and dependent on the assumptions. For instance, the economic discounting mechanism makes negligible the costs of activities taking place far in the future, such as long life nuclear waste disposal and storage.

Theoretical social studies on fusion as a large technical system highlighted the difficult interplay between public discourse and policy making – the issue of "governance" – in such megascience projects and globalized research. The main characteristics of this research enterprise – long time horizon, broad international coordination and dependence on large facilities – seem applicable to energy technologies systems at large [15]. Experimental studies have measured the status of public opinion on fusion related activities making use of the focus group technique. In Germany a strong preference was given to renewables and the funding of associated research, although all groups agreed that fusion research should be upheld at least until the feasibility of a power plant is proven.

Extremely interesting have been the experimental studies on local populations where the construction of ITER has been proposed. Around Cadarache, the focus group technique is being used by a mixed French Belgian Swiss team [16]. When in 1997 the Italian government was considering the idea of hosting ITER, the reaction of a local community (Porto Torres, Sardinia, Italy) has been studied experimentally. The study was based on the "European Awareness Scenario Workshop" methodology, previously developed under the auspices of the European Commission to promote the citizen's participation in collective decisions

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[4] The budget has been 1 M€ per year for 6 years, divided as follows: 27% to externalities, 23% to social studies, 23% to socio-economic ITER site studies, 17% to systems analysis and 9% to direct costs.

concerning technologies. At the beginning it has been very difficult to talk about nuclear fusion with the local population or its representatives – it is well known the nuclear fission is not an option in Italy, after a referendum stopped the small domestic nuclear program in 1987. At the end of the awareness process all the local participants came to a favourable conclusion concerning the construction of ITER in their community. This social research shows that a local community can participate in a positive way in decision making processes concerning its territory and that an effective participation process must include the local dimension [17].

In order to explore the possible share of the electricity market of fusion within the 21st century, European energy scenarios studies have been undertaken, where optimal system cost replace the concept of direct costs. Making use of the technical economic MARKAL model generator [18], the development to the year 2100 of the European energy technologies system has been represented. More than 300 end use technologies have been used, more than 100 conversion technologies. The MARKAL studies showed that the market role of fusion will depend on the implementation of pollution reduction policies [19]. In the unconstrained cases fusion and renewables cannot compete with coal. Fusion starts entering the picture for target CO_2 concentration below 650 ppm. For target concentration below 550 – 450 ppm, the installation of fusion power reaches a predefined upper limit. Renewables and fusion power grow approximately in parallel, with little direct competition between them due to their different role as intermittent and base load power sources.

Making use of the same MARKAL model generator, a model for such a rapid developing country as India has been built [20]. In unconstrained cases, the eightfold growth in 70 years of electric demand would be supplied mainly by coal and later by natural gas, although to a lower degree. If India starts mitigating in 2025, and cooperates to reach a stabilisation level at 550 ppm, at the end of the century fusion might capture 10% of the electric market and contribute with 5% to the integral of CO2 emission reduction – which is evaluated around 50 BtC if the emissions are reduced from 1,7 to 1 BtC/y.

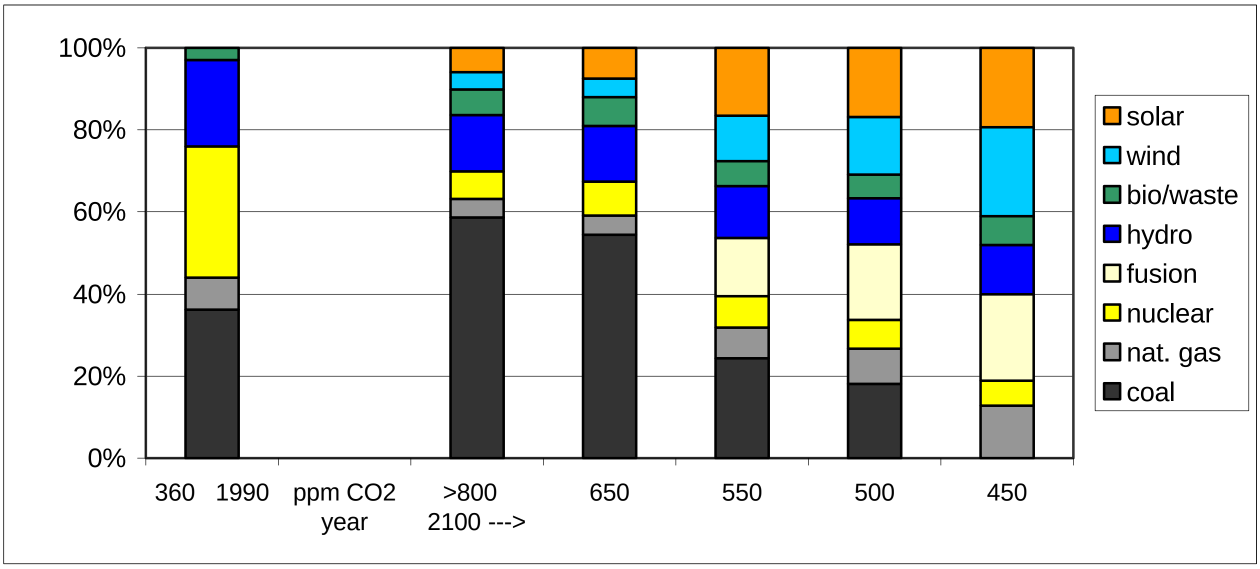

Fig. 1. Power generation by source in 2100: possible CO2 mitigation scenarios in Western Europe (adapted from [3]; in CO2 constrained scenarios more carbon free electricity is supplied to replace some direct uses of fossil fuels in end use sectors)

3. Program

The SERF program has been extended to the 6th EC Framework Research Program, with a budget comparable to the previous years. In the next phase the program aims to demonstrate, through technical economic programming models and global multi-regional energy environmental scenarios, that the potential global benefits of fusion power plants in the second half of the century largely outdo the RD&D costs borne in the first half to make it available. Making the public aware of such benefits through field experiences and asking people what energy system is acceptable will be part of the program. The program is open to the cooperation of major international energy and environmental organization.

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