# Economic and Environmental Performance of Future Fusion Plants in Comparison

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## Abstract:

If the good performance of fusion as technology with no $CO_2$ emission during normal operation and rather low external costs, reflecting the advantageous environmental and safety characteristics, are considered in future energy regulations, fusion can win considerable market shares in future electricity markets.

The economic performance was elaborated for Western Europe for the time period till 2100. The software tool MARKAL widely used in energy research was used to simulate and optimise the development of the Western European energy system. Two different scenarios were considered, the main difference was the interest rate for investments. Stringent $CO_2$-emission strategies lead to considerable market shares for fusion.

As a comprehensive indicator of the environmental and safety performance of fusion plants the external costs following the ExternE method was used. External costs of fusion are rather low, much below the cost of electricity, and are in the same range as photovoltaics and wind energy.

## 1. Introduction

Economic and environmental performance will determine the success - measured in market penetration - of future fusion plants. Although fusion is still a subject of R&D, analysis of economic and environmental performance can give helpful arguments in steering future R&D activities and can be used as basis for political decisions in the field of energy research. Overall the political sphere demands the clarification of the role of fusion in the future energy system [1].

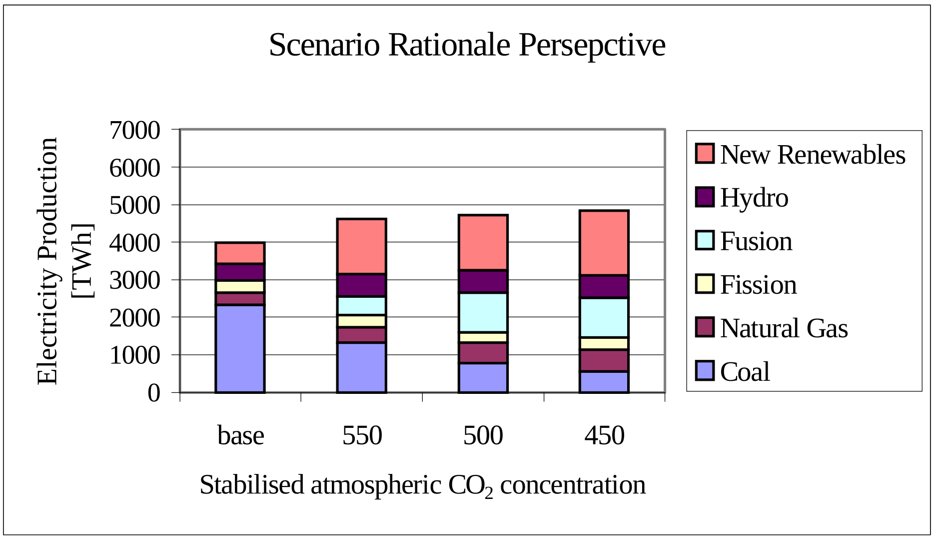
In the framework of the Socio-Economic Research on Fusion (SERF) which was jointly conducted by the European Commission and the Fusion Associations several economic and social questions concerning the future of fusion as a power source were addressed. A first SERF activity ended in 1999, a new set of activities was launched at the beginning of this year. Results from both phases are presented.

## 2. Economic Performance

Economic performance in terms of investment cost and cost of electricity has been the subject of numerous studies [2]. The outcome of these studies can only be understood in the context of a certain energy economy. "Simulation" of future energy economies can be carried out with the help of scenarios.

A very detailed "simulation" of the energy market in Western-Europe was the basis of the first analysis presented [3], which was performed with the software tool MARKAL [3]. Scenarios were made for Western Europe up to the year 2100. Two different scenarios were investigated, the scenarios mainly differed in the value for the interest rate. For both scenarios several sub cases, assuming different greenhouse gas mitigation strategies, were discussed. In general it was assumed that Western Europe will be allowed to make 10 % of the global $CO_2$-emissions.

**Figure 1: Share of the Western European electricity market in the year 2100.**



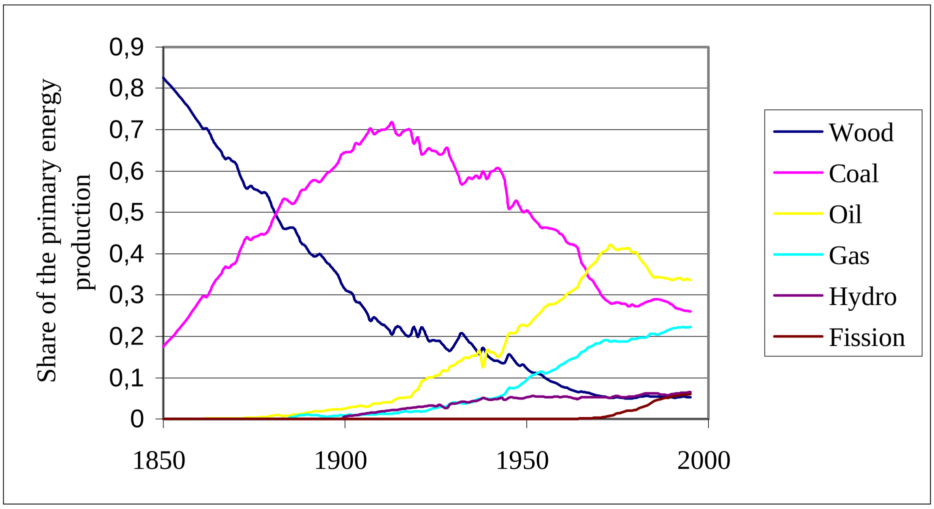

The results are presented in figure 1. Fusion only enters the electricity market, if stringent greenhouse gas mitigation strategies constrain the further development. A second important assumption is that fission is phased out after 2100 and the capacity of fission should not exceed the currently installed capacity, although relaxing this constraint to allow an increase of fission by 60 % still allowed the introduction of fusion.

Beside this rather refined study two more arguments for fusion to win considerable market shares in this century should be mentioned:

The first argument is based on the expected increase in energy demand. Most scenarios expect a definite increase in energy demand in this century and an even larger increase in the electricity demand. These increase will last for the complete century. As a prominent example the study "Global Energy Perspective" [4] elaborated by the Institute of Applied System Analysis (IIASA) and the World Energy Council (WEC) should be mentioned. Three different scenarios were worked out which did differ in the overall global economic performance and in the attention given to environmental concerns. But even in the scenarios in which a global co-operation regarding environmental concerns is assumed, the global electricity demand will rise by a factor four by 2100.

The second argument underlines the inertia of the global energy system. Figure 2 shows the development of the global primary energy carriers in the last 150 years. A period of more than fifty years is necessary for a new energy carrier to reach a considerable market share. If the current development is extrapolated, natural gas will be the most prominent primary energy carrier in the first half of this century. If fusion is available by 2050 it could provide along with others - especially renewable energy conversion technologies - the replacement for gas and of course for the remaining share of coal.

**Figure 2: Share of different primary energy carriers in the last 150 years in the global energy system. The period before a energy technology wins a considerable market share is roughly 50 years.**



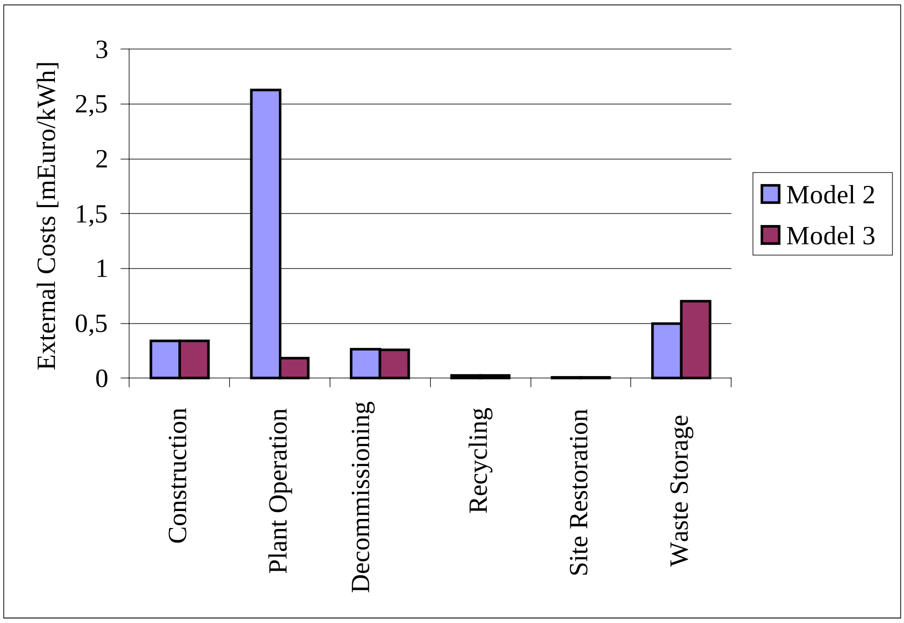

3. Environmental Performance

The introduction of fusion power may depend on the introduction of regulatory measures which punish environmental damages caused by energy conversion techniques. All the damages, which are not reflected in the market price, are called external costs. Externalities or external costs related to energy production are in general defined as costs imposed to society that are not accounted for by the producers or consumers of energy, e.g. public health, agriculture, ecosystems, etc are affected by environmental effects of energy production. The external costs are a scale which allows for the comparison of very different technologies under environmental considerations.

The methodology used for the assessment of the environmental external impacts of the fusion fuel cycle is the one developed within the ExternE project [5]. The method used is a bottom up, site specific and marginal approach, i.e. it considers extra effects due to a new activity at a studied site. Quantification of impacts is achieved through damage functions or impact pathway analysis. The whole fuel and life cycle of the plant is considered.

The plant under investigation is sited at Lauffen in Germany at the river Neckar. Three different fusion plant models are considered. Most characteristics of these models are copied from the European safety study SEAFP and SEAFP II. The models differ considerably in the technology used. The first model uses advanced technology like vanadium alloys as structural material and helium as coolant, while the second model utilises more state of the art technology like low activation martensitic steels as structural materials and water as coolant. The third model has a helium cooled blanket and martensitic steel as structural material. The parts of the plant not included in the above mentioned study are taken from the ITER design and from data of a fission plant.

**Figure 3: External costs of fusion, the results are for the different Life Cycle stages are shown for two plant models [7]. A detailed analysis of the uncertainty is under way.**




The results (Figure 3) indicate that external costs of fusion do not exceed the ones of renewable energy sources. A major factor in the external costs of plant model 2 are the $^{14}C$ isotopes released during normal operation which enter the world wide carbon cycle. Nevertheless, the individual doses related to theses emissions are orders of magnitude below the natural background radiation. For all models a considerable fraction of the external costs is due to material manufacturing, occupational accidents during construction and decommissioning.

**Figure 4: External costs for different electricity sources. The result is split in costs due to $CO_2$-emissions and in other , including all the other effects like sulphur emissions or occupational accidents. For reasons of consistency here the value for fusion is taken from [6].**

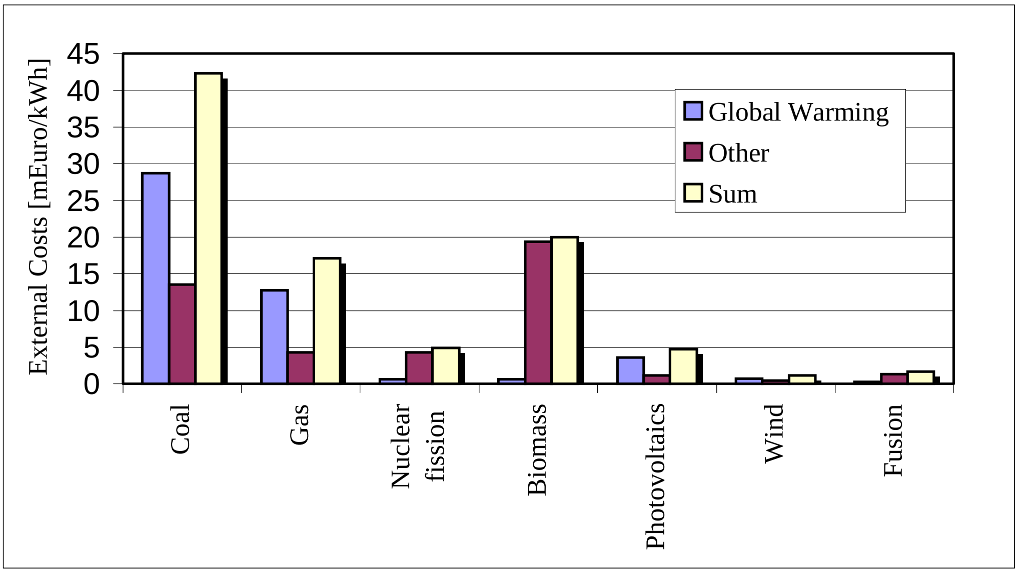


Figure 4 shows a comparison of the external costs of fusion with those of other major electricity sources. The external costs of fusion are rather low and compare well with those of wind and solar, which may play a major role in future energy systems.

## 4. Conclusion

The results indicate that fusion as a technology with high investment cost can hardly compete even in the long term with coal-fired power plants as long as the environmental harms due to coal are not included. If greenhouse gas emissions are constrained, fusion can win certain market shares. The same is true in comparison to conventional fission. Only if the capacity of fission is constrained will fusion win a large market share.

Fusion - as evaluated in the above studies - will only play an increasing role in the electricity markets of this century, if more strict safety and environmental standards are applied to electricity conversion technologies. The high environmental and safety standards of fusion - reflected in its rather low external costs - make fusion in a mix with renewable energies one of the most promising future electricity sources.

## Literature: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