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A global energy model with fusion

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Abstract

Some analysts expect a complete shift of the global energy system in the 21st century, away from fossil fuels to either renewable sources or new nuclear technologies [L. Schrattenholzer, A roadmap to a sustainable global energy system, in: Proceedings of the International Energy Workshop, Paris, June, 2004]. Fusion might become a corner stone of the future energy system. The construction and successful operation of ITER is a necessary condition to reach this goal. Within the Socio Economic Research on Fusion (SERF) programme guided by EFDA, a consortium between CIEMAT, TU Graz (TUG), ENEA and IPP open to other European energy and fusion research laboratories has been formed to analyse the possible role of fusion in the future energy system. Using TIMES, a single region global model has been constructed including fusion as an energy option. Background of the model is a detailed bottom-up description of the complete energy system starting from mining process up to the various demand sectors. The model dynamics is determined by an optimisation process, in which total surplus is maximized. The paper will present the first attempts to set-up a single region global model and the first results.

Keywords: Fusion; Energy models; SERF

1. Introduction

Views on the development of the global energy system in the 21st century diverge among analysts. Some groups expect a complete shift away from fossil fuels to either renewable sources or new nuclear technologies [1]; others foresee that carbon fuels will dominate the 21st Century's global energy economy [2]. The rational behind the shift are numerous: resource depletion, environmental concerns, especially global warming and unacceptable geo-political frictions. Fusion might become a serious option for the future energy system. The construction and successful operation of ITER and the successful qualification of materials for future fusion plants are necessary conditions to reach this goal.

The possibilities of fusion to enter into the energy market are determined by several conditions among

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which are its technical feasibility, safety, social acceptance, economic competitiveness and environmental sustainability. The ITER construction will bring up numerous answers to these questions about the role of fusion in the future energy system. In addition, the EU launched Socio Economic Research on Fusion (SERF) to further investigate some of these questions in close cooperation with other research programmes, such as Power Plant Conceptual Study, Safety and Environmental Studies and Public Information.

One of the objectives of SERF activities [3] is to carry out scenario analysis using long-term energy models in order to investigate the market of fusion under different conditions and constraints. A simple single region global energy model is now running and some results are presented in this paper. Additionally, an industrial contract has been granted to an external contractor to develop a long-term, multi-regional global energy model. This model will be provided to the interested Associations in order to run common EFDA scenarios. Using this model, possible economic benefits of fusion in different energy environment scenarios could be analysed and some conditions under which fusion is preferable to other energy options could be identified.

2. The TIMES model generator

The integrated MARKAL-EFOM System (TIMES) is the latest model generator developed, distributed and maintained by the Energy Technology System Analysis Project (ETSAP), an implementing agreement of the International Energy Agency (IEA). It is the successor of the MARKAL model and it is offering increased flexibility and advanced features [4].

TIMES generates dynamic partial equilibrium models of the energy sector of the economy. In the solution of a TIMES model, the quantities and prices of the various commodities of the energy system are in equilibrium, i.e. their prices and quantities in each time period are such that at those prices the suppliers produce exactly the quantities demanded by the consumers. This equilibrium is present at every stage of the energy system from primary energy forms to final energy demands. TIMES offers the feature to make energy demands price sensitive, by assigning elasticities to them. The demands can thus self-adjust within a certain bandwidth endogenously within the model, allowing a bona fide supply–demand equilibrium. Due to elastic demands, the energy model has the chance to balance welfare losses caused by a more expensive electricity mix with welfare losses caused by demand reductions, leading to an optimal distribution of the two with respect to the net total surplus of the system.

In a TIMES model, energy technologies are explicitly modelled in detail in terms of technological and economic data, which is a bottom-up description of the energy system. The scope of TIMES models is beyond purely energy related issues. The representation of materials and environmental emissions related to the energy system is possible. Thanks to the explicitness of the representation of technologies and fuels, a TIMES model can be constructed to analyse energy-environmental policies.

The energy system in a TIMES model is depicted by flows of energy carriers through energy technologies, modelled by the concept of a Reference Energy System (RES). Energy, material flows and emissions are described by commodities, which are transformed by processes into each other. In this way, the whole path from primary energy to final energy or even energy services can be modelled.

3. The TUG–IPP one region TIMES world model

The TUG–IPP TIMES model is a simple one region global model. Only the demand sector is divided in OECD and non-OECD countries. The purpose of the model is to analyse, in a coarse way, the impacts of major developments: resource availability, overall global demand development and especially carbon mitigation scenarios. These issues can only be discussed with a global model.

All major energy demand and supply sectors are covered in the model. The end-use energy sector is described very schematically to keep the model simple. The model is not driven by a consistent macroeconomic model which translates economic development to the demand of special energy services, but actually by final energy demands only. At present, the demand data are extracted from the IIASA-WEC B scenario [5] combined with additional simple estimates. This will be changed in the future to a more consistent picture, where the demands for energy services derive from macro-economic assumptions whose consistency will be checked by means of an exogenous economic model.

Most emphasis is put on the analysis of the electricity sector. The question of load patterns is at the moment dealt with in a simplified way. The actual electricity demand is split in a base load and a peak load part. In a first approximation, it was assumed that the peak load demand is 20% of the actual electricity demand in each model period. The whole issue of load patterns needs certainly a strong revision especially when a large fraction of renewable technologies is applied.

A database giving technical and economic information on the resources and the conversion technologies was developed.

4. First results with the TUG–IPP world model

The central question of the analysis is to identify the circumstances, which make fusion a competitive technology once fully developed. The question was addressed before by other studies [6–8]. The studies performed within the Socio Economic Studies of Fusion (SERF) showed that especially the limitation of carbon emissions and the restriction of conventional fission opened the chance for fusion to gain market shares at the regional and national level [6,9]. The special task here is to emphasise the global aspect.

The baseline scenario is based on the energy projections of the IIASA-WEC Scenario B. It includes resource constraints on fossil fuels and uranium, and the potential of wind and solar power is limited to 20% of the generated electricity. Three other scenarios have been explored:

- The CO_2 constraint scenario, in which the cumulative emissions are constrained to those producing a concentration of 550 ppm.
- The CO_2 constraint scenario with a high renewable potential; it is the same scenario as the first one but in this one the constraints for wind and solar electricity production are removed allowing these technologies to produce up to 50% of the generated electricity.
- The high resource availability scenario, in which the uranium and fossil fuel resources are considered to be a 200% of the base case.

The results for the electricity sector are depicted in Fig. 1. In the baseline scenario fusion has no chance to enter into the electricity market. At the end of the century, the electricity production is still dominated by fossil fuels and nuclear fission with only a small contribution of renewable sources.

When CO_2 emission constraints are included, coal and gas based technologies reduce their contribution to electricity generation dramatically and solar technologies and fusion appear in the market from 2050 onwards.

The high resource availability scenario has the effect of increasing the nuclear fission contribution, which in the base line scenario almost disappears at the end of the century due to the depletion of the resource.

When a high potential for wind and solar electricity production is included in the CO_2 constraint scenario, fusion does not enter into the market in a significant proportion but its contribution is covered by wind and solar technologies.

As a first conclusion, it can be said that fusion would penetrate into the electricity market, if the emission of carbon is restricted, if fusion becomes the most reliable supplement of fission when uranium resources deplete and if fusion base load capabilities supplement electricity produced by intermittent renewable sources, such as solar and wind.

5. Outlook: the EFDA multi-regional model

More in depth analyses and informative results will be obtained making use of the new long-term multi-regional global EFDA-TIMES energy model [10]. The model covers a time span from 2000 to 2100 and the world is disaggregated into 15 regions. The projections of the economic drivers (GDP, sectoral growth rates, population) are computed in a consistent way by the macroeconomic framework GEM-E3 [11]. These projections are linked via elasticities to the different energy service demands of the model, generating the corresponding demand time series. For technical progress, past trends are the base for the assumed evolution.

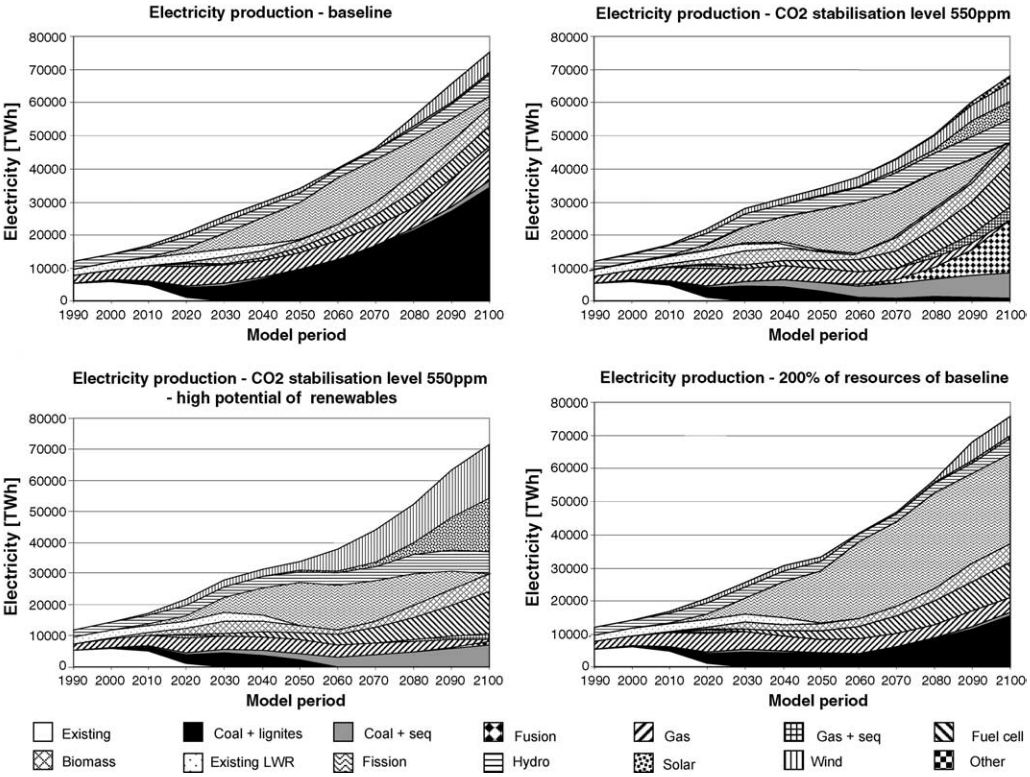

Fig. 1. The development of the electricity production in the studied scenarios.

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