A global energy model with fusion

Yolanda Lechon a,*, H. Cabal a, M. Varela b, R. Saez b, C. Eherer b, M. Baumann b, J. Düweke c, T. Hamacher c, G.C. Tosato d

a CIEMAT, Avda Complutense 22, 28040 Madrid, Spain
b TUG/ITP, Petersgasse 16, 8010 Graz, Austria
c IPP, Boltzmannstr. 2, D-85748 Garching bei Muenchen, Germany
d EFDA Close Support Unit, Boltzmannstr. 2, D-85748 Garching bei Muenchen, Germany

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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 [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.

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
which are its technical feasibility, safety, social accept-
tance, 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 Environ-
mental 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 exter-
nal 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 bene-
fits 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 equilib-
rium. 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 explic-
itly 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 representa-
tion of materials and environmental emissions related
to the energy system is possible. Thanks to the explic-
itness 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 Sys-
tem (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 mit-
igation 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 macroeco-
nomic 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 CO₂ constraint scenario, in which the cumulative emissions are constrained to those producing a concentration of 550 ppm.
- The CO₂ 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 CO₂ 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 CO₂ 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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References