FINAL REPORT –
DEMAND GROWTH IMPACT

Impact of demand growth assumptions in fusion share

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1 Introduction

A survey on impacts triggered by varying demand growth rates on the potential fusion share in the future energy system has been elaborated. As part of the dissemination activities within SERF this analysis feeds into a scientific journal publication.

The future development of the global energy system is a high ranked topic in the scientific debate. New technologies may enter the market and influence the global system development. On the other hand the market entrance of new technologies is also highly depending on market circumstances and competitive developments. To figure out such relations especially with regard to a possible market entrance of fusion power in future is the task of the Socio Economic Research on Fusion (SERF) program launched by the EU. Since fusion power is considered a serious option in the global future energy system it is of interest which market shares can be reached by fusion power in dependency of various impact parameters.

The EFDA TIMES model (zitat) has been utilized to elaborate scenarios on the development of the future technology shares in the power sector for a base and a high demand growth assumption. The model is a bottom-up global long term partial equilibrium model of the entire energy system (Hamacher). It distinguishes 16 world regions (see figure 1) which are connected via trade processes.

![Figure 1.1 ETM regionalisation of the globe.](image)

It is realized in the integrated MARKAL-EFOM system (TIMES) provided by IEA-ETSAP. Similar global multi-regional MARKAL-TIMES models have been used for the preparation of other important long term energy technology evaluation studies as well [IEA 2008, IEA 2010, Loulou 2009].

The model dynamics is determined by a maximization of total economic surplus (which - if demands are not price elastic - is equivalent to a minimization of overall costs). Underlying assumptions require the hypotheses that energy markets are competitive and economic agents have perfect information and perfect foresight, optimizing their decisions along the entire time horizon.

The maximization of the objective function is realized by the TIMES model generator using linear programming techniques. Linearity implies that each technology may be implemented at any level without economies of scale between inputs and outputs. Supply curves are a stepped sequence of linear functions that can be approximated by a non linear interpolation.

The global energy system development is build up for the time horizon from 2000 to 2100. The reference energy system includes five energy consumption sectors (residential, commercial, agriculture, industrial and transportation) and two energy supply sectors (electricity production and upstream/downstream). Industry is further divided into 6 energy intensive subsectors. Technologies considered in the EFDA TIMES model are divided into demand technologies, transformation technologies, extraction/import technologies. Technologies working at the base year are
distinguished from those available in future. Technologies are characterized by a number of parameters that can be classified as:

- Technical parameters (efficiency, technical lifetime, installed capacity and relative bounds, input and output commodities);
- Environmental Parameters (emission factor for the main pollutants CO2, CH4, N2O, SOx).
- Economic parameters (Investment costs, O&M costs, sectoral hurdle rates, constraints to technology penetration).

Therefore the model setup enables the investigation in the overall system development and possible impacts triggered by varying assumptions. It allows for the outline of causal relations. One impact parameter in that context is the possible development of the energy demand in future. In the current study the influence of different assumptions regarding the future energy demand development on a possible market share of fusion power in future is investigated. The multi-regional model approach of the EFDA TIMES model outlines regional specific scenario results which trigger the global market share of fusion power. Therefore demand growth assumptions are investigated under different energy policy constraints in terms of a possible impact on the market share of fusion power in the global future power sector.

## 2 Demand scenarios

The EFDA TIMES model is mainly driven by demand for energy services in the different sectors of final energy demand. Therefore demand scenarios are defined, which consist of a set of annual energy demands for energy services for each EFDA region and all periods within the time horizon to the year 2100. For the development of the demand scenarios a set of socio-economic drivers is defined (Table 1) and each demand category of energy services is assigned to one driver. The five demand sectors Agriculture, Commercial sector, Industrial Sector, Residential sector and Transportation sector are described by specific demand categories. For details on the demand categories in the different sectors of final energy demand and the assignment of the drivers see [ORDECSYS et al. 2004]. For each driver and time step projections are computed within the time horizon of the year 2100. For each demand category, elasticities to the associated driver are defined, which describe the strength of the coupling between driver and demand. The relationship between a demand and its driver is described as follows:

\[
\text{demand}(d, r, t) = \text{driver}(d, r, t)^{elasticity}\]

Table 1 Drivers for demand scenarios (ORDECSYS et al.)

<table>
<thead>
<tr>
<th>Drivers</th>
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<tbody>
<tr>
<td>GDP growth rate</td>
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<tr>
<td>Population growth rate</td>
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<tr>
<td>Household growth rate</td>
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<tr>
<td>Agricultural production growth rate</td>
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<td>GDP per capita growth rate</td>
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<td>Growth rates of sectoral production in 3 industrial sectors:</td>
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<td>- Energy intensive industries</td>
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<td>- Other industries</td>
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<td>- Services</td>
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Two demand scenarios are investigated in this work with demand as the main driver of future energy system setups, a “Low Growth Demand Scenario” and a “High Growth Demand Scenario”. The set of drivers for both Demand Scenarios have been elaborated using the Gtap model (General Trade Analyses Programme) [see Martini, Tommasino 2011] during EFDA SERF studies. In the Low Growth Demand Scenario total final energy demand rises to 743 EJ in 2100 and 1.137 EJ in the High Growth Demand Scenario respectively (Figure 1). The industrial sector has the greatest share of total demand in both scenarios with 44% in the Low Growth Scenario and 42% in the High Growth Scenario, also showing the highest rates of increase until 2100. The demands in the agricultural, commercial and residential sectors only show a slight increase from 2050 onwards in both scenarios.

![Figure 1 Development of total demand until 2100 in the different sectors](image)

On the regional level China shows the highest growth rates with a demand up to 200 EJ in 2100 in the High growth demand scenario, and especially the demand for industrial services increases from 24,6 EJ in 2050 to 90 EJ in 2100 for the Low Growth and 42 EJ to 108 EJ in the High Growth Scenario (Figure 2).
3 Energy system forecast scenarios

The demand development is seen as the main driver of the setup of the future energy system and to which extent technologies are applied. The present study analyses the correlation between demand growth assumptions and related market shares of fusion using three different policy scenario constraints. A “no climate policy” scenario, a “$CO_2-Tax$” scenario and a “550 ppm” scenario are applied. The scenarios show the possible evolution of the future energy system.

In the “no climate policy” scenario no restrictions in regard to $CO_2$ emissions are assumed. There is neither a threshold fixed for emissions nor is the emission of $CO_2$ burdened with any kind of tax in neither region. This scenario assumption implies that currently existing emission trade and tax systems as well as climate agreements are abolished and can be considered as a development that outlines one extreme cornerstone of the possible future energy system.

Climate change mitigation scenarios are presented by the $CO_2$-tax Scenarios and the 550 ppm Scenario. In the $CO_2$-tax scenarios $CO_2$ emitting processes are burdened with a tax related to their $CO_2$ emissions in the range from 0$\$/tonne in 2000 up to 50$\$/tonne in 2100 for the world regions AUS, CAN, WEU, JPN and USA and 25$\$/tonne for the rest of the regions. This $CO_2$ tax shifts the market equilibrium towards less emission intensive technologies. Therefore technologies with no and low emissions gain a higher
market share in these scenarios. The 550 ppm scenario aims at the long term stabilization of atmospheric CO2-equivalent concentrations at 550 ppm. Therefore a threshold for overall global CO2-emission is defined starting at 23Gt/a in 2005, peaking in 2030 at 33Gt/a and going down to 20Gt/a in 2100. In this scenario no additional taxes are assumed.

The total demand is defined in the both scenarios Low Demand Growth and High Demand Growth as described in chapter 1. As the role of fusion power in future energy systems and the correlation with changing energy demand is in the center of interest in this study the scenarios are analyzed with a focus on the power sector.

![Figure 3 Share of energy carriers in the power sector in the three scenarios for low and high demand growth](image)

In the analysis of power sector it appears that the power sector growth by more than a factor of 2 between 2050 and 2100 – for the High Demand Growth Scenario as well as for the Low Demand
Growth Scenario. This implies a shift towards electricity for the satisfaction of energy services with increasing demand (Figure 3). In the “No Policy” Scenario the power sector is dominated by coal for both demand scenarios, with around 50% in 2050 and 65% in 2100. Fission phases out completely until 2080 for both demand scenarios while fusion enters the power sector in 2070 first with a share of 1% and going up to 9% and 15% for the low demand growth scenario and the high demand growth scenario respectively. Fusion power gains more importance in the Tax and 550 ppm scenario from 2070 onwards. In the Tax Scenario fusion enters the system with a share of 2% for both demand scenarios in 2070. In 2090 the share of fusion is already at 20% (low demand growth scenario) and 19% (high demand growth scenario) and rises up to 33% and 35% respectively in 2100. Fission has a quite high share in this scenario with a peak in 2080 of 27% and 22% in the High Demand Growth and the Low Demand Growth Scenario respectively. In 2090 and 2100 parts of fission are substituted by fusion. In the “550 ppm” scenario based on the high demand growth scenario the power sector is mainly dependent on fission with a share of 35% in 2050, peaking in 38% in 2070. From 2080 on the role of fission declines to 16% in 2100 and fusion gets a higher share of the power sector (35% in 2100). The 550 ppm scenario based on the reaches a share of fusion in 2100 of 33%. As oil will only play a marginal role in the power sector from 2050 onwards and therefore is not included in the graphical overview.

Figure 4 shows the development of fusion power in the energy system for the three scenarios and the variances if based on the low demand growth scenario and the high demand growth scenario. In the No policy scenario the share of fusion is lowest. While for the policy scenarios the share of fusion power in 2100 ranges between 30% and 40% in the no policy scenario only a share of 15% is reached. The difference for fusion use in this scenario for high and low demand growth is 6% in 2100. In the 550 ppm scenario the difference lies at 8%. The lowest difference can be found in the tax scenario with only 2% in 2100.

In relative numbers the sensibility on varying demand growth assumptions is highest in the No policy scenario. Compared to the absolute share of fusion power in 2100 laying at 15% for the high demand growth and at 9% for the low demand growth scenario the relative deviation of fusion power share in the system is highest.
A further aspect is the fact that spreading of the fusion power share in 2100 between the low and high demand growth assumption for the 550 ppm scenario is higher than for the Tax scenario. It is triggered by the fact that in the 550 ppm scenario a higher shift towards the power sector in the overall energy demand can be observed (see figure 3).

The share of fusion power is also analyzed in terms of regional distribution (Figure 1). It appears that South Korea has the highest share of all regions around 90% in all scenarios in 2100 and there is no dependency on the low or high demand growth in the different scenarios. Also in Japan, Mexico and Western Europe fusion power enters the power sector in all three policy scenarios and for both underlying demand growth scenarios, but at a lower level. In Western Europe the share of fusion is around 50% in 2100 and also in the 550 ppm and CO2-tax scenario for low demand growth fusion share is over 40%. Only in the No-policy scenario only 26% of power are produced by fusion in 2100. The USA do not use fusion power in case of the no-policy scenario and also in the other policy scenarios the share of fusion is quite low. It is lowest in the 550 ppm scenario based on low demand.
growth (16% in 2100). In the case of India in the No Policy Scenario based on low demand growth there is no use fusion power, but in the CO2-tax and the 550 ppm scenario fusion enters the power sector. If the scenarios are analysed based on high demand growth India has high shares of fusion up to 60% in 2100 in the no policy scenario, but only shares of around 30% in the CO2-tax scenario and 45% in the 550 ppm scenario. This aspect has to be analysed in further studies. In most of the other regions fusion power does not enter the market in the no-policy scenario.

4 Discussion

What can be observed from these studies on sensibilities on fusion power share in the future energy system with regard to varying energy demand growth assumptions is that the sensibility is highest for the no climate policy scenario. In the scenarios with climate policy constraints fusion power has no problems to reach high market shares up to 40% till the end of the century but these market shares are triggered more by policy constraints and less by the growing energy demand. However it is interesting to observe that for the 550 ppm policy scenario a higher shift towards the power sector is triggered by high demand growth assumptions and this results also in a higher share of fusion power in the overall power sector.

On the regional level high deviations in fusion power share between varying demand growth assumptions and the climate policy and no climate policy scenarios are observed. These regional disperse results on fusion power share show high sensibilities on varying scenario assumptions and need further investigations.

5 Literature
