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Global transportation scenarios in the multi-regional EFDA-TIMES energy model

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ABSTRACT

The aim of this study is to assess the potential impact of the transportation sector on the role of fusion power in the energy system of the 21st century. Key indicators in this context are global passenger and freight transportation activities, consumption levels of fuels used for transportation purposes, the electricity generation mix and greenhouse gas emissions. These quantities are calculated by means of the global multi-regional EFDA-TIMES energy system model. For the present study a new transportation module has been linked to the EFDA-TIMES framework in order to arrive at a consistent projection of future transportation demands. Results are discussed implying various global energy scenarios including assumed crossovers of road transportation activities towards hydrogen or electricity infrastructures and atmospheric CO_2 concentration stabilization levels at 550 ppm and 450 ppm. Our results show that the penetration of fusion power plants is only slightly sensitive to transportation fuel choices but depends strongly on assumed climate policies. In the most stringent case considered here the contribution of electricity produced by fusion power plants can become as large as about 50% at the end of the 21st century. This statement, however, is still of preliminary nature as the EFDA-TIMES project has not yet reached a final status.

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1. Introduction

Fusion power is inherently safe, has a large resource base and low environmental impact. Due to these arguments fusion power may be able to gain large market shares as soon as this technology becomes available for commercial use. On the other hand it is a nuclear technology (which undermines public acceptance), it is technically extremely challenging and investment costs can be expected to be very high. However, the actual role of fusion power in the energy system of the future will primarily be determined by the economics of fusion power plants and future energy prices. In order to assess the role of fusion power within the complexity of the world's energy system the EFDA-TIMES project has been brought under way. The EFDA-TIMES model is a global multi-regional energy system model developed under the framework of the Socio-Economic Research on Fusion (SERF) program of the European Fusion Development Agreement (EFDA) using the energy system modeling framework TIMES [1]. TIMES is developed within the Energy Technology System Analysis Program (ETSAP) of the International Energy Agency (IEA). The EFDA-TIMES model represents an ideal tool to explore the conditions under which fusion can become a successful contributor to the future energy market.

Future energy prices and availability are not only determined by future levels of electricity demand but are coupled to the entire system of energy supply, conversions, distribution and consumption. This applies also to the sector of passenger and freight transportation which, with its high dependency on carbon fuels, plays a crucial role for fossil fuel availability. Over the last 30 years the demand for motorized mobility has grown significantly in all industrialized countries. Moreover, the transportation sector is expected to account for a significant share of future greenhouse gas emissions. As about 70% of the world population lives in developing countries, where per capita travel demand is currently low, future trends in mobility will be of critical importance to the world's fuel supply and carbon dioxide emissions throughout the 21st century. It is the aim of the work initiated here to improve on the implementation of the transportation sector within the EFDA-TIMES model and to study the implications for the future role of fusion power within the projected energy system of the future.

2. EFDA-TIMES

EFDA-TIMES is a global multi-regional technology explicit partial equilibrium energy model which uses the The Integrated MARKAL-EFOM System (TIMES) developed by IEA-ETSAP [1]. TIMES is a bottom-up energy model generator which maximizes the total economic surplus. In its simplest variant, this can be expressed via

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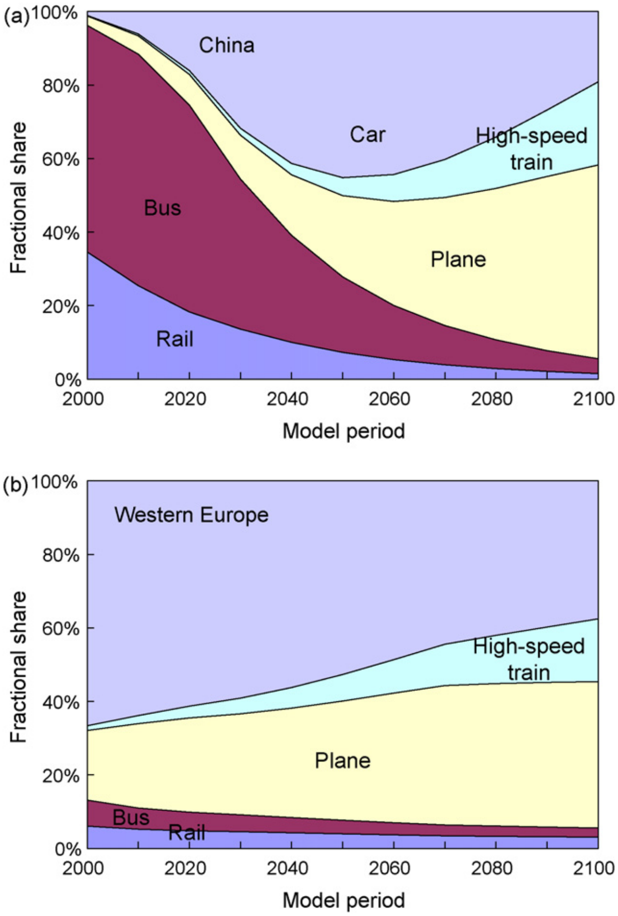

Fig. 1. Modal split in two world regions.

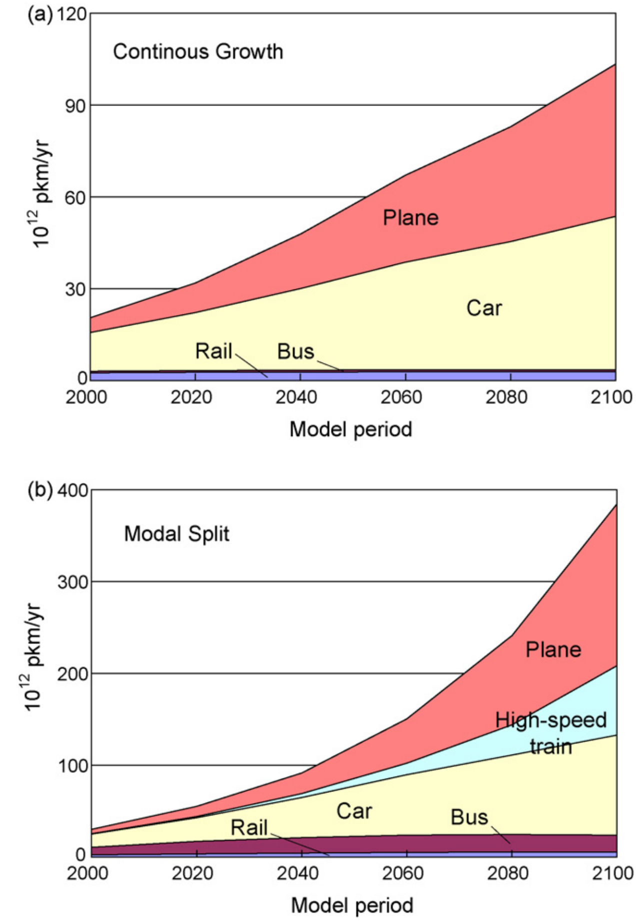

Fig. 2. Global personal transportation activity in both demand scenarios. For the *Continuous Growth* case the transportation activity has been converted to person kilometers per year by assuming an average load factor of 1.7 passengers per car and 25 passengers per bus. For planes and rail we have used energy intensities of 2.1 MJ/pkm and 0.48 MJ/pkm, respectively.

the objective function $\hat{Z}$

$$\hat{Z}(b) = \sum_r \left\{ \sum_y \zeta(r, y, b) \left[C^r_{\text{inv}}(y) + C^r_{\text{itax}}(y) + C^r_{\text{dec}}(y) + C^r_{\text{fix}}(y) + C^r_{\text{ftax}}(y) + C^r_{\text{var}}(y) + C^r_{\text{elast}}(y) - C^r_{\text{rev}}(y) \right] - C^r_{\text{sal}}(b) \right\} \quad (1)$$

which is given as the sum over all model regions r, years y and cost components C^r_i including investment costs, investment taxes and subsidies, decommissioning costs, fixed costs, variable costs, demand loss costs, revenues and salvage values. ζ is a discounting factor discounting all cost components to the base year b. The mathematical rationale of TIMES is to globally minimize the objective function under certain constraints (energy conservation at each step of the energy system, fossil energy resources, renewable energy potentials, growth constraints, etc.) using linear programming techniques.

The EFDA model is a global model spatially subdivided into 15 world regions. It covers a time horizon from 2000 to 2100. The model structure is characterized by four basic components: the supply, demand, technology and policy scenario. The technological data is given for distinct energy sectors: upstream, electricity, transport, industry, residential, commercial and agriculture. The latter five define the energy service demand sectors. The EFDA-TIMES demand scenario is given by a set of demand driver projections obtained from the GEM-E3 general equilibrium model [2]. The supply scenario is represented by a database of costs and bounds on the availability of energy resources. The technology scenario consists of a rich basis of energy conversion technologies characterized by specific efficiencies, availabilities and costs. In the base case the policy scenario of the EFDA-TIMES model is empty but can be used to study the impact of fuel taxes, emission taxes, emission permit trading and so on. Additional information on a very similar model, ETSAP-TIAM, can be found at [3].

3. Transportation sector

In this study we compare two different approaches of modeling the passenger transportation demand scenario. Both recipes will be described briefly below. For the freight transportation sector, however, we use one common approach, introduced briefly thereafter.

3.1. "Continuous Growth"

In this sub-model variant, passenger transportation is subdivided into 7 different modes of transportation, which in the case of the road transportation segments are measured by vehicle kilometers per year and by their final energy consumption for the off-road segments. Future projections for the transportation demands in each of these segments are obtained by relating the individual energy service demands $E(y)$ in the year y to one of the demand drivers $D(y)$, such as GDP (light trucks, planes), GDP per capita (cars) or population (buses, two and three wheels, trains) through the formula

$$\frac{E(y)}{E(y_0)} = \left[\frac{D(y)}{D(y_0)} \right]^{\lambda_E}, \quad (2)$$

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