Perspectives on decarbonizing the transport sector in the EU-28

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ARTICLE INFO

ABSTRACT

The transport sector is of great importance at a global level in order to become a low-carbon economy by 2050. In the European Union the transport sector accounts for 20% of anthropogenic greenhouse gas emissions. Electric propulsion systems might be a feasible solution for greenhouse gas mitigation in the transport sector. Based on our cost assumptions, grid-connected electric vehicles play no major role in the analyzed scenarios until 2030 but reach high market shares (over 90%) under stringent greenhouse gas mitigation targets until 2050. Renewable electricity plays a crucial role in providing the additional power needed in the transport sector. Financial incentives seem to be effective in order to reach the cost optimal car mix in France and Germany.

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1. Introduction

In 2015, the transport sector played a major role in the EU in terms of energy use (33% of final EU-28 energy consumption) and emissions (20% of EU greenhouse gas (GHG) emissions, mostly CO_2) [1,2]. The transport sector experienced a growth in its emissions from fuel combustion in contrast to other major energy sectors, e.g. industry, from 1990 to 2007 and a slow decrease until 2015 [2]. Moreover, traffic emissions are globally a major cause of local air pollution, most notably nitrogen oxides, carbon monoxide, and volatile organic compounds [3]. As in any area with intensive energy use, measures to achieve the EU climate and energy policy objectives must be pursued in the transport sector.

Freight and passenger transport are crucial elements for the vitality of the economy. Within the transport sector, final energy demand is dominated by road vehicles. The technical potentials for increasing the efficiency of internal combustion engine technologies are limited. The main approach for resource conservation and emission reduction, while ensuring the to-date achieved high quality of mobility, is the substitution of conventional fossil fuels by renewable and lower-emission energy carriers [4,5].

In the 'Europe 2020' communication [6], the EU has set the overall objectives of 20% reduction of CO_2 emissions, 20% of renewable energy and 20% improvement in energy efficiency by 2020 (reference year: 1990). The 2011 Transport White Paper [7] puts forward GHG emission reductions for the transport sector by 20% in 2030 (reference year: 2008) and 60% by 2050 (reference year: 1990). In its 2014 climate-energy package communication [8], the EC has put forward goals for 2030: 40% GHG reduction compared to 1990 and 27% share of renewables of EU energy consumption. Furthermore, the EC has recently proposed a 27% improvement in energy efficiency [9]. The EU's Renewable Energy Directive (RED) sets binding targets of 20% (16.7% in 2015 [10]) for gross final energy consumption and 10% (6.7% in 2015 [10]) for transport fuels to come from renewable energy sources by 2020. Liquid biofuels in road transport are expected to make the largest contribution to the target of 10% renewable energy share in the transport sector. However, progress on the targets has been challenging. Currently, almost 80% of biofuel is biodiesel used in road transport.

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The objective of this paper is to outline the status quo of renewable energy in the transport sector regarding the EU goals and to analyse pathways to reach the targets. In particular, a model-based analysis is conducted to show possible least cost evolutions in the transport sector to achieve the EU goals with a focus on emission reductions in French and German road transport. We focus on France and Germany since the transport sector in these two countries had the highest GHG emissions in the EU-28 [2]. Three scenarios (Continuation of Current Policy, Low Commitment (LC) of Member States (MS) and High Commitment (HC) of MS) for the years 2020, 2030 and up to 2050 are analyzed and their effects on the energy system and GHG emissions are quantified.

The modelling exercise is grounded on an optimization model (TIMES PanEU) and a simulation model (TE3). TIMES PanEU minimizes the objective function representing the total discounted system costs over the time horizon from 2010 to 2050. In addition to the optimization model, the system dynamics method is applied to perform simulations and policy analysis using TE3. In this dynamic model, four policy instruments have been examined to approximately arrive at the car mix obtained in TIMES PanEU. The instruments represented in TE3 are emission standards for new conventional cars, taxing conventional fuels, subsidising electric cars and investing in public refuelling/recharging infrastructure.

In the remainder of the paper we first introduce measures to reduce GHG emissions in the transport sector (section 2). Afterwards, the two models used to conduct the analysis are introduced together with the general scenario assumptions (section 3). Section 4 is split into the model results for the entire energy system of the EU-28 as well as the model results for the simulations on the car stock in Germany and in France. The last section (section 5) summarizes the results and points to future research needs.

2. Measures to decarbonize the transport sector

Conventional combustion engines are by far the predominant propulsion system in Europe's transport sector. Since the fuels are mostly based on fossil energy carriers they face important drawbacks such as high import dependency, or CO_2 and NO_x emissions. In order to minimize the associated negative impact of fossil fuel use, we distinguish between three measures for decarbonizing the transport sector. Firstly, improving fuel efficiency can be a short-term measure to reduce GHG emissions from fossil fuel usage. Secondly, nearly carbon neutral fuels (well-to-wheel) (i.e. biofuels) that emit as much CO_2 as was captured while the feedstock grew. In combination with greater fuel economy this can have additional benefits in terms of resource consumption. A drawback of biodiesel usage is generally higher NO_x emissions, which are due to effects of the fuel on factors such as injection timing and ignition delay [11]. Thirdly, energy carriers that do not result in GHG emissions (tank-to-wheel) while being utilized in a vehicle, such as electricity, are considered [12].

Passenger cars have experienced an improvement in fuel economy over the course of the last decade, largely following the adoption of the EU CO_2 performance standards for new passenger cars [13] limiting new car emissions to 95 gCO_2/km by 2021. However, there is evidence that cars have higher emissions in reality than shown in standardized tests [14]. An alternative to the technical approach for increasing fuel efficiency are higher occupancy rates which would reduce emissions per person kilometer if vehicle kilometers are reduced [15].

Biofuels face a variety of challenges. The resource potential for Bioenergy in 2020 in the EU-28 is limited to 267 Mtoe according to the Reference Bioenergy Scenario by JRC [16]. To put this into perspective, final energy consumption in the transport sector in the EU-28 was 359 Mtoe in 2015 [1]. In addition, there are limitations

with respect to the use of biofuels in conventional internal combustion engines (ICE) at present. Both EN 590 and TS 15940 diesel state an upper limit of 7% of fatty acid methyl ester (FAME) content, more commonly referred to as biodiesel. Hydrotreated Vegetable Oils (HVO) are a more recent development and can be used in EN 590 diesel fuel without any limit [17].

Hydrogen electrolysis account for an efficiency of approximately 60% and electric fuel cell efficiency is typically slightly above 50%. The overall conversion is thus ranging from 30% to 45%. This seems modest in comparison to battery system efficiency (above 80%), but there may be applications where the overall conversion efficiency might be outweighed by other benefits. Firstly, hydrogen allows for long-term energy storage and may be produced by excess intermitted renewable electricity in future that would otherwise be curtailed. Secondly, hydrogen fuel cells can be seen as a good compromise between fuel range and global efficiency which is at least on par with conventional combustion engines while maintaining the advantages of pure electric propulsion such as being noiseless and emission free. However, fuel cell electric vehicles might be more expensive in comparison to hybrid fuel cell electric vehicles or battery electric vehicles [18].

The conversion from electrical to mechanical energy and vice-versa is highly efficient. Introducing the electric energy vector at least somewhere along the on-board propulsion system allows alleviating various drawbacks of conventional combustion engines. For example, mechanical energy recovery becomes possible in the deceleration phase. Furthermore, electric vehicles might enable vehicle to grid storage and thereby supporting large share of intermitted renewable electricity generation in the European electricity system if the findings of [19] for Germany can be generalized for the EU-28. In Addition to GHG mitigation, electric mobility might become cost-competitive due to fast decreasing battery prices by 2030 for various vehicle categories and users with high annual mileages. Given strong cost reductions for Li-ion batteries in the long-run, full electric cars could become cost-optimal for every type of user and car [20].

3. Methodology and scenario framework

For the analysis of both, the energy system and the transport sector in the EU-28, the two model applications the Pan-European TIMES model (TIMES PanEU) and the TE3 (Transport, Energy, Economics, Environment) model are used, which are briefly introduced below. A more detailed presentation of the two models can be found in Kunze et al. [21].

Firstly, TIMES PanEU which was developed in a collaborative effort within the EU-funded NEEDS project [22], is used to determine cost optimal development pathways for the three analyzed scenarios within this study. TIMES PanEU is a multi-regional model containing all countries of the EU-28 plus Switzerland and Norway. The model minimizes the objective function representing the total discounted system costs over the time horizon from 2010 to 2050. Perfect competition among different technologies and pathways of energy conversion as well as perfect foresight are assumed in the model. TIMES PanEU covers on a country level all socio-economic sectors connected by energy supply and demand, namely the supply of resources, the public and industrial generation of electricity and heat, as well as the end use sectors industry, commerce, agriculture, households and transport (for a detailed description of the sectors and data please see Refs. [23–25]). For all relevant technologies and energy carriers, GHG emissions (CO_2, CH_4, N_2O) are modelled in TIMES PanEU.

Secondly, the cost optimal GHG mitigation pathways from the TIMES PanEU model are used as framework conditions for policy analysis. For this purpose, the TE3 model is used. TE3 is a multi-