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Biofuel futures in road transport – A modeling analysis for Sweden

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ABSTRACT

First and second generation biofuels are among few low-carbon alternatives for road transport that currently are commercially available or in an early commercialization phase. They are thus potential options for meeting climate targets in the medium term. For the case of Sweden, we investigate cost-efficient use of biofuels in road transport under system-wide CO_2 reduction targets to 2050, and the effects of implementation of targets for an almost fossil-free road transport sector to 2030. We apply the bottom-up, optimization MARKAL_Sweden model, which covers the entire Swedish energy system including the transport sector. For CO_2 reductions of 80% to 2050 in the Swedish energy system as a whole, the results of the main scenario show an annual growth rate for road transport biofuels of about 6% from 2010 to 2050, with biofuels accounting for 78% of road transport final energy use in 2050. The preferred biofuel choices are methanol and biomethane. When introducing additional fossil fuel phase-out policies in road transport (−80% to 2030), a doubling of the growth rate to 2030 is required and system CO_2 abatement costs increases by 6% for the main scenario. Results imply that second generation biofuels, along with energy-efficient vehicle technologies such as plug-in hybrids, can be an important part of optimized system solutions meeting stringent medium-term climate targets.
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Introduction

The dependence on fossil fuels and the continuous increase of energy use in the transport sector have brought attention to transport biofuels as a measure to mitigate climate change and improve energy security. While biofuels currently only contribute a small share of the energy supply to the transport sector, several governments and intergovernmental organizations have declared policy targets which can lead to a significant increase in transport biofuel utilization. In the EU, energy from renewable sources in the transport sector should reach at least 10% by 2020 (EC, 2009). In addition, greenhouse gas (GHG) emissions should be reduced by 20% to the same year, and a long-term ambition of reducing GHG by 80–95% to 2050 has been stated (EC, 2011). In Sweden, the government has declared that the vehicle fleet should be independent of fossil fuels by 2030 while Swedish net emissions of GHGs should be zero by 2050 (Swedish Government, 2008).

Meeting stringent climate targets will in significant ways change the energy system and will involve a large scale integration of low-carbon fuels and technologies in the road transport sector. Due to limited resources, an increased

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utilization of alternative energy carriers in the transport sector can be expected to have system effects over sector boundaries. For instance, biomass is used as raw material in the forest product industry and in the chemical industry as well as for both biofuel production and heat/power production. Changes in biomass demand in any of these sectors will affect biomass markets and, thus, imply altered conditions for other biomass applications. In the analysis of efficient ways of meeting climate targets for transport and energy systems, a wide systems approach is therefore imperative.

This study investigates cost-efficient fuel and technology choices in the Swedish road transport sector in the presence of rigid climate policies in line with policy ambitions communicated nationally and by the EU. We focus on options that currently receive the major attention (and funding) in Sweden, and in the public debate are considered as feasible near-to-medium term options in Swedish context. In particular, we study prospects for first and second generation biofuels, but also electricity is included in the analysis as an alternative option to biofuels. The objective is to provide insights and analytical results to how these options can be utilized in road transport to meet stringent climate and energy security targets. The policy objectives in focus are CO_2 emission reductions for the national energy system as a whole and phase-out of fossil fuels in the road transport sector. The research questions are:

- To what extent could biofuels in road transport contribute to a cost-efficient achievement of stringent, system-wide CO_2 reduction policy targets to 2050?
- How does the attainment of an almost fossil-free road transport sector to 2030 affect cost-efficient fuel and technology choices and system costs?

To address the complex dynamic relationships between different sub-sectors of a national energy system, a systems modeling approach with an integrated view of the energy and transport system is applied. Important linkages between the transport sector and the rest of the energy system include the reliance on a common resource base in regard to biofuels and biomass-based heat and power, and the linkage between electricity generation and utilization of electric vehicles. A system-wide approach is also essential for the possibility to find cost-efficient GHG reduction strategies on an overall societal level and to avoid sub-optimized solutions. The study considers an array of technologies in all sectors of the energy system but, as indicated above, not all potential transport sector options are within the scope of the study. Examples of transport sector technologies and fuels that are not considered include: algae biofuels, hydrogen, electrofuels, fuel cell vehicles and electrified roads.

The number of systems studies that analyze the co-evolution of the stationary energy system and the transport sector has grown in the scientific literature in recent years. The geographical scope of these studies ranges from regional and national to global. Global studies focusing on the development of the transport sector as an integrated part of energy system include Takeshita (2012), Turton (2006), Gül et al.(2009), Azar et al. (2003), Grahn et al. (2009a,b), Hedenus et al. (2010), Gielen et al. (2003), Akashi and Hanaoka (2012), Van Ruijven and van Vuuren (2009), Kitous et al., 2010, Anandarajah et al. (2013), IEA (2008) and Kyle and Kim (2011). Studies with a national scope include Jablonski et al. (2010), van Vliet et al. (2011), Schulz et al. (2007), Martinsen et al. (2010) and Yeh et al. (2008) covering UK, Netherlands, Switzerland, Germany and USA, respectively. The focuses and results of the studies differ. In terms of transport biofuels, the future market penetration range from low to high levels. Most of the studies show low to intermediate transport biofuel market shares at the end of their studied time horizons (usually between 2050 and 2100), with levels below 40% for climate policy scenarios not applying sector-specific polices (see also review by Börjesson et al., 2013a).

In the case of Sweden, the future development of the energy and transport system has earlier been modeled by, e.g., Börjesson and Ahlgren (2012a,b) and Krook Riekkola et al. (2011). However, these studies do not investigate the recent and more ambitious policy targets, including an almost complete GHG emission and fossil fuel phase-out in the 2030–2050 timeframe. Further analysis in relation to these targets is thus required.

Method and data

In this section, the methodological approach is presented, including a general description of the model, main input data assumptions for the road transport sector and model scenarios.

General model description

The analysis is based on MARKAL_Sweden, a dynamic, bottom-up, partial equilibrium, energy system optimization model. The model is an application of the well-established MARKAL model generator (Lolou et al., 2004) and includes a comprehensive description of the Swedish energy system. Under the provided conditions, the model delivers the overall welfare-maximizing[1] system solution meeting all defined model constraints (e.g., regarding energy service demands and

[1] Welfare is here defined as the sum of producer and consumer surpluses. The welfare maximization is achieved by the (equivalent) minimization of the (discounted) total system cost, defined as the sum of the technical energy systems costs (investments, operation and maintenance, fuel costs, etc.) and the loss in welfare due to reduced end-use demand (Lolou et al., 2004).

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