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Combining hybrid cars and synthetic fuels with electricity generation and carbon capture and storage

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ABSTRACT

We examined the co-evolution of the transportation, and electricity and heat generation sectors in the Netherlands until 2040 using a MARKAL bottom-up cost optimisation model.

All scenario variants investigated indicate a switch away from crude oil-based diesel and petrol for transportation. Lowest overall CO_2 abatement cost is achieved by accommodating transportation first and using relatively expensive options for emissions reduction in electricity generation if needed.

Biomass and carbon capture and storage (CCS) are used to full potential. Transportation CO_2 emissions are reduced by switching to ethanol or bio-based synthetic fuels combined with CCS, and series hybrid cars if needed. Depending on the availability of biomass and carbon storage capacity, electricity is produced from biomass, coal with CCS, or wind complemented with natural gas. Indirect greenhouse gas emissions rise to 34–54% of national emissions in 2040.

The difference in annual investment required between the scenario variants with and without CO_2 emissions reductions of 68% by 2040 is 4–7 billion euro/year, or 0.5–1.2% of projected GDP.

Investment costs are mostly determined by the cost of cars and electricity generation capacity. We observe competition for limited biomass supply and CO_2 storage capacity between the transportation and power sectors.

1. Introduction

Electricity and heat generation and transportation are among the largest producers of greenhouse gases (GHG) in the EU, responsible for half of total GHG emissions: 32% for energy supply and 18% for transportation (EEA, 2009a). While overall GHG emissions have been reduced in recent years, both the demand for and the GHG emissions from transportation have continued to grow (EEA, 2009a, 2009b).

In transportation, the consumption of diesel and petrol derived from crude oil is also considered problematic because of uncertainty about cost developments, lack of security of supply (Mitchell, 2006; Campbell, 2006), and local and regional air pollution (EEA, 2009b). Solutions are sought in alternatives for both fuels and drivetrains (cars). On the fuel side, possibilities exist to switch from diesel and petrol to biofuels (ethanol, biodiesel), synthetic fuels (from biomass, coal or gas), hydrogen, or electricity. On the vehicle side, possibilities exist to reduce fuel demand by a shift to more efficient hybrid, electric or fuel cell drivetrains.

In the electricity sector, major challenges are to fulfil growing demand and simultaneously to reduce CO_2 emissions (TenneT, 2008). Potential solutions include enhanced use of renewable sources of electricity (e.g. wind, solar, and biomass), increasing the efficiency of energy conversion and end-use, and applying carbon capture and storage (CCS) technologies. This adds another challenge of integrating these technologies into the electricity system in a way that guarantees reliability of the electricity supply.

In the existing system, the electricity/heat generation sector and transport sector are largely separated. If the alternatives mentioned above come into play, these two sectors may become more intertwined because of the following:

- *Resource competition*: Lignocellulosic biomass (wood and grasses) can be used for both synthetic fuel and power[1] production. All use of biomass competes to some degree because of land scarcity.

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[1] In this paper, we refer to the combined electricity and heat sectors as the power sector, and electricity and heat generation as power generation.

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- *Development of CCS*: Both power plants and synthetic fuels plants can produce streams of CO_2 suitable for storage. Combining these streams can make development of CCS infrastructure more attractive, but also fill up available storage capacity more quickly.
- *Electricity co-production*: Electricity is a major by-product in the thermochemical production of synthetic fuels and can be an input or a by-product in the production of hydrogen.
- *Electricity demand*: Electric cars and plug-in hybrid cars directly increase the demand for electricity and may therefore increase the need for generation capacity and grid upgrades. Batteries that can be flexibly charged can allow for more base load and intermittent electricity sources.

1.1. Existing research

Numerous studies have been done to explore development of the total energy system including the power and transport sectors using a computer model of national or supra-national energy systems (see e.g. UK-MARKAL model (UKERC, 2008), Hyways project (LBST, 2007), Energy Technology Perspectives (IEA, 2008a; Smekens-Ramirez Morales, 2004). However, most all of these studies address the co-evolution of the power and transport sectors in a minimal way. Other studies, like the World Energy Outlook (WEO) 2009, address power and transportation without explicitly discussing interactions (IEA, 2009).

Studies that explicitly explored the interaction between the power and transport sectors still have limitations. One example is a 2006 study by the Pacific Northwest National Laboratory (Kintner-Meyer et al., 2007) investigating the impacts of using the existing idle (off-peak) capacity of the electric infrastructure in conjunction with the emerging plug-in hybrid electric vehicle (PHEV) technology. Their conclusion was that 73% of the light duty vehicle fleet[2] could be supported by existing electric infrastructure for a daily drive of 53 km on average. They also stated that "the mix of future power plant types and technologies may change as a result of the flatter load-duration curve favouring more base-load power plants and intermittent renewable energy resources". However, this analysis did not project a mix of power plants in the future and, thus, did not analyse the consequences for costs or emissions resulting from this mix.

Using the UK MARKAL model coupled to a GIS, Strachan et al. (2008) studied scenarios for the use of hydrogen in transportation with CCS to reduce CO_2 emissions, including the matching of energy supply and demand in time and space. Their conclusion was that spatial clustering of demand allows for essential economies of scale, and proximity of production sites to demand centres is preferable over pipelines. However, they did not investigate other options to attain comparable levels of CO_2 emissions reductions in transportation. Using the MARKAL-NL-UU model coupled to a GIS, van den Broek et al. (2009, in press) similarly examined the development of CCS in the power sector of the Netherlands. This study focused on underground storage of CO_2 from production of electricity and heat only.

Proost et al. (2009) explored the role of taxation in transport in GHG emissions reductions in the EU, and find that taxes currently do not cover all external costs. They find that GHG emissions reductions are most cheaply achieved outside transportation, but do not include plug-in or series hybrid cars.

Wise et al. (2010) explored the effect of introducing plug-in hybrid vehicles using the Minicam model. They found that plug-in hybrid cars can reduce demand for biofuels but increase demand for CCS, and that stronger climate policy and limited availability of biofuels drive adoption of plug-in hybrid cars. However, they did not take other vehicle technologies into account. Ichinohe and Endo (2006) examine the vehicle mix using a MARKAL model, but use only modest GHG emissions reduction.

Using the UK MARKAL model coupled to a macro-economic model, Strachan and Kannan (2008) studied the macro-economic impact of 60% CO_2 emissions reduction in the UK. They find that demand response to mitigation costs causes a smaller increase of energy demand when carbon constraints are included when compared to standalone MARKAL. Preferred options for decarbonisation appear to be the use of coal with CCS, nuclear and wind energy. However, uncertainties in the future costs and characteristics of these technologies make it is impossible to robustly project the emergence of a dominant technology. A reduction in 2050 GDP of 0.3–1.5% was found, with the largest reduction in GDP caused by limiting technology to what is available in 2010. Transportation shifts towards biofuels, diesel- and hybrid cars in all scenarios, including baseline. Further decarbonisation is achieved using hydrogen after 2030 but only if reductions cannot be achieved in electricity generation and this is not explored in depth. Anandarajah and Strachan (in press) report use of PHEV and EV instead, as well as tradeoffs between use of biomass in power generation and in transportation.

Grahn et al. (2009) explored co-evolution between the transportation and power sectors until 2100 using the GET model. They found largely uniform mixes of fuels and cars in the short to medium term, with continuing large shares of diesel and petrol. Only after 2040 did mixes of vehicles and fuel technologies diverge. They also found that concentrated solar power and CCS delay a transition in the transportation sector in the long term, because CO_2 emissions reductions can more easily be attained in electricity generation. However, their technology descriptions are generic. They also assume challenging cost reductions for batteries, hydrogen storage and fuel cells based on policy targets and manufacturer projections, which are an order of magnitude lower than the current costs. The latter also applies to Gül et al. (2009).

Hedenus et al. (2010) also used the GET model for a global study until 2100 and find that hydrogen cars are used instead of plug-in hybrids if coal with CCS is dominant, though a sufficiently low cost of batteries causes EV to be used instead. An energy system using solar or nuclear makes biofuels tends to make biofuels and hybrid cars cost-effective.

Studies that investigate the power sector usually assume constant growth rate of demand for energy services. These projections do not include major changes in trends such as a strong increase in electricity demand from transportation. Therefore, short to medium term advantages and disadvantages of, for example, a combination of CCS, renewables, and electrified transportation has not been analysed. We address these issues in combination this chapter.

1.2. Approach and objectives

In this chapter, we aim to explore the co-evolution of the power and transport sectors under strict CO_2 emission reduction policies. Specifically, we addressed the following research questions:

- What shifts in the mix of fuels, vehicles and electricity generation capacity may emerge when we need to reduce CO_2 emissions?

[2] By their definition, the light duty vehicle fleet includes cars, pickup trucks, sport utility vehicles (SUVs), and vans.