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Assessing the cost-effectiveness of electric vehicles in European countries using integrated modeling

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HIGHLIGHTS

- Electric vehicles were assessed through the minimization of the total energy systems costs.
- EU climate policy targets could act as a major driver for PHEV adoption.
- Battery EV is an option before 2030 if costs will drop by 30% from expected costs.
- EV deployment varies per country depending on each energy system configuration.
- Incentives at the country level should consider specific cost-effectiveness factors.

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ABSTRACT

Electric vehicles (EVs) are considered alternatives to internal combustion engines due to their energy efficiency and contribution to CO_2 mitigation. The adoption of EVs depends on consumer preferences, including cost, social status and driving habits, although it is agreed that current and expected costs play a major role. We use a partial equilibrium model that minimizes total energy system costs to assess whether EVs can be a cost-effective option for the consumers of each EU27 member state up to 2050, focusing on the impact of different vehicle investment costs and CO_2 mitigation targets. We found that for an EU-wide greenhouse gas emission reduction cap of 40% and 70% by 2050 vis-à-vis 1990 emissions, battery electric vehicles (BEVs) are cost-effective in the EU only by 2030 and only if their costs are 30% lower than currently expected. At the EU level, vehicle costs and the capability to deliver both short- and long-distance mobility are the main drivers of BEV deployment. Other drivers include each state's national mobility patterns and the cost-effectiveness of alternative mitigation options, both in the transport sector, such as plug-in hybrid electric vehicles (PHEVs) or biofuels, and in other sectors, such as renewable electricity.

1. Introduction

Passenger cars in the European Union (EU) delivered 82% of the total land-based passenger transport in 2010. The future of the EU transport sector will be shaped mainly by two policy goals: decreasing oil dependency (the oil import bill in 2010 was approximately € 210 billion, representing more than 32% of the EU's final energy consumption (EC, 2011)) and greenhouse gas (GHG) emission reduction (the transport sector is the second-largest GHG source in the EU). In the last two decades, the transport sector was the only sector increasing GHG emissions. Heat and power and the industry sectors both decreased their emissions by more than 200 million t CO_2 each (EEA, 2012). Within the EU's policy goals of reducing 2050 GHG emission by 80–95% vis-á-vis 1990 levels, the transport sector is required to reduce 2050 GHG emissions by at least 60% vis-á-vis 1990 levels. This requires additional investment in innovative vehicles, equipment and vehicle-charging infrastructures estimated at one trillion euros up to 2030 (EC, 2011). EU policies are geared toward a shift to alternative fuels (electricity, hydrogen, biofuels and methane) (EC, 2012), and the deployment of passenger car technologies relying on electricity (hereafter,

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electric vehicles, or EVs), ranging from battery electric vehicles (BEVs) to plug-in hybrid electric vehicles (PHEVs), is considered crucial.

EVs are gaining importance globally due to their high energy efficiency and their potential to reduce GHG emissions, especially when combined with low carbon electricity. According to the literature, the competitiveness of EVs is conditioned by several factors: (i) the cost and lifetime of batteries for the case of BEVs (Cheah et al., 2010; Etacheri et al., 2011; Tie and Tan, 2013, OECD/IEA, 2011); (ii) prospects on carbon-neutral biofuel availability as a preferred option for low-carbon mobility alternatives (OECD/IEA, 2011a); (iii) improvements to internal combustion engines (ICEs) (Schäfer et al., 2009); and (iv) consumer preferences (Tran, 2012). The success of EVs appears to be at a crossroads, benefitting from high oil prices, carbon constraints, and the rise of organized car sharing and intermodality practices, while at the same time being conditioned by the on-going large investments in the development of fossil fuel-based ICE vehicles, the preference for cheaper ICE cars in emerging markets, and the current dominance of cultural attachment to owning rather than leasing vehicles (Dijk et al., 2013).

The European automotive industry is responsible for over 12 million jobs and a positive contribution to EU's trade balance of approximately € 90 billion (in 2011), making the sector vital for the European economy (Proff and Kilian, 2012). Sustainable mobility lies at the heart of the sector's competitiveness, with emphasis on the entrance of newly emerging competitors from the Asian and US automotive industries, which are currently investing to secure a strong position in electric mobility. Worldwide market data for 2012 show that the USA had the largest share of PHEVs (70%), followed by Japan (12%). For BEVs, Japan held the largest market share (28%), followed by the USA (26%), China (16%) and France (11%). Although in Europe, PHEV and BEV sales in 2012 were more than double those in 2011, on track to meet the 2DS targets (OECD/IEA, 2013), the current EU economic conditions suggest that some caution should be adopted when looking at optimistic expectations for future massive adoption of EVs. This view is shared from both policy (Kampman et al., 2011) and market (Zubaryeva et al., 2012; Proff and Kilian, 2012) perspectives.

Prospective studies (Contestabile et al., 2011; Bahn et al., 2012; Kyle and Kim, 2011; Huo et al., 2010; Zheng et al., 2012) have assessed alternative fuel and vehicle options, mostly through simulated scenarios rather than optimization (OECD/IEA, 2012) methods. There is no agreement on the future role of each vehicle technology (PHEVs, biofuels, BEVs and hydrogen fuel cells), but all studies agree that strong policies are needed to achieve massive market adoption. For the EU, prospects on EVs have been assessed mostly for the region as a whole (Kampman et al., 2011; EC, 2011a; Thiel et al., 2010; Streimikiene and Sliogeriene, 2011; Pasaoglu et al., 2012) or for specific regions (Juul and Meibom, 2012; Calnana et al., 2013). We argue that the cost-effectiveness of EVs may vary significantly among EU member states due to their specific energy system characteristics, namely the cost-effectiveness of renewable sources for power generation, biofuels and mobility patterns. Thus, the same EV cost curve may represent a cost-effective technology option for one country but not for another. Available results for the EU as a whole obscure the differences in the national drivers governing the adoption of EVs at the member state level, which in turn hampers the effectiveness of related policies and instruments. In this paper, we overcome this knowledge gap.

The adoption of EVs, whether PHEVs or BEVs, is not about simply changing the car; it also requires changes along the energy supply chain, from the energy supply to distributed infrastructures, as well as changes in the consumers' mind sets. This represents a new paradigm, and as such, it is a major challenge to policy measures and instruments.

This paper aims to assess, up to 2050, whether EVs in general and BEVs in particular, may represent a large-scale option for the consumers of each of the 27 EU member states, considering the present available knowledge on its cost curves. We focus primarily on BEVs to assess to what extent electricity-only mobility can play an important role. We use a set of 12 scenarios generated by a Pan-European technological partial-equilibrium model to assess the impact of climate mitigation targets and of different cost curves for BEVs on the adoption of electric mobility and on the rest of the energy system for each EU member state. We investigate the level of cost reductions that triggers the adoption of BEVs in each EU member state, which may inform the design of national policies and instruments, along with EU-wide policies to promote electric mobility. As other authors have noted, we argue that costs (both investment and fuel) play a major role in the adoption of electric vehicles. We have developed a sensitivity analysis to address uncertainty due to other factors, such as fuel prices, biomass availability and discount rates, as a proxy for consumer preferences. The novelty of this research is its in-depth analysis of the conditions for a massive adoption of EVs for each EU member state using an energy system optimization approach.

The remainder of the paper is structured as follows: Section 2 introduces the Pan-European TIMES energy model, data, assumptions and scenarios supporting the modeling exercise. Section 3 presents selected results and discusses them. Finally, Section 4 concludes and highlights the contributions for policy design.

2. Methods

2.1. The Pan-European TIMES model

The PET36 (Pan-European TIMES) bottom-up model was used to generate a set of scenarios to assess how and when EVs will become a cost-effective alternative by 2050. PET36 is an optimization technological TIMES model covering the EU27 plus Norway, Iceland, Switzerland, and the Balkan countries, running from 2005 to 2050. The TIMES code is described in Loulou et al. (2005, 2005a). PET36, in particular, is described in RES2020 Project Consortium (2009), Lavagno and Auer (2009) and Oikonomou et al. (2011). It is a 36 multi-region model of these countries' energy systems linked through trade of the main energy forms. National teams have validated the national energy system data, and the model was calibrated for the year 2005 and validated for 2010. PET36 is driven by exogenous country-specific energy service demand, and it takes into consideration several conditions, such as the evolution of energy prices, national endogenous energy potentials and policy assumptions. Its main output is the cost-effectiveness of a mix of energy supply and demand technologies for the following seven sectors: primary energy supply (e.g., oil and bio refineries, natural gas distribution pipelines), electricity and heat generation, industry, residential, commercial, agriculture and transport. PET36 has been used in several EU-funded projects (RES2020, REALISEGRID, REACCESS and COMET).

PET36 is supported by a detailed database, with the following exogenous inputs: (1) end-use energy services and material demand, such as residential lighting, passenger and goods mobility, process heat or steel; (2) characteristics of the existing and future energy-related technologies, such as efficiency, stock, lifetime, availability, investment, operation and maintenance costs, and discount rates; (3) present and future sources of primary energy supply and their potentials; and (4) policy constraints, such as CO2 emissions caps.

The ultimate objective of PET36, as with any TIMES model, is