

DEFINE Synthesis Report

DEFINE - Development of an Evaluation Framework for the Introduction of Electromobility

Institute for Advanced Studies, Environment Agency Austria, Vienna University of Technology, German Institute for Economic Research, Oeko-Institut, Center for Social and Economic Research

December 2014

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Project Coordinator

Institute for Advanced Studies



Project Partners

Vienna University of Technology



German Institute for Economic Research



Center for Social and Economic Research



Environment Agency Austria



Oeko-Institut



Funding Institutions

EU-Commission and national funding institutions:

Austria: Ministry for Transport, Innovation and Technology (BMVIT) – Management by Austrian Research Promotion Agency (FFG)

Germany: Federal Ministry of Transport and Digital Infrastructure (BMVI, formerly Federal Ministry for Transport, Building and Urban Development, BMVBS)

Poland: The National Centre for Research and Development



Project duration: May 2012 – December 2014, Call: Electromobility+

Project homepage: <https://www.ihs.ac.at/projects/define>

Contact:

Mag. Michael Gregor Miess

☎: +43/1/599 91-138

email: miess@ihs.ac.at

Mag. Stefan Schmelzer

☎: +43/1/599 91-138

email: schmelzer@ihs.ac.at

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1. DEFINE – Project Short Description

The project DEFINE – Development of an Evaluation Framework for the Introduction of Electromobility – was conducted by the Institute for Advanced Studies (IHS), Vienna, in cooperation with the Environment Agency Austria (EAA), the Vienna University of Technology (TUW), Austria; the German Institute for Economic Research (DIW Berlin), the Institute for Applied Ecology (Oeko-Institut), Germany; and with the Center for Social and Economic Research (CASE), Poland.

Electromobility is often viewed simply as the solution for combining the individual transport system with sustainable economic development. In this report, however, the precise questions to be raised are: under which conditions is a mobility paradigm that is primarily based on individual transport economically, ecologically beneficial and viable regarding the energy system? Can electromobility breach the growth dynamics of CO₂ emissions in the transport sector under supportable economic costs?

The analysis of the overall economic and systemic effects of an increased market penetration of electric vehicles requires a comprehensive approach. For this reason, the aim of DEFINE was an estimation of economic costs in an analytical framework that suits the complexity of the matter and explicitly relates electromobility to the energy system, environmental effects and household behaviour.

The main results of the project are the economic costs of an increased penetration of electric vehicles under different incentive regimes and tax measures, the effects on the electricity system and the related emission reduction potential. The core of the project consists in the development of a model-based evaluation framework that systematically combines the relevant dimensions of electromobility: the economy in sectoral disaggregation, consumption and mobility preferences of private households regarding electric vehicles, and the electricity system for several countries in Europe (Austria, Germany, Poland). Emissions and environmental effects associated to electromobility are quantified in a case study.

In a first step, scenarios regarding the market penetration of electric vehicles and associated vehicle stock projections were developed for Austria by the Environment Agency Austria and for Germany by the Institute for Applied Ecology. On this basis, the effects of an enhanced penetration of electromobility on the electricity system for Austria and Germany were assessed with detailed and comprehensive electricity market models by the Vienna University of Technology and the German Institute for Economic Research, respectively.

As a methodical instrument for the estimation of economic costs, a computable general equilibrium (CGE) model developed at the Institute for Advanced Studies was specifically expanded and tailored to simulate the enhanced shift-in of electric vehicles into the vehicle stock. For a realistic depiction of the individual transport system, a micro-econometric discrete choice model was estimated based on a representative household survey for Austria that was conducted in DEFINE to elicit consumer preferences regarding the purchase and use of electric vehicles. This micro-econometric model was directly implemented into the macro-economic CGE model, thereby implementing an innovative approach. Preferences of households regarding to their car purchase and mobility decision can thus be modelled more realistically and comprehensively. Moreover, the results of the detailed electricity market models by TUW and DIW Berlin were embedded in the CGE model. Thus, a novel method for the scenario-based analysis of the economic costs of an increased penetration of electromobility under a systemic perspective was created.

The emission reduction potential of electromobility for Austria and Germany was assessed by the Environment Agency Austria and by the Institute for Applied Ecology.

The work conducted by the Polish partner CASE particularly aimed at eliciting consumer preferences for alternative fuel vehicles. Consumer preferences were analysed using data from an original questionnaire survey representative of Polish adult population and people who intend to buy a car. Willingness to pay for alternative fuel vehicles and their specific attributes such as driving range, charging time, availability of fast-mode charging infrastructure was derived from discrete choice experiments. Although, a few dozens of such studies have been conducted in Western Europe, Northern America and Asia, this study is first of its kind being conducted in the region of central and eastern Europe. CASE then prepared data and build the hybrid CGE model for Poland. Last, CASE developed an approach to link the hybrid CGE model and impact pathway analysis in order to quantify external costs (environmental benefits) attributable to air quality and GHGs pollutants due to electro-mobility.

The following sections provide policy briefs to these topics:

- Scenarios for electromobility and vehicle stock for Austria
- Scenarios for electromobility for Germany and their effects on the German electricity system until 2030
- Simulation of the effects of electromobility on the electricity system for Austria and Germany in 2030
- The impact of electric vehicle integration on the low voltage grid (scenarios up to 2030)
- Economic costs and benefits of electromobility
- External costs of electromobility
- Preferences for alternative fuel vehicles and car systems in Poland

Conclusions and policy guidance can be obtained from the respective policy briefs.

2. Scenarios for Electromobility and Vehicle Stock for Austria

Günther Lichtblau, Sigrid Stix

Environment Agency Austria

As part of the two-year European project DEFINE (Development of an Evaluation Framework for the Introduction of Electromobility), the Environment Agency Austria investigated possible achievable potentials of electric vehicles in two scenarios: BAU Business-As-Usual and EM+- Electromobility Plus. On the basis of empirical data on actual transport behaviour and a conjoint-analysis to simulate purchase decisions, experts from the environmental agency derived vehicle stock projections and their environmental effects.

Scenarios for Austria – 1 million electric vehicles in 2030

In the BAU scenario, which includes the measures currently in place, a total of about 886,000 electric passenger cars and plug-in vehicles are expected for 2030. If, in addition to the BAU measures, the measures assumed for the EM+ scenario are implemented, the stock of electric vehicles is expected to rise to about 1 million in 2030. The necessary additional measures in the EM+ scenarios for increasing the use of electromobility are: stricter CO₂ regulations, a tighter reform of the Austrian car registration tax (NOVA), higher taxes on fossil fuels and an expansion of the charging point infrastructure. The expected CO₂-emission reductions in the BAU-scenario would amount to 1 million tonnes, in the EM+ scenario the reductions raise to 1.2 million tonnes. Additionally, the analysis shows that women in an urban environment and car-sharing users have the greatest affinity for electric vehicles.

Introduction

The transport sector is with 21.7 million tonnes (in 2012) one of the major contributors of CO₂ emissions in Austria. The period 1990–2012 saw a 54% increase in the greenhouse gas emissions from this sector, which means that instead of moving towards the relevant environmental policy targets, emission trends are pointing in the opposite direction. Specifically the Austrian target – to achieve a 16% reduction of greenhouse gas emissions by 2020 (compared to 2005 levels) – should be mentioned here. Furthermore the European Commission has to reduce EU domestic greenhouse gas emissions by 40 % below the 1990 level. In the transport sector, an increase in the use of alternative propulsion technologies in passenger cars would be a suitable measure, apart from expanding public transportation, which is another way of counteracting rising GHG emissions. Vehicles using only electric motors for propulsion are of particular importance as they represent a CO₂ free alternative in private motorised transport. Pure electric vehicles, supplied with energy from renewable sources, are considered to have the greatest potential among the sustainable technology solutions of the future.

Compared to vehicles with conventional propulsion systems, the use of electricity from renewable energy sources has a lower impact on the environment when the entire process chain is considered. Because of their efficiency, which is significantly higher, electric vehicles require less energy than conventional ones. Since electric vehicles do not cause air pollutant emissions locally and emit less noise than conventional vehicles, they are ideal for use in urban areas. At the moment the problem is that there is only a limited supply of marketable electric vehicles (the main reason being that batteries have low energy densities and come at a high price) so that market penetration is modest. For the future it can be assumed that the supplies will increase considerably.

Possible paths for the development of the vehicle stock are, therefore, of particular interest, as well as the acceptance of electric vehicles among users and technological developments in the future.

Analysis in two scenarios

As part of the DEFINE project the Environmental Agency Austria analysed vehicle stock and possible CO₂ - emission reduction potentials. Two scenarios were investigated: a BAU Business-As-Usual and EM+- EmobilityPlus scenario, in the latter the overall conditions are changed in such a way that a higher proportion of pure electric vehicles and plug-in hybrid electric vehicles (PHEV) (EM+) can be reached. Particular importance was given to the selection of the measures for the EM+ scenario, as these measures were designed together with the Oeko-Institut to establish political plausibility for Germany as well.

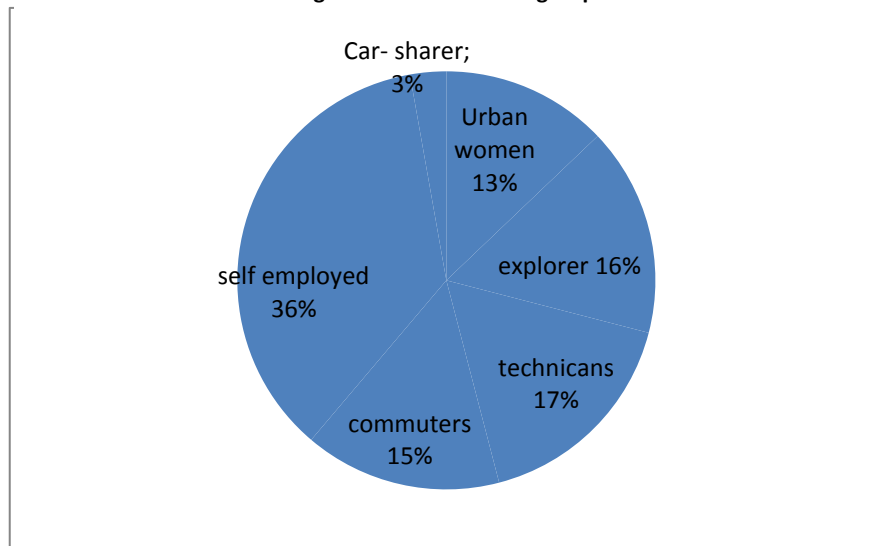
Database

On the basis of empirical data on actual transport behaviour and a conjoint-analysis to simulate purchase decisions, experts from the environmental agency derived vehicle stock projections and their environmental effects. The data used for this study came on the one hand from a survey on vehicle acceptance among the buyers of new vehicles, for which data that were representative of Austria were collected by GfK using a discrete choice experiment. The results were fed into the Transport, Emission and Energy model (TEEM) of the Environment Agency Austria, which is based on data from the Austrian air emissions inventory (OLI). Additionally a cluster analysis was carried out to identify specific affinity towards electro vehicles among various users.

User groups

The cluster analysis revealed six groups: urban women, explorers, technicians, commuters, self-employed persons and car sharers. The group of the self-employed are the largest group (36%), the car sharers the smallest (3%). Of all user groups, urban women and car sharers are most likely to buy an electric vehicle. The likelihood of buying an electric car is smallest among the technicians. Technicians are most likely to buy plug-in vehicles (PHEV). In this group, high educated men comprise a higher proportion than women, 15% are paid a commuters' allowance.

Figure 1: Identified Usergroups



Source: Calculations by Environment Agency Austria

Vehicle stock developments

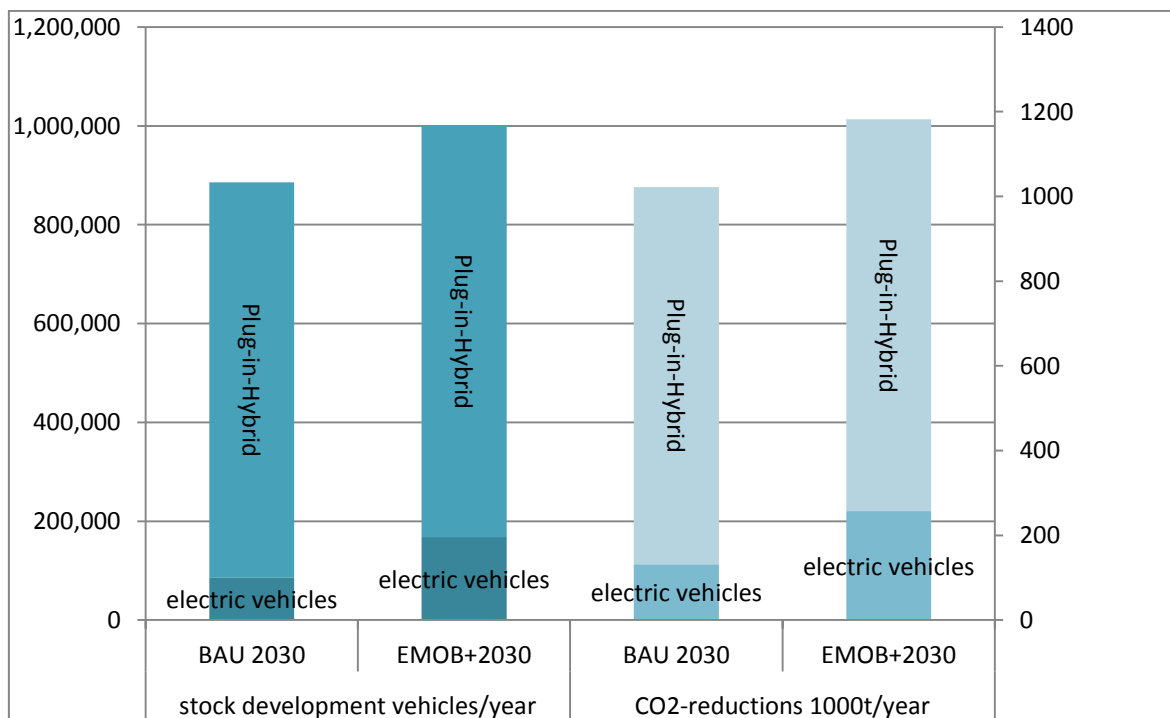
Currently 3.038 electric vehicles are in the Austrian vehicle fleet. In the BAU scenario, which includes the measures currently in place, a total of about 886,000 electric passenger cars and plug-in vehicles are expected for 2030. If, in addition to the BAU measures, the measures assumed for the EM+ scenario

are implemented, the stock of electric vehicles is expected to rise to about 1 million in 2030 (figure 2, right side).

Emission effects

In the BAU scenario, the direct CO₂ emission reductions expected to be achieved in 2030 amount to about 1 million tonnes (excluding HEVs). In the EM+ scenario, the direct CO₂ emission reductions expected to be achieved with additional measures amount to about 1.2 million tonnes (16 per cent greater than in the BAU scenario). Regarding the NO_x emissions, the following reductions are expected: in the BAU 127 tonnes and in the EM+ 143 tonnes.

Figure 2: vehicle stock developments and emission reduction potentials



Source: Calculations by Environment Agency Austria

Conclusions

Among the existing technological solutions, electric vehicles make a key contribution to achieving long-term climate targets and individual carbon dioxide-free mobility. The potential can only be realized, if the necessary electricity stem from renewable energy sources. Furthermore, the technology holds great potential for reducing noise and air pollutant emissions. On an overall basis, due to regulatory measures and price signals, supply and demand of efficient technologies can be intensified.

3. Scenarios for Electromobility for Germany and their Effects on the German Electricity System until 2030

Clemens Gerbaulet, Wolf-Peter Schill

German Institute for Economic Research (DIW Berlin)

Peter Kasten

Oeko-Institut (Institute for Applied Ecology)

The CO₂ emission impact of introducing electric vehicles (EV) strongly depends on the power plant fleet and the EV charging mode. Our analyses illustrate that additional renewable capacities compared to current expansion scenarios are needed to fully exploit the emission reduction potential of EV; without such generation adjustments, the introduction of electromobility might increase CO₂ emissions compared to a reference case without EVs, irrespective of the charging mode.

Two scenarios of electric vehicle (EV) deployment in Germany up to 2030 are developed: a business as usual (BAU) and an electromobility+ (EM+) scenario that includes policy measures to support EV market introduction (a feebate system, adjusted energy taxation and ambitious CO₂ emission targets). Plug-in hybrid and range extended electric vehicles constitute the largest part of the EV fleets in both scenarios (around 5 million EV in 2030 in EM+). Using a unit-commitment dispatch model, we analyse the integration of these EV fleets into the German power system. The overall energy demand of the modelled EV fleets is low compared to the power system at large. Yet, hourly charging loads can become very high. User-driven charging largely occurs during daytime and in the evening with respective consequences for the peak load of the system. In contrast, cost-driven charging is shifted to night-time. Accordingly, cost-driven EV charging strongly increases the utilization of hard coal and lignite plants, while additional power generation predominantly comes from natural gas and hard coal in the user-driven mode. Overall, specific CO₂ emissions related to the additional power demand of EV are substantially larger than specific emissions of the overall power system in most scenarios as improvements in renewable integration are over-compensated by increases in the utilization of hard coal and lignite. Only if the introduction of electromobility is linked to a respective deployment of additional renewable generation capacity (RE+), electric vehicles become largely CO₂-neutral. Additional analyses on the net CO₂ balance of both the power and the transportation sector show that additional power-related CO₂ emissions over-compensate emission mitigation in the transport sector in BAU; in EM+, this effect reverses.

Based on our findings we suggest the following policy conclusions. First, policy makers should be aware that EVs increase the power demand and thus also fossil power plant utilization. If the introduction of electromobility is intended to be linked to the use of renewable energy and zero emissions, it has to be made sure that a corresponding amount of additional renewables is added to the system. Second, because of generation adequacy concerns, purely user-driven charging may have to be restricted with increasing EV fleets. Third, cost-driven charging – or market-driven charging, respectively – will only lead to emission-optimal outcomes if emission externalities are correctly priced. Last, but not least, we want to highlight that the introduction of electromobility should not only be evaluated with respect to CO₂ emissions; EV may also bring about other benefits such as lower emissions of other air pollutants and noise, and a reduced dependence on oil in the transport sector.

Introduction

In the context of the project DEFINE, Oeko-Institut and DIW Berlin jointly analysed possible future interactions of the introduction of electromobility with the German power system. We were particularly interested in the impacts of electric vehicles (EV) on the dispatch of power plants, the integration of

fluctuating renewable energy, and resulting CO₂ emissions under different assumptions on the mode of vehicle charging.

To do so, Oeko-Institut has developed two market scenarios of electric vehicle deployment in Germany up to 2030: a business as usual (BAU) scenario as well as an electromobility⁺ (EM⁺) scenario. Empirical mobility data and a conjoint analysis have been used to derive the market and stock developments of EV in both scenarios. Building on mobility data, 28 hourly patterns of power consumption and maximum charging power for different EV types have been derived for both 2020 and 2030. These parameters served as inputs for a numerical model analysis carried out by DIW Berlin. Using DIW Berlin's unit-commitment dispatch model, we have analysed the integration of these EV fleets into the German power system for various scenarios, drawing on different assumptions on the charging mode. CO₂ emission outcomes, in turn, were handed over to Oeko-Institut. These served as inputs for the Oeko-Institut's TEMPS model in order to determine the overall emission effects of EVs, while also considering the substitution of conventional vehicles in the transport sector.

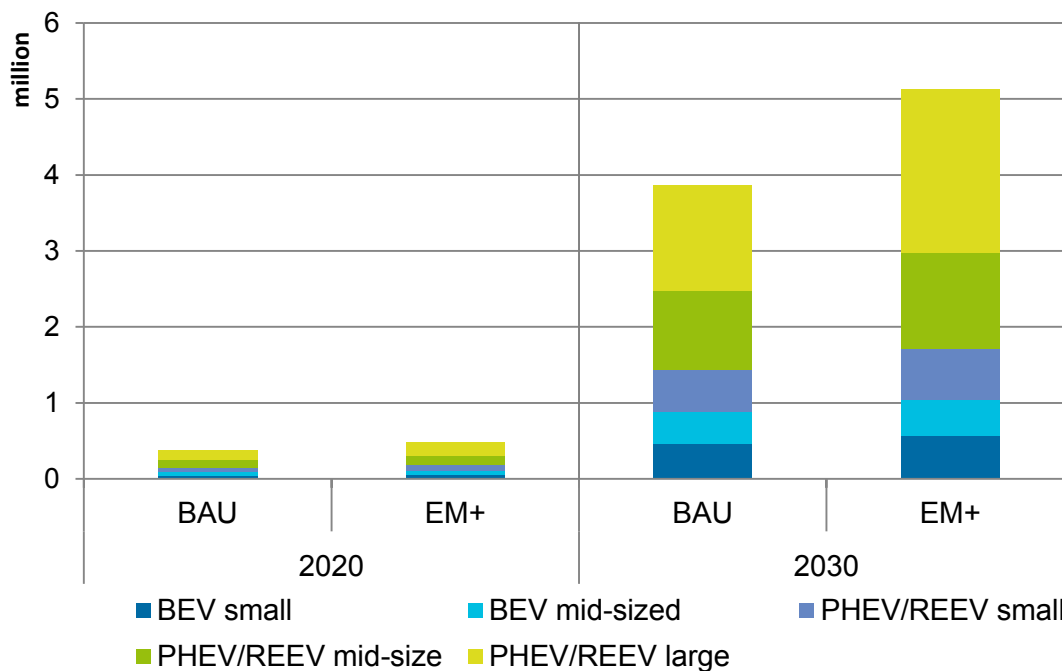
Two scenarios of electromobility

Two market scenarios for EV in Germany up to 2030 have been developed as a part of DEFINE. The BAU scenario takes current policy into consideration. In contrast, policy measures such as higher energy taxation of fossil fuels, more ambitious EU CO₂ emission standards for new passenger cars and a feebate system are considered in the EM⁺ scenario. Representative mobility data for Germany has been used to account for mileage and usability restrictions of EV. The purchase decision between cars of different propulsion system has been modelled with a conjoint analysis that consists of data from 1,500 interviewees.

Major restrictions for EV usage and EV purchase are the charging infrastructure requirements and long trips that exceed the maximum mileage of battery electric vehicles. Roughly 50 % of car owners in German city centres do not own a parking spot at their property and are completely dependent on charging infrastructure in (semi-)public environment when using electric vehicles. This number decreases to less than 30 % in the outskirts of urban areas and in rural areas. Long trips are a severe restriction for battery electric vehicles and the probability that cars will be used for trips above their maximum mileage at least 4 times per year is higher than 70 %.

The conjoint analyses shows high acceptance for electromobility under the given assumptions of both scenarios. The potential market share of EV is around 50 % in the BAU scenario and increases up to roughly 60 % in the EM⁺ scenario. Generally, the acceptance of plug-in hybrid vehicles is higher compared to battery electric vehicles. We also consider restrictions to the market diffusion of EV in the analysis, such as production capacity restrictions and a lack of EV model variety.

The share of newly registered EV is 5–6 % in 2020 and rises to 20 – 25 % in 2030. Higher market shares are achieved for plug-in hybrid (PHEV) and range extended vehicles (REEV). This new car registration data has been used as an input for vehicle stock modelling. For 2020, an EV fleet of roughly 400,000 (BAU) to 500,000 (EM⁺) cars has been derived. The EV fleet increases to 3,900,000 cars in 2030 in the BAU scenario and to 5,100,000 cars in the EM⁺ scenario, in which around 13 % of all cars are EV (Figure 3).

Figure 3: Electric vehicle stock in BAU and EM+ scenario

Power system impacts of electric vehicles in Germany

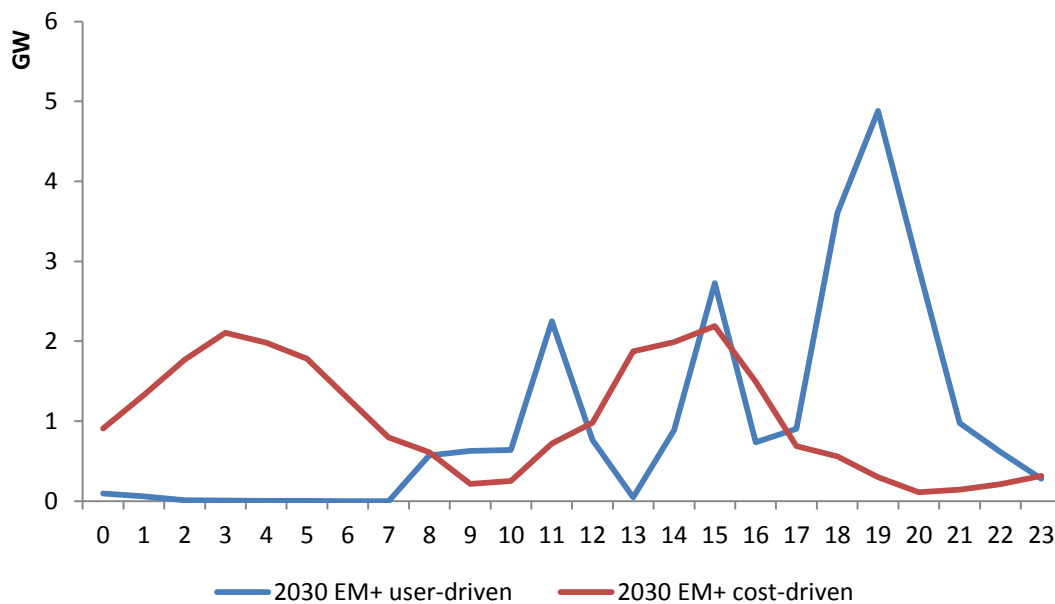
We use a numerical cost minimization model that simultaneously optimizes power plant dispatch and charging of electric vehicles. The model determines the cost-minimal dispatch of power plants, taking into account the thermal power plant portfolio, fluctuating renewables, pumped hydro storage, as well as grid-connected electric vehicles. Interactions with neighbouring countries are not considered here. The model has an hourly resolution and is solved for a full year. It includes realistic inter-temporal constraints on thermal power plants, for example minimum load restrictions, minimum down-time, and start-up costs. The model draws on a range of exogenous input parameters, including thermal and renewable generation capacities, fluctuating availability factors of wind and solar power, generation costs and other techno-economic parameters, and the demand for electricity. We largely draw on semi-governmental data as well as on DIW Berlin's own database.

We apply the dispatch model to the BAU scenarios and the EM+ scenarios of both 2020 and 2030. With respect to installed generation capacities, we draw on the semi-governmental German Grid Development Plan, which foresees a substantial expansion of renewables according to the targets of the German government. In addition, we carry out six additional model runs for the 2030 EM+ scenario with further increase renewable capacities (RE⁺). These capacities are adjusted such that they supply exactly the yearly power demand required by EVs. We assume that the additional power either comes completely from onshore wind, or completely from PV, or fifty-fifty from onshore wind and PV. EV usage is considered by applying the aforementioned 28 EV profiles that are derived by the Oeko-Institut from representative German mobility data. Hourly data of electricity consumption and grid connectivity of EV serve as inputs to the model. We further distinguish two extreme modes of charging: fully user-driven or fully cost-driven. In user-driven charging, EVs are charged as fast as possible after a connection to the grid has been established. In the cost-driven mode, EV charging is shifted – given the restrictions of the EV profiles – such that electricity generation costs are minimized.

Model results show that the overall energy demand of the modelled EV fleet is low compared to the power system at large. In 2020, the EV fleet accounts for only 0.1% to 0.2% of total power consump-

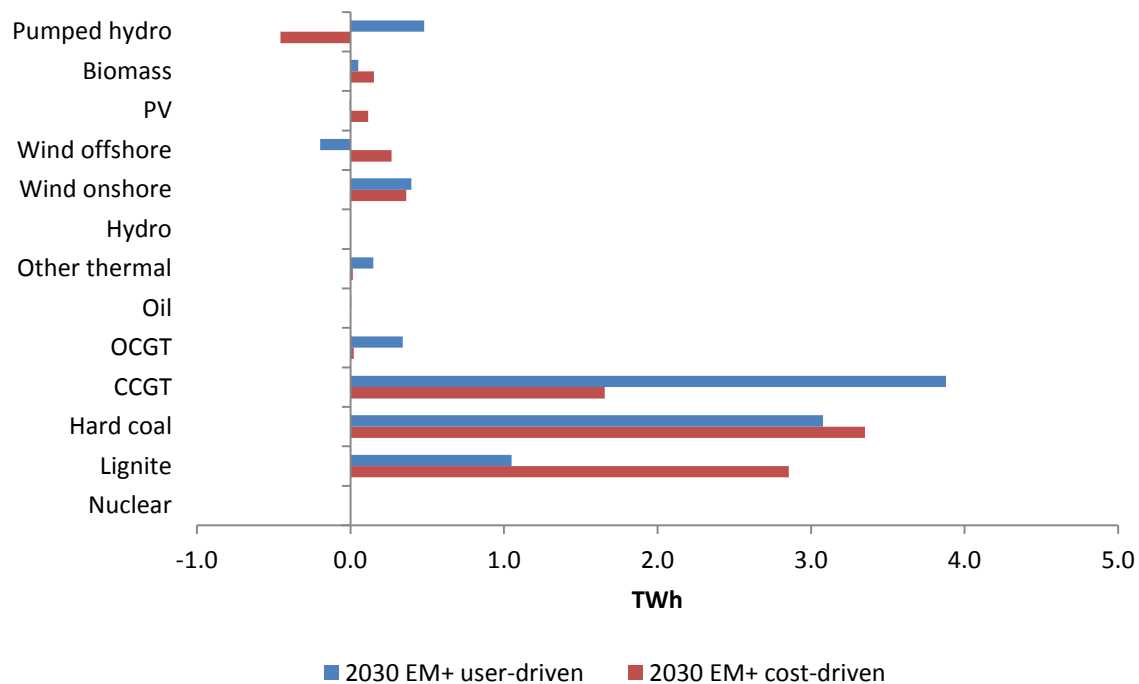
tion, depending on the charging mode. By 2030, these share increase to around 1.3% (user-driven) and 1.6% (cost-driven), respectively. Yet the hourly charging loads can become very high, with according effects on the power system. Hourly charging levels vary significantly over time and differ strongly between the user-driven and the cost-driven modes. User-driven charging largely results in vehicle charging during daytime and in the evening (Figure 4). This may lead to substantial increases of the system peak load, which raises serious concerns about system security. In the user-driven scenarios of the year 2030 there are several hours both in BAU and EM⁺ during which the available generation capacity is fully exhausted. In contrast, in the cost-driven mode, the evening peak of EV charging is shifted to night-time, which results in a much smaller increase of the system peak load. The average charging profile of the cost-driven mode is much flatter compared to the user-driven one.

Figure 4: Average EV charging power over 24 hours



The different charging patterns go along with respective changes in the dispatch of the power plant fleet. In the 2030 EM⁺ scenarios, cost-driven EV charging strongly increases the utilization of hard coal and lignite plants compared to a scenario without EVs. In the user-driven mode, in which charging often has to occur in periods when lignite plants are producing at full capacity, additional power generation predominantly comes from combined cycle natural gas plants, followed by hard coal and lignite (Figure 5).

Figure 5: 2030 EM+: dispatch changes relative to scenario without EV



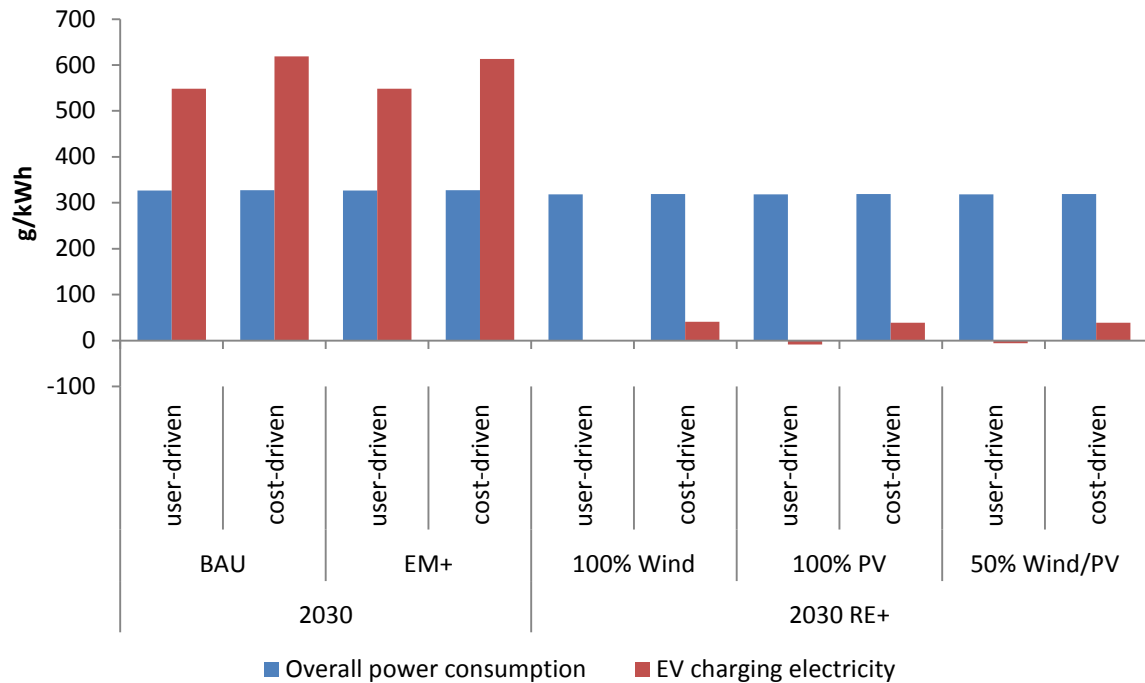
In additional model runs (RE⁺), we link the introduction of electromobility to an additional deployment of renewable power generators. Under user-driven charging, this leads, obviously, to increased power generation from renewables, but also to a slightly decreased utilization of lignite plants and increased power generation from natural gas, compared to a scenario without EVs and without additional renewable capacities. Under cost-driven charging, we find an opposite effect: generation from lignite increases while generation from natural gas decreases. This is due to the additional demand-side flexibility of the EV fleet.

As regards renewable integration, temporary curtailment of fluctuating generators is generally low in all scenarios, given the underlying assumptions on the power system. Having said that, model results show that the potential of EVs to reduce renewable curtailment is much higher in case of cost-driven charging compared to the user-driven mode. In the 2030 EM⁺ scenario, cost-driven charging decreases the share of renewable curtailment from 0.65% in the case without EVs to 0.29%. In the RE⁺ scenarios, the one with 100% PV has the lowest curtailment levels whereas the one with 100% onshore wind has the highest ones. Accordingly, PV feed-in patterns may match the charging patterns of electric vehicles slightly better than onshore wind.

Specific CO₂ emissions of the additional electricity demand related to EV in the different scenarios depend on the underlying power plant fleet as well as on the mode of charging. EV may increase the utilization of both emission-intensive capacities such as lignite or hard coal, and fluctuating renewables. While the first tends to increase CO₂ emissions, the latter has an opposite effect. In the BAU and EM⁺ scenarios of 2020 and 2030, the first effect dominates the emission balance, in particular in the cost-driven charging mode. Specific emissions of the charging electricity are thus substantially larger than specific emissions of the overall power system, irrespective of the charging mode (Figure 6). In contrast, introducing additional renewable capacities (RE⁺) pushes specific emissions of the charging electricity well below the system-wide average, and they even become negative in some cases. Importantly, these effects strongly depend on the power plant structure and on the extent of renewable curtailment in the system. In the future, the emission performance of cost-driven charging may improve substan-

tially, if emission-intensive plants are removed from the system and if renewable curtailment gains importance.

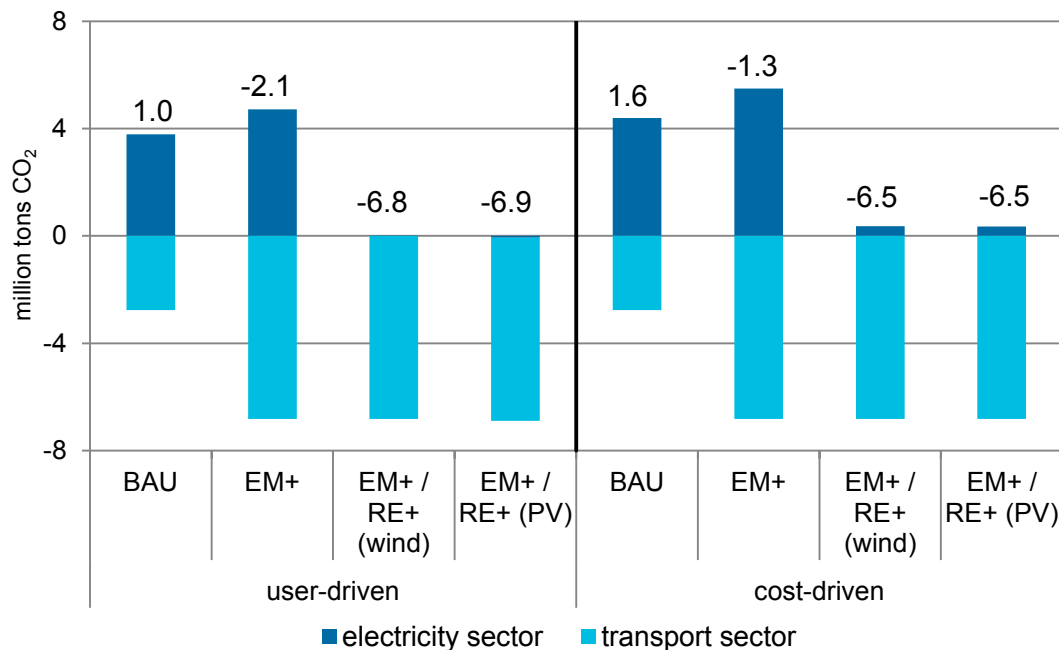
Figure 6: Specific CO₂ emissions of electricity generation in the 2030 scenarios



The net CO₂ balance of electromobility

Substituting cars with internal combustion engine (ICE) by EV reduces CO₂ emissions in the transport sector. In contrast, emissions of the electricity sector might increase due to additional power demand from EV (see above). Moreover, we assume decreasing specific CO₂ emissions of ICE cars in EM+ in the context of the assumed policy measures. A combined net CO₂ balance of the transport and electricity sectors has been conducted to evaluate the total CO₂ impact of introducing electromobility. In 2030, the CO₂ mitigation of the transport sector is over-compensated by additional CO₂ emissions in the electricity sector in the BAU scenario, and net CO₂ emissions increase by 1.0 to 1.6 million tons CO₂ (compared to a scenario without EV), depending on the charging mode (Figure 7). A negative (decreasing) CO₂ balance is achieved in the EM+ scenarios (-2.1 to -1.3 million tons CO₂), but this is caused by assumed lower emissions of ICE cars (more ambitious CO₂ emission standards compared to the BAU scenario). In both BAU and EM+, specific CO₂ emissions of EV are still higher compared to ICE cars by 2030, as emission improvements in the power plant fleet are compensated by improvements of conventional cars. In the cases with additional renewable capacities (RE+), EV become largely CO₂-neutral even when considering the power sector only, and the overall CO₂ balance becomes as low as -6.9 million tons CO₂. Thus, the potential for EV-related CO₂ mitigation is fully exploited only in the RE+ scenarios.

Figure 7: Net CO₂ balance of transport and electricity sectors in 2030 (in million tons CO₂, comparison to the scenario without EV and without additional renewables)



Policy conclusions

First, the overall energy requirements of electric vehicles should not be of concern to policy makers for the time being, whereas their peak charging power should be. With respect to charging peaks and system security, the cost-driven charging mode is clearly preferable to the user-driven mode. Because of generation adequacy concerns, purely user-driven charging may have to be restricted by a regulator in the future, at the latest if the vehicle fleet gets as large as in the 2030 scenarios.

Second, policy makers should be aware that cost-driven, i.e., optimized, charging not only increases the utilization of renewable energy, but also of hard coal and lignite plants. If the introduction of electromobility is linked to the use of renewable energy, as repeatedly stated by the German government, it has to be made sure that a corresponding amount of additional renewables is added to the system. With respect to CO₂ emissions, an additional expansion of renewables is particularly important as long as substantial – and increasingly under-utilized – capacities of emission-intensive generation technologies are still present in the system. Importantly, from a system perspective it does not matter if these additional renewable capacities are actually fully utilized by electric vehicles exactly during the respective hours of EV charging.

We suggest a third – and related – conclusion on CO₂ emissions of electric vehicles. Cost-driven charging, which resembles market-driven or profit-optimizing charging in a perfectly competitive market, can only lead to emission-optimal outcomes if emission externalities are correctly priced. Otherwise, cost-driven charging may lead to above-average specific emissions, and even to higher emissions compared to user-driven charging. Accordingly, policy makers should make sure that CO₂ emissions are adequately priced. Otherwise, some kind of emission-oriented charging strategy would have to be applied, which is possible in theory, but very unlikely to be implemented in practice.

Last, but not least, we want to highlight that the introduction of electromobility should not only be evaluated with respect to CO₂ emissions. EV may also bring about other benefits such as lower emissions of other air pollutants and noise, and a reduced dependence on oil in the transport sector. In

particular, EV allow the utilization of domestic renewable energy in the transport sector without relying on biofuels.

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4. Simulation of the Effects of Electromobility on the Electricity System for Austria and Germany in 2030

Gerhard Totschnig, Markus Litzlbauer

Institute for Energy System and Electrical Drives, TU Vienna

Summary: A high-resolution power and heat system simulation model (HiREPS) for Austria and Germany was deployed to compare the relative impact and cost factors for market-led and non-market-led charging. Further investigations assessed how electric vehicle owners' charging behaviour impacted the benefits of market-led charging.

Introduction

This analysis is based on the HiREPS high-resolution simulation model from TU Vienna. The model optimises unit commitment and investment in power generation capacity, pumped hydro power expansion, and simulates and optimises the coupling of the electrical/thermal system in cogeneration plant for district heating and by P2H (power to heat, i.e. use of power by the heating sector) across all space heating/hot water production sectors. It simulates potential use of industrial load management, alternative storage options such as adiabatic compressed air energy storage and power to gas, while simulating electric vehicle charging for multiple charging strategies.

The simulation of the charging of electric vehicles (EVs) was performed for 100 representative drive profiles and 6 types of EV, based on data from vehicle use surveys in Austria and Germany.

2030 scenario assumptions

A total of 6 scenarios were assessed for 2030. Market-led (ML) and non-market-led (NL) charging on the one hand, plus for each an assumption of frequent (FC) or infrequent (IC) charging. Frequent charging makes the assumption that the electric vehicle owner will always hook the EV up to a charging point if the opportunity presents itself at a stop. Conversely, if electric car owners connect their vehicles to charging points only if the battery is so low that it must be charged in order to use electric power for as many subsequent journeys as possible, this type of user behaviour is termed *infrequent* charging. For the 2 market-led charging scenarios (frequent/infrequent charging), a scenario with and without V2G was each simulated for battery electric vehicles.

In the HiREPS simulations depicted here, Austria and Germany are analysed together. Fuel costs and power plant capacities for Germany are taken from Scenario B of the scenario framework for the Electricity Grid Development Plan 2013 [1]. For Austria, maintenance of thermal capacities at 2012 levels has been assumed, plus an installed PV capacity double that of the 2020 target in the Green Electricity Act 2012 and a wind power rollout equalling 50% of the feasible potential for 2030 as simulated in the AuWiPot project [2]. Based on the 2011 PRIMES reference scenario, an increase in electricity demand of 10% has been assumed as regards 2010 [3].

In the EMOB+ 2030 scenario analysed here, 6.4 million cars (13% of all cars) use electric power in 2030: 20% as battery electric vehicles (BEVs) and 80% as plug-in hybrid vehicles (PHEVs). For PHEVs, a simplification was made by assuming that these drive using only electricity until the battery is empty, and then use diesel or petrol. Further assumptions were made that all electric cars can charge at night, that 15% of all cars have a charging point at the workplace and that 30% of stops at public facilities offer a charging point. The lifetime of modern batteries used in electric vehicles is currently limited to

around 3000–5000 full cycles at a 100 percent depth of discharge of the nominal capacity or a service life totalling 12 calendar years. The use of car batteries as storage for the national grid (vehicle to grid, V2G) was viewed as possible only in cases where 3000 full charging cycles had not been exhausted in normal driving within the 12-year period. In complying with this criterion, the simulated drive profiles permit V2G operation only for BEVs (see **Figure 3**).

To ensure that market-led charging does not infringe grid restrictions in the low-voltage grid, the figure of 3 kW is implemented in the HiREPS model as the scenarios' maximum total power per household (i.e. electrical load of household appliances, plus electric vehicles and power to heat plant).

GW Installierte Leistung 2030		
	AT	DE
Wind-Land	4.6	61.2
Wind-OffSh		21.9
PV	2.4	64.1
GuD	5.1	38.6
Steinkohle	1.2	21.9
Braunkohle		13.5
Preise 2030		
Kohle	Euro/MWh	10.31
Braunkohle	Euro/MWh	1.50
Erdgas	Euro/MWh	26.70
CO2 Preis	Euro/tCO2	39.60

Table 1: 2030 scenario assumptions

EMOB+ Scenario: AT+DE	2020	2030
small BEV-small	59,695	634,340
PHEV-small	96,317	979,269
mid-size BEV-medium	53,686	547,301
PHEV-medium	161,616	1,580,138
large BEV-large	1,677	65,625
PHEV-large	213,638	2,563,584
Total EV	586,629	6,370,257
Alle Autos	47,222,830	47,986,415
	%	1% 13%

Table 2: Vehicle fleet in the scenarios

Simulation

Figure 1 provides an illustrative example of power generation and electricity consumption for the "market-led and frequent charging" (MD + FC) scenario in Austria and Germany during summer 2030. The area segments depict generation while the line segments depict demand components. The black line is the normal electricity demand in 2030. The dark blue line supplements the normal electricity demand with power consumption from pumped storage hydropower plants. The red line then also adds in the market-led demand from the use of electricity by the heating sector (P2H) and industrial load management. The bright blue line then also adds in the electricity consumed by the charging of 6.4 million EVs, led by the electricity market.

One can see that the electric vehicles contribute to the integration of the 66.5 GW of PV into the electricity system in summer, by creating an additional load at noon, while also contributing to increased demand at night. The diagram also illustrates how the simulated flexibility options – pumped storage, industrial load management, power to heat and 6.4 million EVs – enable the thermal power stations to enjoy relatively smooth operation, despite the major fluctuations in normal load and renewable energy generation. V2G grid feed-in is indicated by dark green areas. V2G exhibits similar application characteristics as pumped storage and an example area is marked with the red arrow.

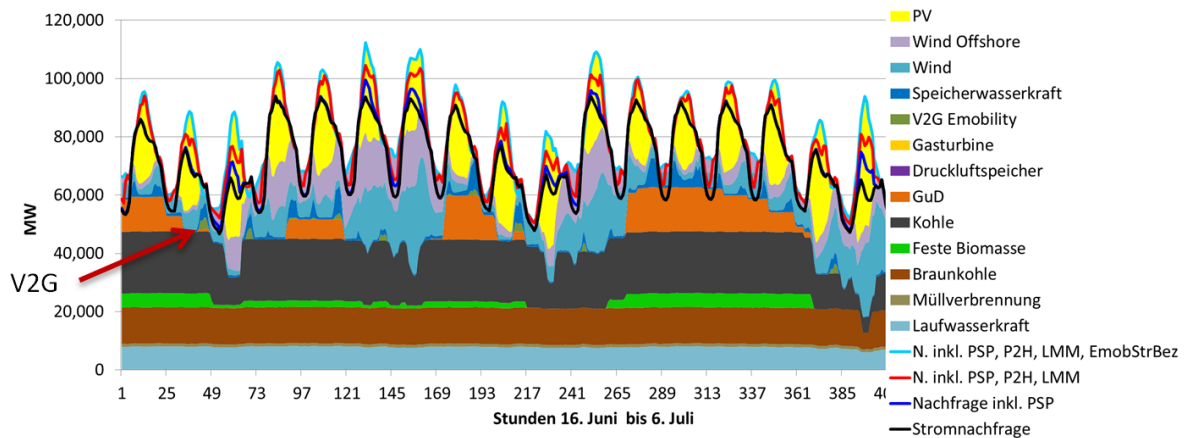


Figure 1: Power generation and consumption for Austria + Germany, summer 2030

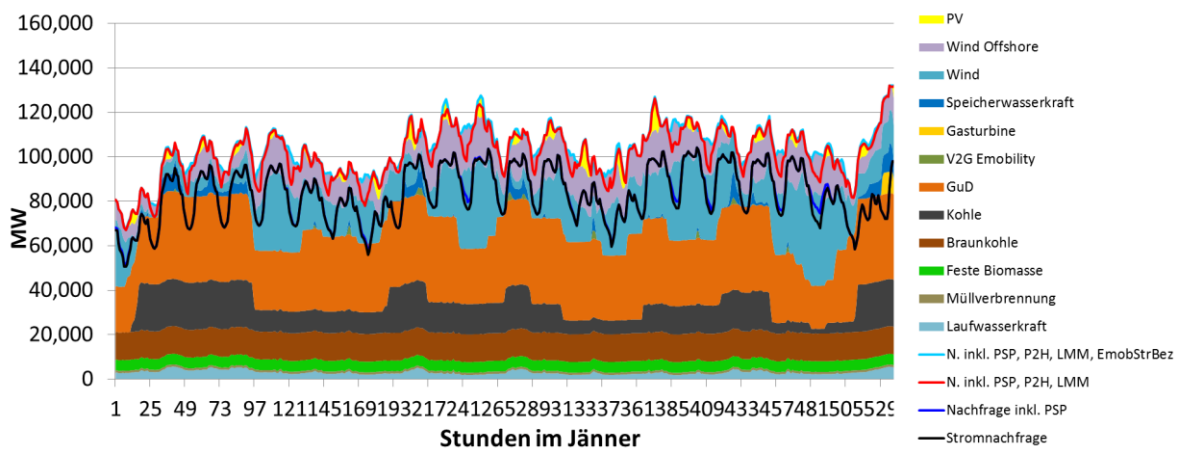


Figure 2: Power generation and consumption for Austria + Germany, winter 2030

The diagram for winter is similar (see **Figure 2**). Here, however, the market-led power draw from electric vehicle use is concentrated more on night-time hours, enabling smooth operation for thermal power plant. Demand from EV use for Austria and Germany with 6.4 million electric vehicles amounts to 17 TWh (without V2G power draw). The V2G power supply amounts to 1.6 TWh. As can be seen from **Figure 3**, the charging cycle limit of 3000 full cycles in 12 years is not exhausted even with V2G operation of BEVs.

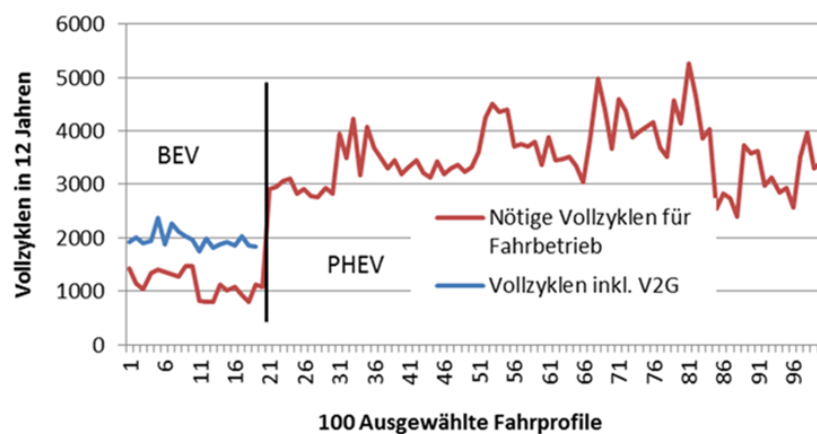


Figure 3: Full charging cycles for the 100 simulated drive profiles for EV use.

The maximum V2G power feed-in amounts to 5.4 GW (see **Figure 4**).

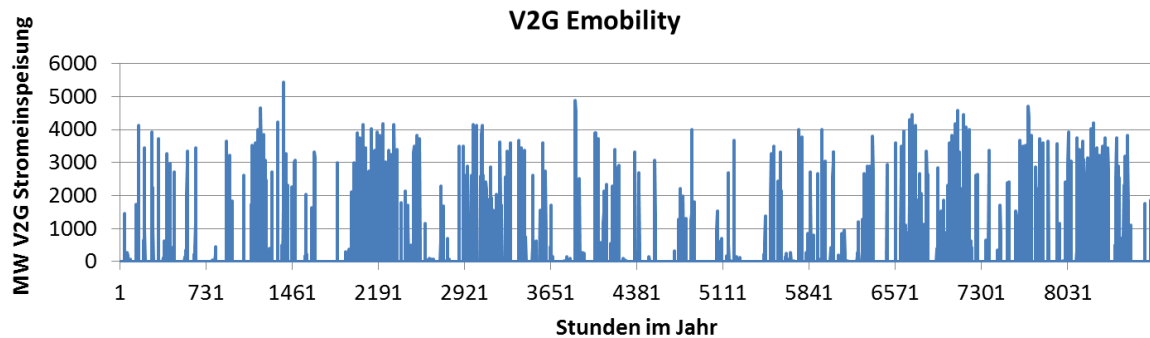


Figure 4: V2G usage during the 8760 hours of the simulated year.

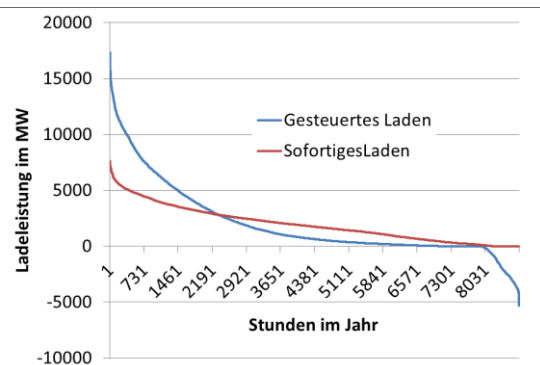


Figure 5: Duration curves for EV charging capacity in the scenarios "market-led, frequent charging with V2G" (MD+FC+V2G) and "non-market-led, frequent charging" (ND+FC).

Figure 5 shows the duration curves for the scenarios "market-led, frequent charging with V2G" (MD+FC+V2G) and "non-market-led, frequent charging without V2G" (ND+FC). The maximum charging current for market-led charging of 6.4 million cars amounts to 17.4 GW. At 7.6 GW, the charging current for non-market-led charging is much lower. This is because vehicle usage and idle times are sufficiently well-distributed to avoid major cases of concurrency – even if charging takes place immediately on arriving at the charging point. In contrast, market-led charging creates significantly greater concurrency between charging events. This is desirable, however, since the market signal (cheap electricity) is sent only if generation surpluses exist in combination with low electricity demand. Accordingly, market-led charging does not work to increase the maximum electricity demand. Conversely, non-market-led charging causes the maximum electricity demand to rise by 7.1 GW. As explained above, a figure of 3 kW was used from the outset in the HiREPS model for the market-led charging scenario as the maximum total power per household (electrical load of household appliances, plus EVs and "power to heat" plant), to ensure that no infringements are made to grid restrictions in the low-voltage grid. A detailed simulation was made of the impact of the market-led charging simulated here on the low-voltage grid for the Policy Brief by Markus Litzlbauer.

The electricity volume transferred by market-led charging versus non-market-led charging amounts to 12.6 TWh for Austria and Germany in 2030. The 6.4 million cars simulated thus surpass pumped storage (after optimum pumped storage rollout) in terms of the transferrable electricity volume: the power draw of pumped storage amounts to 8.3 TWh for the non-market-led charging scenario and 4.5 TWh for the market-led charging scenario.

The cost savings from market-led charging (ML+FC) amount to €179m/year or €28 per electric vehicle per year. For the 100 drive profiles simulated, the electricity cost savings from market-led charging (ML+FC) varied from €52 to €13 per EV per year. Electricity cost savings from V2G operations (ML+FC+V2G) amount to €9m/year or €10 per BEV per year. This V2G saving is in addition to the savings achieved by market-led charging. For the 20 battery electric vehicles simulated, electricity cost savings vary between €13 and €7 per BEV and year.

The figures stated above are based on the frequent-charging scenarios (see scenario definitions above). In accompanying research conducted by TU Vienna for "ElectroDrive Salzburg" [5], however, an idle time of over 2 days was required before half of the vehicles were connected to charging points. Further research was therefore conducted to study the impact of infrequent charging by EV owners (see scenario definitions above). This research revealed that market-led and infrequent charging (ML+IC) reduced the cost savings compared to market-led and frequent charging (ML+FC) by 17%, and amounted to €148m/year or €23 per electric vehicle and year. For the 100 separate drive profiles simulated, the electricity cost savings from market-led and infrequent charging (ML+IC) varied from €40 to €7 per EV per year.

For market-led and infrequent charging (ML+IC), the cost savings from V2G are reduced in comparison to ML+FC by 85% and thus amount to a mere €1.5m/year or €1.50 per BEV and year (contrasted with €9m per year in the ML+FC+V2G scenario). This V2G saving is in addition to the savings achieved by market-led charging.

The average number of hours that the electric vehicles spend connected to charging points is reduced for BEVs from 6553 h in the case of frequent charging to 1811 h (-72%) in the case of infrequent charging. For PHEVs, these hour totals change from 6822 h for frequent charging to 4702 h for infrequent charging (-31%).

Conclusions

In the simulated EMOB+ 2030 scenario, EVs make up 13% of all vehicles. With this proportion of electric vehicles, market-led charging leads to more uniform, smoother operations for thermal power plant and reduces dependence on pumped storage. If electric vehicle owners connect their EVs to charging points whenever possible (here termed "frequent charging"), the combined cost savings in 2030 for Austria and Germany with market-led compared to non-market-led charging amount to €179 million/year or €28 per electric vehicle and year. Cost savings from using V2G amount to €9m/year or €10 per BEV per year. Conversely, if electric car owners connect their vehicles to charging points only if the battery is nearly drained and must be charged in order to use electric power for as many subsequent journeys as possible (here termed "infrequent charging"), the cost savings from market-led charging are reduced by 17% and the cost savings from V2G by 85%, compared to frequent charging. This analysis does not consider IT costs, nor the costs for modifying the charging systems to use market-led charging or V2G.

As the proportion of EV usage increases, so too does the need to use market-led charging.

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5. The Impact of Electric Vehicle Integration on the Low Voltage Grid (scenarios up to 2030)

Markus Litzlbauer

Vienna University of Technology, Institute for Energy System and Electrical Drives

Abstract – Charging the batteries of electric vehicles will take place to a large proportion decentralized in private space (at home or at work). This directly results in an additional grid load on the existing low voltage grids to which the necessary charging infrastructure is connected. In the research project "DEFINE" different EV penetration scenarios were expected by 2030 with a share of electric vehicles (BEV and PHEV) of up to 16 % of the total Austrian vehicle stock.

Using load flow calculations the effects of uncontrolled and cost-based controlled charging were examined on the basis of a representative low voltage grid. The results show that under the chosen conditions neither grid components will be overloaded or voltage limits are violated.

However, to use the grid infrastructure efficient and as long as possible, the charging of electric vehicles in private space (at home or at work) is recommended with a low power level. Furthermore, a three-phase charging is to prefer to achieve a balanced grid load.

Introduction

Towards a sustainable and environmentally friendly mobility in the motorized individual transport, it is necessary to increase the electrification of the power train. This change, however, means that the charging of electric vehicles (EV) will take place not only at neuralgic points in the (semi-)public space, but to a large proportion decentralized in private garages and parking spaces (Leitinger 2011). This leads – depending on the connection power and the EV penetration – to a significant additional grid load in the low voltage systems. Furthermore it leads on the one hand to an increased utilization of the grid components (e.g. transformer and cables) and on the other hand to a reduced local voltage.

The completed research project "V2G-Strategies" (Prüggler 2013) showed that cost-based controlled charging can increase the simultaneity of charging processes (same connecting powers assumed) and that the existing grid resources will be more stressed than in the case of uncontrolled charging. Based on this knowledge the grid restrictions in the research project "DEFINE" were already considered in the very beginning of the modelling of the charging strategies. The Vienna University of Technology has analyzed the impact on the low voltage grid of various scenarios with the help of load flow calculations. The methodology and the results are discussed below.

Grid analysis on the low voltage level

The basis for the analysis is a low voltage grid model of a residential area, which represents the Austrian building situation and housing conditions. The settlement involves a population of 300 people in 126 households and 60 residential buildings.

To simulate simultaneously single areas in the settlement with low and high power densities, a mixed approach of radial and open loop distribution systems was chosen. The open loop represents the urban area, while the radial grid segment – with partly very long feeders – represents the rural area.

Based on practical experiences characteristic cable lengths for the different grid areas as well as typical building types were adopted. Taking into account the cable data for standard types, the whole electrical low voltage distribution grid was fully mapped in the load flow calculation program NEPLAN®. For the electrical connection powers also typical values for households – according to the respective build-

ing categories – were assumed and for the individual households synthetic, appliance-based load profiles for an entire calendar year were deposited (Zeilinger 2014). The synthetic load profiles have compared to standardized, normalized H0-household load profiles the advantage that they replicate the load peaks more exactly and provide more plausible results for analysis in low voltage grids.

In the research project "DEFINE" different EV penetration scenarios for electric vehicles were expected by 2030. This results in a maximum share of electric vehicles (BEV and PHEV) in the total Austrian vehicle stock of up to 16 %. Based on these EV penetrations various cost-based controlled and uncontrolled charging strategies were applied by the Vienna University of Technology. For every considered electric vehicle a charging profile for an entire calendar year was determined.

In addition to the involved electrical loads of the household, the charging profile for each electric vehicle was assigned to different grid nodes in the settlement grid model.

Using load flow calculations the impact of various scenarios on the low voltage grid were investigated. Thereby, an extreme case has been adopted, in which the overlaying grid has already a high degree of capacity utilization ("peak-load"), caused through intensive electrical demands. Based on these grounds the remaining voltage reserve for the observed low voltage grid is only 6 % (Maier 2014). However, in this worst-case scenario, none of the low voltage grid components (transformer or cables) was thermally overloaded and no voltage limit at any grid node was violated.

Conclusion

For a EV penetration (BEV and PHEV) of up to 16 % of the total Austrian vehicle stock and connection power per charging point of 3.7 kW (single-phase) and 11 kW (three-phase) no violations of grid constraints (thermal and voltage limits) on the low voltage level are expected.

In future the charging loads of electric vehicles, corresponding to the degree of EV penetration, will inevitably lead to grid congestion problems on the low voltage level. Therefore, it is recommended to use low charging power levels and a symmetrical three-phase connection to preserve existing grid reserves. In addition, it should be noted that in grid sections with long feeders (with already high utilization) grid bottlenecks may already occur earlier.

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6. Economic Costs and Benefits of Electromobility

A Model-based Analysis

Michael Miess, Stefan Schmelzer

Institute for Advanced Studies (IHS), Vienna

This synthesis report offers an overview of the main results of a model-based assessment of the costs and benefits of an increased penetration of electric vehicles in Austria. Effects are obtained from a macro-economic computable general equilibrium (CGE) model for the Austrian economy. In DEFINE, this model was specifically extended and enhanced in relation to the transport sector.

6.1. Introduction

The traffic sector is one of the major emitters of greenhouse gas (GHG) in Austria: 21.7 million t (27 % of total emissions) in 2012 primarily attributed to road traffic. The sectoral targets of the Austrian climate strategy are missed to the highest extent in the traffic sector: emissions exceeded the sectoral targets of 19.9 million t in 2012 by 15 %; the increase from the year 1990 to 2012 was 54 % (Environment Agency Austria, 2014). These numbers point to a need for action in the traffic sector to reach given environmental and climate targets.

There has been an ongoing debate whether alternatively fuelled vehicles, especially battery electric vehicles or plug-in hybrid electric vehicles, offer a solution to obtain a low-carbon emission transport system that still heavily relies on individual transport using passenger cars. The objective of the analysis presented here is to answer the question: which costs and benefits arise for a higher market penetration of electromobility in individual transport? What is the role of government incentives, and how do different measures for the support of electromobility affect economic growth? Can electromobility breach the growth dynamics of CO₂ emissions under economically supportable costs?

The analysis of these costs and benefits is conducted on the basis of a macro-economic computable general equilibrium (CGE) model specially designed for this task in DEFINE. The model was specifically expanded and tailored to depict electromobility in motorised individual transport. A special role is taken by the preferences of households regarding electromobility in their vehicle purchase decision. These preferences have been investigated within a representative household survey for Austria in the project and have been implemented in the macro model. A distinction was made between conventional cars (CVs) fuelled by gasoline or diesel, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs). The vehicle fleet is explicitly calculated in the CGE model according to annual depreciation and new registrations, so that the inertia in vehicle stock developments is explicitly considered.

The electricity sector is depicted in the macro model on a technology level and was calibrated to the additional demand of an increased stock of electric vehicles according to inputs of a detailed electricity market model of the Vienna University of Technology.

Private households are disaggregated into nine different groups. We differentiate between household types according to highest education attained (low, medium and high skilled), and according to degree of urbanisation (urban, sub-urban and rural), since we expect different effects and preferences in relation to an increased market penetration of electric vehicles.

The government sector is modelled in detail: different tax instrument such as a mineral oil tax (“Mineralölsteuer” or MoeSt) on gasoline and diesel for the individual transport sector, the new registration tax for cars in Austria¹ (NoVA), taxes on consumption, labour and capital, as well as different energy taxes for households and firms are explicitly considered in the model.

6.2. Model Simulations

We calibrated the model to a steady state growth path, where we assume an average long term growth rate of 1% per year. This balanced growth path represents a realistic development of the Austrian economy. It includes assumptions regarding the expansion of renewable energy technologies in electricity production, CO₂ regulation for vehicle fleets, and the development of fuel and car purchase prices. Furthermore, the reform of the Austrian new registration tax for cars and the increase of mineral oil tax in 2011 are considered. However, a higher penetration rate of electric vehicles and the expansion of a charging station system for electric vehicles are not included.

In our simulations the growth path described above that excludes electromobility was compared to the following scenarios:

- A Business-As-Usual (BAU) scenario with realistic market penetration of e-mobility and without government incentive measures
- An electromobility plus (EM+) scenario with enhanced public incentive measures for electromobility

Both scenarios were designed according to the elaborations by the Environment Agency Austria (Environment Agency Austria 2014: Ibesich et al., DEFINE project report), see section 2 of this report. The macro CGE model at this point is primarily used to investigate the according overall economic costs of the increased penetration of electric vehicles².

BAU Scenario - Assumptions

The „Business as Usual“ (BAU) scenario describes a moderate projection of implemented and decided-upon political measures in Austria, as well as a penetration of electric vehicles according the vehicle stock calculations by experts of the Environment Agency Austria (EAA). In the macro model a preference shift of households to electromobility was simulated, so that the vehicle fleet projections for the BAU scenario by the EEA for the years 2008 to 2030 (see section 2) were replicated. Furthermore, to-be-expected investments into the expansion of infrastructure for electromobility were explicitly considered. We assume a rather low number of 1.25 charging stations per electric vehicle, prices at the lower end as provided by producers of this infrastructure as well as a low amount of charging stations in semi-public (workplace) and public environment. Thereby, we calculate a total sum of investment of about 1.5 billion Euros for the time between 2008 and 2030 in connection with the vehicle stock calculations by the Environment Agency Austria. Per electric vehicle we have investment costs amounting to ca. 2,250 Euros, whereby we assume a linear cost degression of 33 % until 2030 so that the costs per vehicle reduce to about 1,500 Euros in 2030. The additional demand for the provision of this charging infrastructure is attributed to the building sector by about 57 %, by ca. 33 % to the engineering sector

¹ The tax rate of this new registration tax, the NoVA (“Normverbrauchsabgabe”), is related to vehicle emissions, favouring low emission vehicle types and currently includes a rebate of 500 Euro for HEVs, PHEVs and BEVs, implementing a feebate system for electric vehicles.

² All indications of costs in this section are given in real Euro of the year 2008 (base year of the model).

and by ca. 10 % to the service sector³. Furthermore, we make the model assumption that these investments are fully financed by the private sector with an according business model that takes into account the increased market penetration of electromobility.

Results of the BAU scenario are compared to the steady state growth path without the expansion of electromobility described above. Thereby, we want to assess the effect of electromobility on the development of relevant macro-economic indicators such as government revenue and the gross domestic product (GDP).

Results - BAU

The expansion of charging stations clearly has positive effects on domestic GDP in Austria due to the stimulating effect of the additional investments. Due to a high share of domestic value added mostly in the building sector, most of these effects remain within Austria. The positive net effects on domestic GDP amount to between ca. 68 million Euros (0.02 %) in the year 2015 and ca. 143 million Euros in 2030 (0.03 %), with a smooth development in the years in-between.

The increased penetration of electromobility, however, resulting in a stock of 886,000 electric vehicles in the year 2030 due to a preference shift of the Austrian population, has slightly negative effects on domestic GDP: growth decreases by about 73 million Euros (0.02%) in 2015 and by ca. 263 million Euros in 2030 (0.07 %), with an almost linear progression in-between. This reduction can be attributed to shifts due to the changed structure of intermediate inputs⁴ as electric vehicles replace conventional ones, as well as to a lower demand for individual transport. While the former effect relates to an increased import share for the Austrian economy leading to a rather small reduction of domestic GDP, the latter has higher impacts. PHEVs and BEVs have a higher purchase price on average, and thereby the price for the bundle of goods “individual transport” rises in the model. Households react to this development and shift part of their demand for transport services to public transport and reduce their transport demand by a small amount.⁵ In total, this leads to a slightly negative effect on Austrian domestic GDP.

Altogether, the increased penetration of electric vehicles, due to both the opposite effects delineated above, has rather low economic costs. The latter are almost neutral in 2015 and costs in domestic GDP rise up to ca. 120 million euros (0.03 %) in 2030. The additional investments in infrastructure even have positive effects on growth.

What has to be pointed out at this stage is the fact that this scenario does not entail an absolute reduction of GDP. Rather, it describes a reduction in comparison to the balanced growth path, which was conservatively set to 1 % yearly. The Austrian economy grows with 0.97 % on average in the BAU scenario, a rather slight reduction of 0.03 percentage points from the balanced growth path.

Relating to the figure of 1 million tons of CO₂ emission reduction as calculated by the Environment Agency Austria for 2030 (see section 2), the economic net costs⁶ for saving a ton of direct CO₂ emis-

³ Assumptions to the sectoral allocation of the provision of charging infrastructure are based on calculations as part of the project ECONGRID, Bliem et al. (2013).

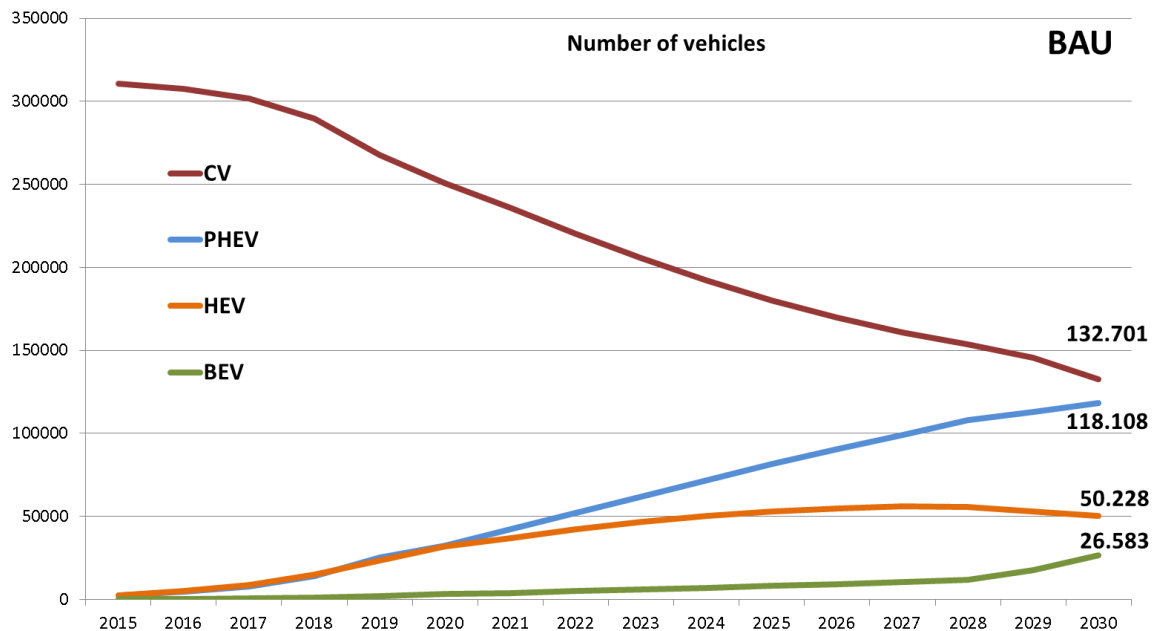
⁴ See Miess et al. (2014) for the sectoral structure of the model and assumptions for the construction of the vectors of intermediate inputs for the different vehicle types. Conventional vehicles, according to assumptions by IHS, almost exclusively require intermediate inputs from the sector “Motor vehicles, trailers and semi-trailers”, whereas electric vehicles (PHEV and BEV) use intermediate inputs from the engineering sector to a higher extent (mostly for the battery).

⁵ This effect is due to the assumed consumption behaviour of households in the macro model: the price of the good individual transport increases because of the on average higher purchase price for electric vehicles. This leads to a reduction of total consumption of transport services by households, since the price increase cannot be completely compensated by substitution with other goods.

⁶ Economic net costs in the CGE model relate to those costs that arise due to the intertemporal optimization behavior of households and because of the political measures

sions amount to 120 Euros⁷. However, in this scenario already more than 44 % of new registrations are electric vehicles (PHEVs or BEVs) in 2030. Thereby, one can assume that under continuation of this trend (see Figure 8 for the development of new registrations in cars until 2030) CO₂ emissions in the transport sector will be substantially further reduced in the time span after 2030.

Figure 8: Development of New Registrations in Cars 2015 -2030



Source: Model calculations by IHS Vienna.

EM+ Scenario - Assumptions

The more progressive “electromobility plus (EM+)” scenario describes a clear expression of political intention regarding the support of electromobility. It is compared to the Business As Usual scenario illustrated before, which depicts a realistic penetration of electric vehicles, and describes a more ambitious expansion path of electromobility. Thus, for the EM+ scenario, besides higher private investments in charging infrastructure, policy measures to foster an increased penetration rate of electric vehicles were simulated:

- Increase of mineral oil taxes in two steps:
 - 2015 and 2019: rise by 5 cent for each gasoline and diesel
- Reform of the feebate system (new registration tax - NoVA): setting the pivot to
 - 105 g/km from 01.01.2015,
 - 95 g/km from 01.01.2020
- Charging infrastructure: Expansion in three stages from low – medium – high until the year 2030

⁷ In relation to relevant literature, this value is rather low, see Thiel et al. (2010, p. 7149). There, the technological costs of CO₂ abatement for a medium scenario are about 180 Euros/t for PHEVs, and ca. 15 Euros/t for BEVs. With a share of more than 90 % of PHEVs in the total stock of electric vehicles in the DEFINE – BAU scenario for 2030, costs according to the estimations of Thiel et al. (2010) would amount to 163.5 Euros, clearly more than the 120 Euros given in this report. However, it has to be mentioned that overall economic costs calculated with the modelling approach chosen in DEFINE consider the reaction of households, firms and government to changes of the general economic equilibrium. Thus, due to different approaches of model-based analysis, the scope for comparison is only limited, since we estimate total economic costs rather than mere technological costs.

The amount of investments necessary for the additional expansion of charging stations relates to the qualitative features regarding availability of charging infrastructure that were given in the representative household survey for Austria in DEFINE (see Hanappi et al., 2013) for the different expansion stages. Along with this, the following assumptions regarding expansion stages were made:

- Low (until 2019): Charging stations available at private garages and parking places.
- Medium (from 2020): Charging stations available at key areas (working place, P+R facilities, shopping centres, car-parks) and at private garages and parking places.
- High (from 2030): Charging stations available comprehensively in public space, at key areas and at private garages and parking places.

The amount of investment for these expansion paths was estimated referring to relevant literature (WIFO 2011, Huetter, Stigler 2012, Bliem et al. 2013, among others), price information by producers and to own assumptions and calculations. Since at this point a scenario of a clear expression of intention by Austrian politics to electromobility is simulated, costs per vehicle for the highest expansion stage are assumed already beginning with 2025, five years earlier than in the EM+ scenario by the Environment Agency Austria (2030).⁸

The low – scenario for charging infrastructure was defined as in the BAU scenario described above. For a medium availability of charging stations from 2020 onwards, more charging stations per electric vehicle (1.3) were assumed with an increased focus on charging stations in semi-public and public space as well as on rapid charging stations. Prices for the different charging station types were located within a medium range of producer information. The costs of provision per electric vehicle amount to ca. 3,400 Euros in the year 2020, reduced by a linear cost degression of 33 % to about 2,700 Euros until 2025. From 2025 investments relating to a high availability of charging stations are assumed that take effect in 2030 and lead to the following situation: 1.5 charging stations per electric vehicle, 45 % of charging stations in semi-public or public space, with a high share of accelerated and rapid charging. Here, costs per electric vehicle amount to about 5,100 Euros in 2025, which is reduced to ca. 4,450 Euros in 2030 due to cost degression.

The total amount of investments comes to about 4.17 billion Euros for the years 2008 until 2030. A large part of these costs arises towards the end of this period. This can be mostly attributed to the strong growth of electric vehicle stock in the years 2025 until 2030 and the higher costs assumed.

The vehicle stock in the EM+ scenario is an endogenous result of the CGE model. Households react to an increase in mineral oil taxes and the new registration tax (NoVA), as well as to the raised availability of charging stations, and increasingly opt to buy electric vehicles in their car purchase decision. Due to different modelling and methodological approaches, the projections by IHS and Environment Agency Austria (see section 2) naturally differ.

Results - EM+

Also in this scenario the infrastructure investments induce positive growth effects. The positive net effects lie between an additional raise in GDP by 88 million Euros (0.03 %) in 2015 and 360 million Euros (0.1 %) in 2030, clearly more than in the BAU scenario.

⁸ Due to the political objective target, it can be assumed that the security of investment for firms in relation to electromobility is increased, inducing private investments for the provision of charging infrastructure to rise. Moreover, it is assumed that investments have to be increased already in 2025 to elicit the subjective perception of a higher availability of charging stations by the population. This draws on the qualitatively inferable hypothesis that a higher difference in the amount of charging stations is necessary to progress from a medium to a high expansion stage in order to subjectively convey an impression of a high availability of charging stations to the population.

The political measures, besides the positive environmental effects of a “greener” vehicle fleet, also have effects on government revenues and GDP (see below).

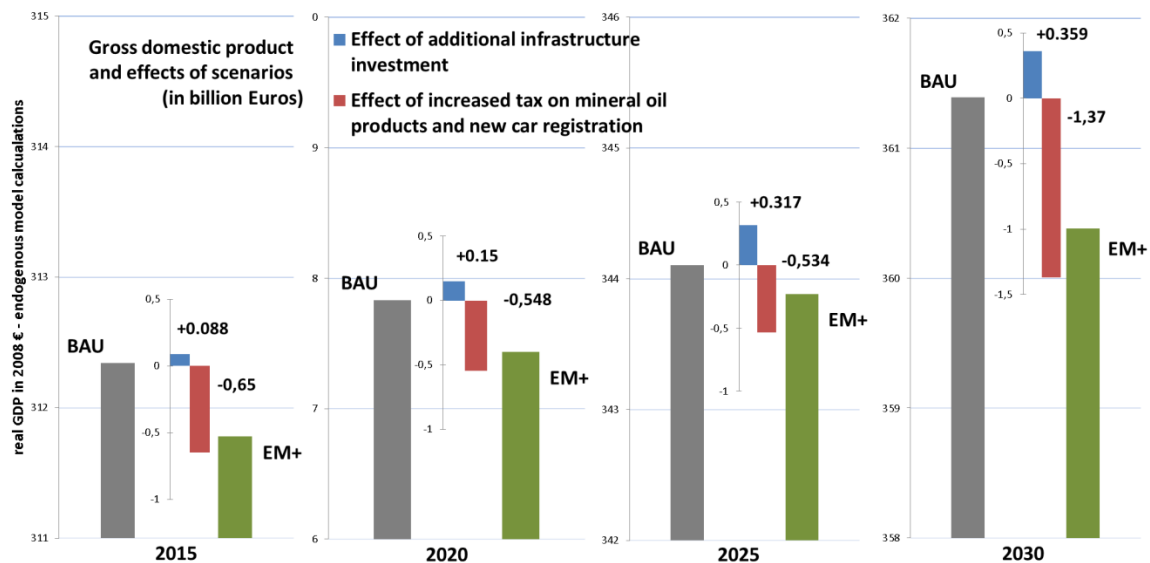
Especially for the increase in mineral oil taxes (as already observed for the last raise in 2011) one has to assume that it leads to a reduction of *price-induced fuel export* (“tank tourism”), which was explicitly considered in modelling. Based on calculations by the Environment Agency Austria an elasticity was calibrated that was implemented in the CGE model, where it reduces the demand for mineral oil products from Austria in foreign countries as well as the tax revenues arising from this foreign demand. Since we implicitly assume by this that there will be no parallel rise in fuel taxes in Austria’s neighbouring countries (e.g. Germany), we provide an upper estimation of the economic costs of the simulated policy measures. Altogether, the Austrian government suffers losses in mineral oil tax revenues between 85 million Euros in 2015 and 196 million Euros in 2030, while fuel exports decrease by 102 million Euros in 2015 and by 234 million Euros in 2030. Furthermore, an elasticity of demand for domestic consumption of mineral oil products was applied to assess the reduction of domestic fuel demand induced by an increase of the mineral oil tax.⁹ The effects on total consumption of mineral oil products resulting from these elasticities strongly enter model results and are responsible for a major part of the reduction in domestic Austrian GDP growth. Further burden on GDP growth ensues due to the framework scenario assumptions set for the consortium – including an increase of fuel and purchase prices for CVs within the car purchase decision of households – that negatively affect the consumption of fuels and vehicles.

The inhibiting effects of the additional tax burden from the increase of mineral oil taxes and the new car registration tax on the Austrian economy as well as the loss of revenues from price-induced fuel export for the corporate and public sectors induce economic growth to decline by about 650 million Euros (0.2 %) in 2015 and by 1.37 billion Euros (0.37 %) in 2030. The development in-between is influenced by the point in time at which the political measure is introduced (see Figure 9).

Altogether, due to the two opposite effects of infrastructure investments and tax increases outlined above, the political incentive measures to foster the introduction of electromobility seem to have supportable political costs in comparison to the BAU scenario: GDP is reduced by 563 million Euros (0.18 %) in 2015, and by 1.01 billion (0.28 %) in 2030 (see Figure 9). In the EM+ scenario, the Austrian economy on average grows by 0.95 % p.a. from 2008 – 2030, i.e. by 0.02 percentage points less than in the BAU scenario.

⁹ The value was chosen in accordance with the literature (Brons et al. 2008) and set to the short-term value of -0.34, since in the dynamic macro model of IHS yearly price effects are calculated. Thus, a short-term reaction of households and firms is calculated every year.

Figure 9: Gross Domestic Product - BAU and EM+, positive and negative effects in billion Euros p.a.



Source: Model calculations by IHS Vienna.¹⁰

Figure 9 clearly shows the development of GDP effects: costs for the tax measures (the red bars) are high in the years 2015 and 2019 (increase of mineral oil taxes and car new registration tax), and then decline slightly due to the adaptation behaviour by households in 2025. By the end of the period until 2030 costs rise because of the long-term impact of negative effects on investment rate and capital stock due to the loss in price-induced fuel exports as well as the higher tax burden, among others. Positive growth effects due to the expansion of charging stations (the blue bars) visibly rise in 2025 due to the higher expansion path for charging infrastructure. These two opposite effects lead to lower GDP levels in the EM+ scenario (the green bars) in comparison to the BAU scenario (the grey bars).

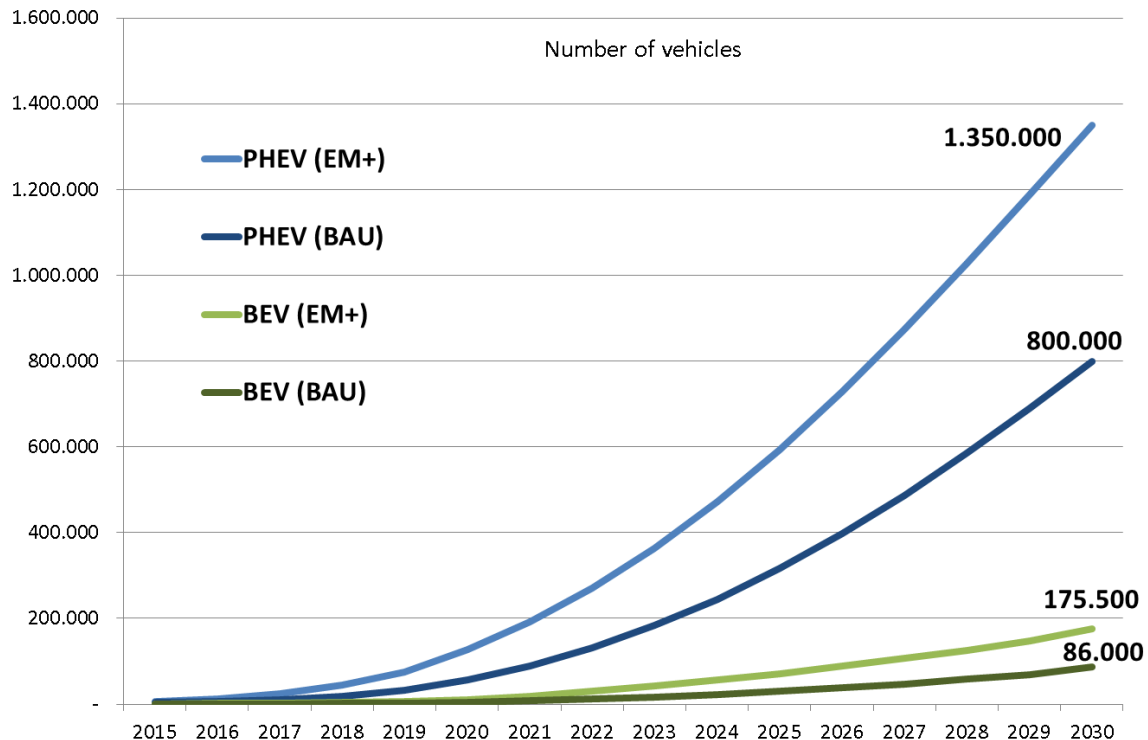
An increase in the rate of the mineral oil tax, even though reducing demand for mineral oil products and economic growth, still has a positive effect on government revenues. The latter is diminished by the decline of other tax revenues due to lowered overall economic activity. Also regarding revenues from the car new registration tax NoVA, the state suffers losses due to the shift in new car purchases towards the lower-taxed electric vehicles in later modelling periods due to their increased uptake then. All in all, however, the government receives a surplus budget of more than 508 million Euros in 2015 because of the first increase in the mineral oil taxes and the new car registration tax, and of 668 million euros due to the second rise in 2019. In-between and after this date, this surplus decreases but still remains positive in 2030 with 267 million Euros. In the model, the budget surplus was used for more government spending according to the structure of government consumption in the base year.

Altogether, according to results of the IHS macro model, the increase in mineral oil and new car registration taxes as well as the higher availability of charging stations, has significantly positive effects on new car purchases of electric vehicles in comparison to the BAU scenario. The number of electric vehicles in the vehicle fleet rises to 1,525,500 (BEV: 175,500 PHEV: 1,350,000), implying a rise of about 72.1 % in comparison to the BAU scenario. The amount of electromobiles thereby almost doubles in

¹⁰ GDP in the CGE model is an endogenous result. Starting from the base year (2008: 291.929 billion Euros), it is stated in real Euros of the year 2008. Short-term business cycles, such as the financial and economic crisis of 2008/2009, cannot be considered in this type of model. To partly compensate for this, a lower estimate for medium to long term growth of 1 % was taken as model input.

the EM+ scenario (see Figure 10). The percentage increase of BEVs is by far the highest (+ 104 %). The share of electric vehicles in the total vehicle stock already would reach 28 % in 2030.

Figure 10: Comparison vehicle stock BAU and EM+ in numbers of vehicles



Source: Model Calculations by IHS Vienna.

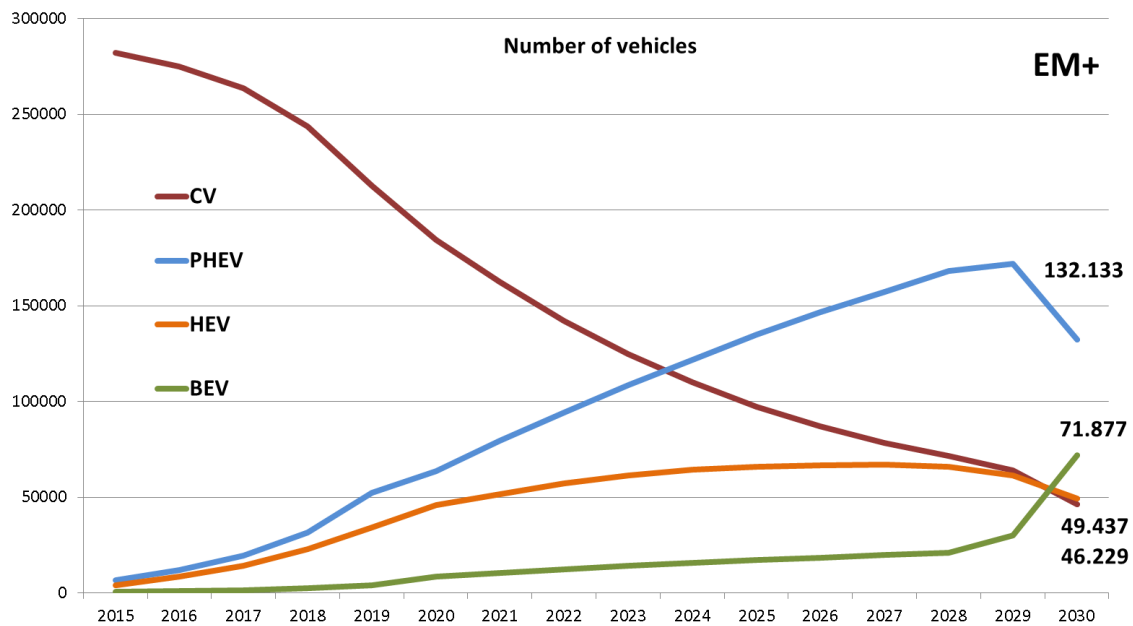
The reduction in CO₂ emissions of 1.2 million tons as calculated by the Environment Agency Austria (section 2) would be much higher according to these figures due to the higher market penetration rate of electric vehicles.¹¹ The share of newly registered electric vehicles in total new registrations already reaches 68 % in 2030, see Figure 11. In this graph it is clearly visible that already from the year 2023 on less conventional vehicles are sold than PHEVs and that in 2030 (high availability of charging stations) the amount of new registrations of BEVs strongly increases. With this result the modelling conducted for this study clearly shows that the market can react flexibly from the demand side, provided that the preferences of the population change. This means that a decisive structural change towards electromobility is possible, and with this a crucial innovation in the individual transport system, at supportable economic costs.

Furthermore, it should be mentioned that by the loss of price-induced fuel export for Austria the corresponding part of CO₂ emissions attributed to Austria will be assigned to one of its neighbours. Thereby, Austrian traffic-induced CO₂ emissions could be reduced by almost 30 % (cf. Kromp-Kolb et al. 2014, S. 76)¹². In relation to current EU climate targets and corresponding prices for CO₂ and thus possible government savings, this reduction could entail further positive economic effects, since government spending that would have to be used for the purchase of CO₂ certificates or any other payments due to falling short of emission targets could be directed to other purposes.

¹¹ More detailed emission accounting for this scenario can be conducted as soon as the corresponding module for the CGE model is completed by the Polish partner CASE. At the time of writing of this report, this module was not yet available.

¹² However, these estimations are associated with a high uncertainty according to the authors of the article.

Figure 11: Development of new registrations in number of vehicles in the EM+ scenario



Source: Model calculations by IHS Vienna.

Scientific Progress in DEFINE

For modelling in DEFINE, the computable general equilibrium (CGE) model MERCI¹³ was expanded and applied.

To this purpose, a representative household survey was conducted in Austria (1449 respondents) and a discrete choice experiment between car types with different drivetrains was realised.¹⁴ The respondents could choose between different vehicle types (CV, HEV, PHEV, BEV) in a hypothetical car purchase situation. Based on a microeconomic model estimated from this discrete choice experiment, an innovative micro-macro link between a discrete choice model and the macro-economic model MERCI was implemented. Thereby, the demand for electric vehicles, explained by empirical data, can be simulated directly in the macro model. This is a scientifically innovative approach to depicting the market introduction of a technological innovation in the transport sector within a computable general equilibrium model.

Furthermore, a detailed vehicle fleet model was integrated into the macro model. Cars in physical units are explicitly considered, as well as the expenditures of households for these vehicles, which represents another extension to standard CGE models. New registrations are calculated according to the survey-based preference structures of households regarding their vehicle purchase decision between the different vehicle types. The depreciation within the vehicle fleet is determined by the amount of cars purchased 12 years before the current period (vintage accounting). Thereby, inertia and age structure of the vehicle fleet can be considered, and the yearly dynamics of the penetration rate of electric vehicles can be depicted realistically.

¹³ 'Model for Electricity and Climate Change Policy Impacts': the model, based on literature (Böhringer and Rutherford, 2008), was adapted to Austria and expanded in DEFINE. For a description of the base model used in DEFINE, see Miess et al. (2013, DEFINE project report). The base year of the model is 2008.

¹⁴ For documentation of the survey see Hanappi, Mayr (2013, DEFINE Project Report).

Further progress in relation to comparable models is achieved by the detailed consideration of the electricity sector (disaggregated into electricity producing technologies¹⁵) in connection to electromobility. The electricity market, which is depicted in a yearly aggregate in the CGE model, is calibrated to the detailed electricity market modelling results of the Vienna University of Technology and is directly related to the amount of electric vehicles (BEVs and PHEVs) in the macro model. Thereby, emissions and investment costs for the electricity system that are due to the increased market penetration of electric vehicles can also be considered.

6.3. Conclusions

Altogether, it has been shown that electromobility can make a significant contribution to the reduction of CO₂ emissions in the traffic sector under supportable economic costs. An essential precondition for this, however, is the preference shift to electric vehicles by households that is assumed in the BAU scenario. The magnitude of this shift is based on the representative household survey for Austria as well as on the detailed vehicle fleet modelling by the Environment Agency Austria (section 2).

In the BAU scenario as well as in the EM+ scenario investments in charging infrastructure have expansive economic effects. Thereby, an example is shown that the ecologisation of society can also contribute positively to growth.

In comparison to the BAU reference scenario, the fleet penetration rate of electric vehicles in the EM+ scenario can almost be doubled by a clear expression of political intention and an intensified taxation of purchase and use of conventional vehicles. These incentive measures might have slightly negative effects on GDP growth, but lead to higher net government revenues.

Due to the large share of electric vehicles in new registrations, a significant shift of vehicle stocks towards electric vehicles can be expected for the years after 2030 because of the vehicle fleet depreciation of conventional vehicles. This shows that the measures investigated in this study designed to support electromobility can effectively counteract the ongoing growth of CO₂ emissions in the traffic sector in Austria.

Beyond that, the model simulations show that the vehicle market depicted in the model can react flexibly to a shift in preferences by consumers towards electromobility. Thereby, according to model results, structural change in the direction of electromobility and hence a decisive innovation in individual transport is possible at supportable economic cost.

¹⁵ Technologies in the model: water (running water and pump storage), wind, biomass and biogas, photovoltaics, landfill and sewage gas, natural gas, coal.

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7. External costs of Electromobility

Milan Ščasný, Jan Weinzettell, Vojtěch Máca

Center for Social and Economic Research (CASE), Warsaw

Michael Miess, Stefan Schmelzer

Institute for Advanced Studies (IHS), Vienna

This synthesis report provides the results on quantification of environmental benefits due to electromobility. Specifically, we quantify the environmental benefits attributable to air quality and GHGs pollutants for BAU and electro-mobility scenario. ExternE's Impact Pathway Analysis was linked to the hybrid CGE model in order to relate predicted effects on economy to the pollutant-specific damage factors.

For Austria, we found that in total EM+ is environmental-saving policy, i.e. EM+ generates total net environmental benefits cumulated until 2030. We found that EM+ scenario in comparison to BAU generates overall smaller externalities but the year-by-year differences are very small in absolute magnitude, corresponding to about -0.3% in relative terms. EM+ generates small benefits due to changes in the structure of domestic economic sectors, while changes in vehicle fleet and fuel use solely will result in about 2.5 times larger benefits. Annual environmental benefits of EM+ are about 80 to 90 million EUR after 2025. EM+ scenario would also lead to changes in electricity market that would result on the contrary in damage of value about 10 to 33 million EUR in the same period as the benefits would be generated. This environmental damage is however not sufficiently large to counterbalance the environmental benefits, yielding overall net benefits.

7.1. Method

The effects on economy and electricity generation are quantified by means of the hybrid computable general equilibrium model as developed in other Work Packages within DEFINE project. Environmental benefits attributable to air quality and GHGs pollutants due to electro-mobility are then quantified using ExternE's Impact Pathway Analysis as developed within the most recent ExternE projects (Externalities of Energy). In order to quantify the monetized environmental and health benefits associated with the effects of electro-mobility, the two modelling approaches - the hybrid CGE model and the ExternE's IPA are linked through emission factors.

Specifically, we consider the environmental and health effects attributable to a] direct emissions stemming from domestic economic production, b] indirect emissions attributable to all imported goods produced worldwide, c] direct emissions released by vehicles, and iv] direct external costs associated with electricity generation. In order to quantify these benefits we derived the emission-output factors for a], the emission-import factors for b], the emission-fuel use factors for c], gather damage factors per kWh electricity generated in various technologies for d].

The ExternE's IPA method is very similar to an integrated assessment model used in the American studies to connect emissions to changes in concentrations, human exposures, physical effects and monetary damages by the Air Pollution Emission Experiments and Policy model (APEEP, see for instance, Muller and Mendelsohn 2007, Muller et al. 2011). The ExternE and IPA is widely accepted method for deriving benefits of new governmental proposals, programs or policies in Europe or in order to derive new sustainability indicators (see, e.g., Holland et al. 2014).

In order to consider the effect of possible changes in technology, we quantify emissions attributable to car usage and electricity generation outside of the economic production module. While the emission factors of economic production and imports are based on CREEA multi-regional environmentally-extended input-output database that describes state of the economy in year 2007, the emission factors for the two key technologies are derived elsewhere. Specifically, the emission factors per fuel use in passenger vehicles and freight transport are based on TREMOVE model from which we generate time variant emission factors. Utilizing CASES database on external costs per wide set of technologies, we derive the damage factors per each electricity generating technology that are included in the electricity model embodied in the hybrid CGE model.

7.2. Results for sectors

Over the period 2008-2030 in Austria, fuel use is increased by 19% in the baseline scenario, mainly in other transportation than in passenger cars. EM+ results in lower use of fuels in cars, but overall consumption increases over time. The external costs attributable to emissions released from fuel use in cars are estimated at about 1,636 million euros in 2008. Despite the fact that fuel use is increasing over time (by +16% in passenger cars, or +24% in freight transport, respectively), total damage in the baseline scenario is declining over time as a result of increasing share of AFVs and declining emission intensities. As a result, externalities reach a value of 1,233 million euros in 2030 (by 25% less than in 2008). EM+ slows down the increase in fuel use (by +6% and +20% only) and simultaneously enhances more the uptake of AFVs. As a consequence, total external costs of EM+ declines at 1,168 million euros in 2030, that is 29% less than in the reference 2008 year. At the end of the period, EM+ results in the external costs attributable to passenger cars that are almost 9% smaller than in the business-as-usual case. Externalities attributable to remaining fuel use are by almost 6% smaller in the EM+ than in the BAU. In absolute terms, external costs are reduced by about 40 million euros in the second 2020's decade and by 65 million euros smaller in next decade.

EM+ will lead to increase in electricity use by 27% over the entire period 2008-2030 compared to BAU in Austria. Share of coal and hydro is decreasing, whereas demand for natural gas, wind and PV is increasing in both BAU and EM+. EM+ involves slightly more usage of natural gas in electricity generation. The effect on technology mix in EM+ is however very small. The external costs attributable to electricity generation in the reference year amount 502 million euros; climate change impacts contribute the largest share, about 56%, while health impacts contribute by about 40%. Higher generation of electricity also involves larger externalities. Damage in 2030 is 689 million euros in BAU and 722 million euros in EM+. In relative terms damage in EM+ is almost 5% larger.

Total externalities attributable to all economic sectors in Austria, excluding the externalities attributable to FUEL and ELE sectors, amount about 25 billion euros in the reference year. Major part of this damage is due to indirect emissions, i.e. the emissions released outside in Austria embedded in net imports of goods and services, and amount 14.3 billion euros attributable to combustion emissions and additional 2.3 billion euros attributable to non-combustion emissions. Direct emissions, i.e. those emissions that are released by sources in Austria, stemming from combustion contributes are estimated at 6.8 billion euros, non-combustion processes deliver another 1.9 billion euros. Externalities attributable to domestic economic production and imports are increasing over time, reaching in total about 31.43 billion euros in 2030 in BAU and more-less same amount in EM+ (31.36 billion euros). EM+ generates about 68 million euros of externalities in 2030 less than BAU scenario, in relative terms it is only about 0.2% in 2030.

7.3. Results: Total external costs

Summing all the external costs across domestic production in economic sectors, fuel use, and electricity production, we get total value of external costs that amount about 27 billion euros in the reference year and 33 billion euros in 2030. This value also includes impacts attributable to net imports embodied through indirect emissions. Total value of externality corresponds to about 4% of total economic value of Austrian economy in 2008.

EM+ scenario generates lower externalities but the year-by-year differences are overall very small in absolute magnitude, about 100 million euros smaller than in BAU in 2030, which is 0.3% less in relative terms. We get qualitatively similar results for the externalities attributable to direct emissions, but they correspond about 1.3% of total economic value of Austrian economy.

Figure 11: Total external costs in million EUR - direct and indirect emissions, 2008-2030, Austria

	BAU, in million EUR					EM+, in million EUR				
	direct comb	direct noncomb	indirect comb	indirect noncomb	Grand Total	direct comb	direct noncomb	indirect comb	indirect noncomb	Grand Total
2008	8 902	1 900	14 311	2 322	27 435	8 898	1 899	14 304	2 320	27 422
2009	8 998	1 920	14 458	2 346	27 722	8 991	1 919	14 451	2 345	27 706
2010	9 455	1 940	14 606	2 370	28 371	9 447	1 939	14 600	2 369	28 356
2011	9 540	1 957	14 735	2 390	28 622	9 533	1 956	14 731	2 389	28 608
2012	8 920	1 977	14 882	2 414	28 193	8 912	1 976	14 879	2 413	28 180
2013	9 564	1 997	15 029	2 439	29 029	9 554	1 996	15 028	2 438	29 016
2014	8 914	2 017	15 178	2 463	28 571	8 904	2 016	15 179	2 463	28 563
2015	9 769	2 037	15 328	2 488	29 622	9 721	2 034	15 310	2 482	29 547
2016	9 295	2 057	15 480	2 513	29 345	9 247	2 054	15 464	2 508	29 273
2017	9 887	2 078	15 634	2 538	30 138	9 840	2 075	15 621	2 533	30 069
2018	9 522	2 099	15 791	2 564	29 977	9 476	2 097	15 782	2 560	29 914
2019	9 276	2 121	15 951	2 590	29 938	9 197	2 116	15 926	2 581	29 820
2020	9 405	2 142	16 113	2 617	30 276	9 328	2 137	16 090	2 608	30 163
2021	9 487	2 164	16 274	2 643	30 568	9 411	2 159	16 254	2 634	30 458
2022	9 573	2 186	16 438	2 669	30 866	9 499	2 181	16 419	2 661	30 760
2023	9 661	2 208	16 603	2 696	31 169	9 590	2 204	16 585	2 688	31 066
2024	9 752	2 230	16 769	2 723	31 474	9 683	2 226	16 752	2 715	31 375
2025	9 844	2 253	16 936	2 750	31 783	9 779	2 248	16 921	2 742	31 690
2026	9 937	2 275	17 104	2 777	32 093	9 875	2 270	17 087	2 769	32 002
2027	10 031	2 298	17 273	2 805	32 406	9 971	2 293	17 254	2 796	32 314
2028	10 126	2 320	17 442	2 832	32 720	10 067	2 315	17 420	2 823	32 625
2029	10 220	2 343	17 613	2 860	33 036	10 163	2 337	17 586	2 850	32 935
2030	10 313	2 366	17 786	2 887	33 353	10 256	2 360	17 758	2 877	33 252

Different sectors contribute to the total outcome on externalities attributable to direct emissions differently. We find that EM+ will generate small benefits due to changes in the structure of domestic economic sectors, while changes in vehicle fleet and hence fuel use solely will result in about 2.5 times larger benefits than the change in overall economy structure. Annual environmental benefits of EM+ are about 80 to 90 million euros after 2025. However, EM+ scenario would also lead to changes in elec-

tricity market that would result on the contrary in damage of value about 10 to 33 million euros in the same period as the benefits would be generated. This environmental damage is however not sufficiently large to counterbalance the environmental benefits, yielding overall net benefits.

**Figure 12: Effect of EM+ on total external costs attributable to direct emissions,
2008-2030, Austria**

	Difference EM+ vs. BAU, in million EUR				Percentage change EM+ vs. BAU			
	sectors	FUEL	ELE	TOTAL	sectors	FUEL	ELE	TOTAL
2008	-2.8	-1.3	0.0	-4.1	-0.04%	-0.08%	0.00%	-0.05%
2009	-2.8	-3.1	-1.6	-7.5	-0.04%	-0.19%	-0.31%	-0.08%
2010	-2.4	-4.8	-0.3	-7.5	-0.04%	-0.28%	-0.03%	-0.08%
2011	-1.9	-5.9	-0.1	-7.9	-0.03%	-0.38%	-0.01%	-0.08%
2012	-1.3	-7.0	-0.2	-8.4	-0.02%	-0.47%	-0.06%	-0.09%
2013	-0.6	-8.0	-1.8	-10.3	-0.01%	-0.56%	-0.17%	-0.11%
2014	0.4	-9.0	-0.5	-9.1	0.01%	-0.67%	-0.12%	-0.10%
2015	-5.9	-40.6	-1.8	-48.4	-0.08%	-3.20%	-0.14%	-0.50%
2016	-6.4	-40.6	-0.8	-47.8	-0.09%	-3.33%	-0.11%	-0.51%
2017	-6.3	-40.5	-0.5	-47.3	-0.09%	-3.43%	-0.04%	-0.48%
2018	-5.6	-40.4	-0.5	-46.5	-0.08%	-3.50%	-0.05%	-0.49%
2019	-11.6	-66.0	-0.4	-78.1	-0.15%	-5.80%	-0.07%	-0.84%
2020	-12.0	-65.8	0.7	-77.1	-0.16%	-5.82%	0.11%	-0.82%
2021	-12.4	-65.9	2.5	-75.8	-0.16%	-5.83%	0.38%	-0.80%
2022	-12.7	-66.2	4.7	-74.1	-0.16%	-5.84%	0.70%	-0.77%
2023	-12.9	-66.3	7.3	-71.9	-0.16%	-5.82%	1.08%	-0.74%
2024	-13.2	-66.4	10.3	-69.3	-0.17%	-5.78%	1.50%	-0.71%
2025	-12.6	-66.3	13.9	-65.0	-0.16%	-5.72%	2.01%	-0.66%
2026	-13.7	-66.1	17.4	-62.4	-0.17%	-5.65%	2.51%	-0.63%
2027	-15.3	-65.9	21.1	-60.1	-0.19%	-5.57%	3.03%	-0.60%
2028	-17.5	-65.7	24.9	-58.4	-0.21%	-5.48%	3.58%	-0.58%
2029	-20.5	-65.7	28.8	-57.4	-0.25%	-5.40%	4.16%	-0.56%
2030	-24.0	-65.8	33.0	-56.9	-0.29%	-5.34%	4.79%	-0.55%

We caution to generalize our conclusions for Austria, since the overall result on the effect of electromobility on external costs will strongly depend on the technology mix to generate electricity. Positive finding for Austria is partly determined by environmentally-friendly technology mix to generate electricity, whereas more polluting electricity generating technology mix might switch environmental benefits of electromobility towards environmental damage.

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8. Preferences for alternative fuel vehicles and car systems in Poland

Milan Ščasný, Iva Zvěřinová, Mikolaj Czajkowski

Center for Social and Economic Research (CASE), Warsaw

This synthesis report provides the results on original survey conducted among Polish people in order to identify potential and barriers for adopting alternative fuel vehicles. Consumer preferences were analysed using data from an original questionnaire survey representative of Polish adult population and people who intend to buy a car. Charging time, availability of charging stations and driving range are currently the most important barriers to development of market for electricity driven vehicles. Providing other benefits, such as free parking and public transport, increases the probability to choose the electricity driven vehicles. The second-hand car purchasers stated implicit WTP value for free public transport for all family members of 1,700 zł and for free parking in Poland at 2,550 zł. The new car segment stated higher WTPs - 5,300 zł and 6,600 zł. Using the estimation results and simulating the effect of purchase price and operational costs on the probability to choose specific vehicle, the price elasticities for various household segments were derived. For example, low educated respondents are most sensitive to purchase price of conventional cars and almost insensitive to the changes of operational costs.

8.1. Motivation and objectives

Electromobility is seen as part of strategy to reduce dependence of the European Union on oil and other fossil fuels, improve air quality, reduce noise in urban/suburban agglomerations, and contribute to a CO₂ reduction (Directive 2014/94/EU). The Directive 2014/94/EU sets that each Member State shall adopt a national policy framework for the development of the alternative fuel market and submit to the Commission a report on its implementation that should among others describe the policy measures taken in a Member State to support the deployment of the alternative fuel vehicles, including electricity driven vehicles. To prepare a national policy framework and to encourage the development of the alternative fuel market, among others, understanding of consumer behaviour and preferences for alternative fuel vehicles is crucial.

For these reasons, the objectives of our research carried out in this project are:

- i) to identify factors influencing purchase of electricity driven vehicles, and
- ii) to examine consumer preferences and estimate willingness to pay for three electricity driven vehicles, specifically hybrid (HV), plug-in hybrid (PHEV) and electric vehicles (EV).

Consumers demand for certain goods can be modelled using existing data on market penetration or consumption decisions (revealed preferences). However, if the supply of certain durable goods is constraint or almost zero as is the case for new or not yet existing technologies, potential demand can be examined using stated preference methods. The main aim of our survey is to analyse consumers preferences for transport-relevant durables that are recently characterized by negligible or zero market penetration. In other words, individual preferences are elicited and demand for passenger cars with alternative driven technologies and for transportation-specific innovations are estimated. To fulfil

these objectives a discrete choice experiment is conducted to elicit consumers preferences for several vehicle attributes.

8.2. Results from the literature review

The stated preference methods, especially discrete choice experiments, serve as useful tool to elicit preferences for very specific attributes of alternative fuel vehicles and thus provide support for policy and help to forecast market potential for new technologies and their share. Even hypothetical levels of attributes can be included in the discrete choice experiments, such as the driving range of the electric vehicle that is better than any available on present-day's market, in order to examine consumer preferences for such technological improvement.

The fuel types of the vehicles introduced to respondents in the discrete choice experiments reflect current and also possible technologies in concerned countries. In most of the studies, there is one side a conventional vehicle represented by petrol (or additionally by diesel), the other fuel types, such as compressed natural gas (CNG), liquefied petroleum gas (LPG)), and on the other side low carbon vehicles represented by hybrid, electric or hydrogen vehicles.

Most of the studies provide the willingness to pay estimates for different attributes. There is not sufficient evidence whether consumers would prefer AFVs to conventional vehicles. Consumers' preferences depend on both i) characteristics of the respondents, and ii) characteristics of the vehicles.

- i) The willingness to pay values vary not only among the countries, but WTP values also vary across household segments due to observed or unobserved preference heterogeneity.
 The evidence on the effects of sociodemographic variables is far to be conclusive, it is country and study specific. However, several studies found that early adopters of AFVs are more likely:
 - home owners and those who live in detached or semi-detached family homes;
 - people owning more than one vehicle;
 - higher educated, younger to middle aged, higher income, environmentally conscious.
- ii) Preference and hence willingness to pay for AFVs:
 - increases with the length of driving range, fuel availability (such as percentage share of fuel stations), car performance (such as engine power), greenhouse gas emissions reduction, policy incentives (such as remission of vehicle tax, free parking, bus lane access);
 - decreases with length of charging (refuelling) time, purchase (capital) costs, fuel and maintenance costs.

Short driving range and long battery charging time are very important barriers of purchase of AFVs because both bring significant dis-utility to car buyers.

- Marginal utility of increasing driving range by 1km ranges about 10 to 60 EUR per a car.
- Utility from reducing battery charging time by one minute lies in similar range, however, the disutility related to refuelling hydrogen vehicles is larger compared to the disutility from battery charging of electric or plug-in hybrids. Consumers are willing to pay more if they do not have to refuel their vehicle every day but only every other day, or even once a week.
- The barriers associated with driving range and charging time seem to be the main reason why people tend to prefer hybrid technology over electric vehicles. Because of the limited driving range of electric cars these are perceived as insufficient for special journeys such as holidays or week-ends away. Alternative mobility options for "long journeys" are therefore needed to enhance the acceptance of electric vehicles.

In order to achieve higher market shares of AFVs,

- taxation of conventional gasoline and diesel vehicles or a subsidization of AFVs could be successful in promoting hybrid, hydrogen and electric vehicles. A study carried out In Denmark has shown that AFVs with present technology could reach fairly high market shares, if tax regulations that are applicable in the present vehicle market are utilized;
- alternative mobility options for “long journeys”, such as public transport or different car rental, sharing or pooling systems, should be supported;
- installing refuelling infrastructure and increasing the visibility of refuelling stations;
- policy incentives, such as access to bus lanes or free city parking, could be introduced to reduce the obstacles for buying electric car, however, it seems that the utility related to these incentives would not be strong enough to motivate for increasing electric car penetration in the fleet without improving driving range and battery charging. The remission of vehicle tax was in one study valued higher than free parking;
- research and development, especially focused on improving driving range and battery charging, needs to be promoted;
- marketing strategies that would target younger, higher educated, environmentally conscious consumers can be utilized and effective.
- Media messages should raise the awareness among people about the positive consequences of AFVs adoption, such as the environmental and energy security benefits, such as political independence from oil producing countries, and benefits deriving from local traffic policies (free access to the town centre, free parking).
- As AFVs are still at an early stage of diffusion, therefore information on what for example hybrid vehicles offer, except of financial and environmental benefits also affective and practical information, such as quietness and spaciousness, should be provided.

8.3. Results from the study in Poland

In our discrete choice experiments, respondents are asked to choose their preferred car from four types of cars (conventional, electric, hybrid car and hybrid car with plug-in) described by a set of six attributes. The cars differ from one another in the levels of several attributes. Purchasing price of a car is one of the attributes, which allows us to estimate marginal willingness-to-pay for specific attribute of a vehicle. Except price, further attributes are: operational and fuel costs, driving range, refuelling / recharging time, availability of fast-mode recharging infrastructure, and additional benefits such as free parking or free public transport.

Quota sampling was used to draw a representative sample of the Polish adult population in terms of several socio-demographic characteristics (853 respondents) and a sample who intend to buy a passenger car within next three years (1760 respondents). The survey took form of structured computer-assisted web interviews by using an e-panel well managed by Millwardbrown, Poland. In total, 2613 Polish inhabitants were interviewed. This survey is the first on this topic and using stated preference method in Poland and in Central and Eastern Europe.

Identification of triggers and barriers of purchase of low carbon vehicles and car-sharing in Poland

- Most of people who intend to buy a vehicle within 10 years have already heard about electric or hybrid vehicles (87% or 83%), however, hybrid vehicles with plug-in are much less known (64%).

- Only 27% of consumers have ever considered buying an electricity driven vehicle, most of them hybrid and then hybrid with plug-in (33% and 29%).
- Under current conditions – and prior detailed information on alternative fuel vehicles were provided to a respondent – only small share of respondents informed us about their plan to buy an alternative vehicle (5% CNG, and 2% electric or hybrid car).
- Narrower assortment than of conventional vehicles, lack of service places, and poor availability of public charging stations in Poland are considered important barriers for their potential purchase of electric vehicle. Electric vehicles are then generally perceived as less noisy. People tend to believe that if they buy an electric vehicle they will contribute to lowering of CO₂ emissions and air pollution in cities and towns. However, these advantages of electric vehicles are not among the most important factors when deciding on car purchase. Rather, more likely low failure rate, car safety, fuel efficiency, maintenance and fuel costs, car equipment, interior space and purchase price are more decisive factors of car choice.
- About a quarter of our respondents have heard about car-sharing or car-pooling systems, and higher share of them has used the former rather than the latter system. Lowering the cost of car-sharing, for instance, by providing a tax rebate on fuel or electricity used for recharging a car, could motivate Polish travellers to use this system more. As a result of our contingent scenario, we find that car-sharing system using EVs only seems to be potentially widely exploited than the system merely relying on conventional vehicles.
- The results providing above are based on the representative sample of the Polish adult population.

Estimation of willingness-to-pay of Polish consumers for hybrid, plug-in hybrid and electric vehicles

- We asked respondents to imagine that a public program is introduced and slow mode charging sockets with electricity use meters would be installed that would allow recharging an electric or plug-in hybrid vehicle in the place where they usually park their car, even if they don't own a garage. Under this scenario, still preferences of Polish consumers for hybrid and electric vehicles were significantly lower than their preferences for a conventional vehicle. Respondents are more likely to buy hybrid plug-in cars, then hybrid, and consider electric vehicles as the most (unfavorably) different to conventional cars. We note, however, that there is considerable preference heterogeneity with respect to these car labels, and a substantial share of the population would have more positive preferences for the alternative fuel vehicles.
- We estimate both a simple multinomial logit model and a mixed logit model which is superior in being able to take the respondents' unobserved heterogeneity into account, i.e. it does not assume that every respondent has exactly the same preferences. In the summary, we report results for mixed logit model estimated for three segments of households defined according to what car they plan to buy (a new car, used car, or are not decided yet). Pooled data from both samples are used, only respondents who plan to buy a car answered the questions.
- Driving range is important attributes of a passenger car which Polish consumers intend to buy. On average, Polish drivers are willing to pay about 1,500 zł for each additional 100 km of driving range. Drivers who intend to buy a second-hand car value the driving range less than consumers who intend to buy a new car.
- Recharging time and availability of fast-mode charging stations are currently the most important barriers to larger spread of electric and plug-in hybrid vehicles. On average, Polish drivers are willing to pay slightly less than 1,000 zł for each hour saved for recharging. Those who intend to buy a new car are willing to pay twice than what second-hand car buyers. Preference for AFVs markedly

rose, when availability of fast-mode recharging improved from low level (20% of fuel stations + at few public places) to medium level (60% of fuel stations + at half of public places) or even high level (90% of fuel stations + at almost all public places). Corresponding willingness to pay for medium or high availability of fast mode recharging infrastructure is about 5,600 zł and 8,600 zł, respectively.

Figure 13: Estimation results – Mixed Logit for three household segments, WTP-space

	new car	used car	undecided	pooled data
HV	-19 750 zł	-13 469 zł	-12 054 zł	- 17 116 zł
PV	-9 643 zł	-10 807 zł	-8 898 zł	- 12 726 zł
EV	-29 251 zł	-17 651 zł	-29 727 zł	- 26 272 zł
Operational costs	-48 408 zł	-24 021 zł	-44 224 zł	- 381 zł
Driving range (in 100km)	1 418 zł	1 145 zł	1 344 zł	1 522 zł
Recharging time (in hours)	-1 080 zł	-524 zł	-1 250 zł	- 940 zł
Free public transport	1 705 zł	1 010 zł	622 zł	1 387 zł
Free parking	3 043 zł	1 887 zł	2 420 zł	2 298 zł
Fast-mode recharging infrastructure – medium availability	6 666 zł	4 728 zł	6 137 zł	5 562 zł
Fast-mode recharging infrastructure – high availability	7 507 zł	6 105 zł	12 235 zł	8 579 zł

Note: All coefficients are significant at 1% level, except the coefficients for free public transport that is significant at 5% level (new car) or not significant at any convenient level (undecided).

- Providing other benefits, such as free parking and free public transport, increases the probability to choose the AFVs. Average WTP is 2,300 zł and 1,400 zł, and again new car buyers are willing to pay more than second-hand buyers.
- Results of the mixed logit models indicate that consumer preferences for AFVs and their characteristics are highly diverse. An interaction model reveals that higher levels of income increase probability to purchase HV and PHEV and weaken the effect of operational cost attribute. Effect of income on other attributes seems to be not significant. Having at least one child in a family reduces importance of other benefits (public transport and parking).
- Larger vehicle engine size reduces probability to buy an EV and in general reduces WTP value for all vehicle attributes due to lowering coefficient on purchasing price (marginal utility of income). Larger engine size increases importance of driving range, recharging time and parking for free. The longer mileage that a consumer expects to drive, the higher WTP for HV and PHEV and the lower WTP for EVs. And the more kilometres a respondent intend to drive, the more important operational costs are. On the other hand, driving more leads to considering the purchase price less.
- Using the estimation results and simulating the effect of purchase price and operational costs on the probability to choose specific vehicle, the price elasticities for various household segments were derived.

- We find that low educated respondents are most sensitive to purchase price of CV, while this elasticity has the lowest value among more educated respondents who are rather most responsive to price changes of EVs, followed by price changes of HVs. On average, the highest price elasticity is estimated for price changes of EVs, especially among households living in urban and suburban area.
- Regarding the operational costs, low educated respondents are almost insensitive to the cost changes. Again the largest elasticity with respect to operational costs is estimated for EVs. Respondents living in rural area are then more sensitive on the cost changes than the respondents living in suburban and urban areas. These results also hold for changes in operational costs at lower levels that reflect rather fuel costs.

Authors: DEFINE Consortium

Title: Synthesis Report DEFINE

Project report/Research Report

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Stumpergasse 56, A-1060 Vienna • ☎ +43 1 59991-0 • Fax +43 1 59991-555 • <http://www.ihs.ac.at>
