Project:

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

Combined Report on Work Package 6

Deliverable 6.1

Report on the Calibrated and Validated CGE Model with Implemented Scenarios Ready for Use

Deliverable 6.2

A Set of Simulation Results and Case Studies

Authors:
Stefan Schmelzer
Michael Miess

Institute for Advanced Studies, Vienna (IHS)

Due Date of Deliverable:
February 28^{th}, 2015

1 Introduction

The computable general equilibrium (CGE) model MERCI was developed at the IHS Vienna within the last years. While initally being a model with focus on the electricity sector, it has been used in many studies for national ministeries in several topics of applied macroeconomics. In the course of the DEFINE project, the model was extended to include a detailed representation of the transportation sector. This report explains in detail the modelling work that was carried out in the DEFINE project, and gives an overview of how to use the model, and what it can be used for.

A discrete choice model of the consumer purchase decision between conventional, hybrid, plug-in hybrid and electric vehicles was implemented in the MERCI model in a "hard-link" fashion. The combined model features a detailed accounting of stock development, including yearly numbers of vehicle purchases and cohort depreciation. It depicts 9 households differentiated by degree of urbanization and education, and accounts for detailed consumer preferences, mode choice decisions, and includes several electricity producing technologies.

In our policy scenarios, (see Deliverable 6.2.) we assess the economic costs necessary to reach an electric vehicle target in Austria. These costs include tax revenue changes and effects on government budget, private infrastructure expenditures, and effects on GDP. We assess the influence of two policy measures on the market penetration of electric vehicles: A rise in the mineral oil tax and a penalty on the car purchase tax, which in Austria is connected to CO_2 emissions. Thereby we account for the overall economic effect on GDP growth and the effect on the government's budget. This enables us to compare the economic costs of electromobility to the connected environmental benefits (see Deliverables 9.1 and 9.2).

1.1 Background and Related Literature

There has been an ongoing debate whether alternatively fuelled vehicles, especially battery electric vehicles or plug-in hybrid electric vehicles, offer an solution to obtain a low-carbon emission transport system that still heavily relies on individual transport using passenger cars. Even though a high-price alternative to conventional vehicles powered by gasoline or diesel, rapid technological development by the automobile industry together with a shift in preferences by consumers, both possibly incentivized by state subsidies, could lead to an increased penetration of electric vehicles in the coming years and decades.

For a comprehensive analysis, electric mobility should be viewed in a systemic perspective in order to assess whether it is an economically viable option to reduce greenhouse gas (GHG) emissions in the transport sector. On the one hand, the take-up of electric cars by consumer depends on their car purchase preferences as well as on the choice of products offered by the automobile industry. On the other hand, emissions attributed to electric vehicles, who themselves do not directly emit GHGs when operated, arise in the electricity production sector providing the electric fuel.

Our work relates to existing research by assessing the economic costs and benefits of market penetration scenarios of electric vehicles in a comprehensive modelling framework. By applying and extending the methodology of Truong and Hensher (2012) we link the discrete choice model to a continuous demand computable general equilibrium (CGE) model. We aim for a realistic characterisation of the household vehicle purchase decision while keeping track of the physical quantities (new registrations and stock of cars) in a stock-flow consistent way and in relation to the electricity system as well as the macroeconomy in sectoral decomposition. This approach extends on the existing literature by integrating the energy system, consumer preferences and a stock-flow consistent vehicle fleet turnover model in one coherent economic framework based on general equilibrium theory.

In recent years, several modelling approaches have been applied to examine the electrification of individual passenger transport from an analytical perspective. On a global level, the MIT EPPA model, a recursive-dynamic CGE model, was used and extended to assess market entry and emission reduction potential of plug-in hybrid electric vehicles (PHEVs) facing a strong global carbon constraint, see Karplus et al. (2010). In a later version of the model, it is expanded to project the physical demand for transport services from passenger cars including the option of alternatively fuelled vehicles (AFVs) in individual passenger transportation with a focus on electric vehicles, see Karplus et al. (2012). While taking account of the physical stock of cars and related energy use in the later version of the model, the technological options of AFVs are modelled as so-called backstrop technologies that are not cost-competitive in the benchmark year of the modelling periond, but may become so according to price changes in future periods.

While this approach offers a possibility to model the gradual shift-in of a new technology, it has no explicit depiction of consumer demand based on heterogenous preferences.

Several studies rely on discrete choice models based on survey data to forecast market penetration of electric vehicles such as Öko Institut (2011) (Germany), Hanappi et al. (2012) or Link et al. (2012) (Austria). They usually find substantial market potential of electric vehicles based on stated preferences by consumers.

Another approach is a scenario analysis using total cost of ownership (TCO) models, where the total costs of purchase, operation and maintencance of a vehicle determine the choice of vehicle technology by consumers, in combination with bottom-up vehicle fleet models. Examples include Plötz et al. (2013) or Kloess and Müller (2011). As fully electric vehicles (EVs) and PHEVs are cheaper in operation and maintenance, these models often allow for higher penetration of electric vehicles in their policy scenarios.

While all these modelling approaches offer a certain angle on the economic effects of certain penetration rates, they all have to abstract either from consumer preferences, the macroeconomy, the energy system or detailed vehicle accounting.

The model developed in DEFINE aims most of all to integrate consumer preferences into a hybrid energy-economy model. This approach offers a viable explanation for the fact that rational agents would make a car purchase decision for a product that is more expensive than its substitute.

In the absence of elicited market data, stated preferences offer a feasible way to estimate consumer preferences in relation to vehicle purchase choice. By wrapping a simplified discrete choice model in a sectoral hybrid energy-economy CGE model, a realistic and feasible way to introduce a high-priced alternative to CVs in their car purchase decision is reached. This improves on existing CGE models related to the assessment of electric vehicle take-up such as Karplus et al. (2012) by directly implementing empirically derived consumer preferences into the model, and adds a macroeconomic perspective founded on general equilibrium theory. Including an addditional detailed stock-flow consistent vehicle fleet accounting, the relation to physical quantities in the model is kept. With these features, the model offers a comprehensive simulation tool for various tax and subsidy policy instruments.

1.2 Overview of the Modelling in DEFINE

The MERCI model is implemented in MCP/GAMS, which is a standard software environment for applied CGE models, see Rutherford (1995). MERCI is based on the structure of Böhringer and Rutherford (2008), including different electricity producing technologies. The combination of a detailed electricity sector and vehicles fuelled by electricity replacing conventional vehicles in a CGE framework allows us to assess total economic costs of different penetration levels of electric vehicles. The vehicle types conventional vehicles (CV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and electric vehicles (EV) are the choice alternatives for the consumers in their purchase decision in the model. We distinguish 9 consumer agents (or households) by education level and living area (degree of urbanisation). Mobility preferences of these agents were assessed in a household survey carried out in the DEFINE. Based on the resulting micro dataset a discrete choice (DC) model, see Train (2003), was estimated for each agent. For each household this DC model yields choice probabilities between the vehicle types in the purchase decision, depending on prices, socio-demographic characteristics of the household, and technological attributes of the vehicles.

Following Truong and Hensher (2012), we integrated this DC model into the CGE model by deriving an ”effective price” for each choice alternative, an ”aggregate price” for the purchase of a car of any type (both of which depend on the household′s preferences) and, using Shephard′s Lemma, demand for overall car purchases. The choice probabilities are interpreted as market shares, and serve to split up this overall demand into demand for vehicle purchases of each type. This creates a "hard-link" between the models, which is in line with micro-founded economic theory. Endogenous variables in the CGE model (e.g. prices for vehicles, fuel and taxes, maintenance costs) enter the DC model, which, completely integrated in the CGE model, determines the purchase decision between and hence expenditures on the different vehicle types.

While the numbers of new registrations develop according to this purchase decision, stocks for each of the four alternatives develop according to a standard accumulation and depreciation process. The stock equals last period’s stock plus newly registered cars less depreciation of worn out cars.[1] For depreciation, we assume a constant rate of 0.05 for CVs, while for HEVs and xEVs (i.e. PHEVs and EVs), since these are still at the beginning of their lifecycle as a technology, we do not assume depreciation for the first

[1] We explicitly account for numbers of vehicles (for stocks, newly registered, and depreciating cars) in physical units.

12 years.[2] After that, the exact amount of vehicles that was purchased 12 periods before depreciates. In this way a detailed and consistent accounting of vehicle stocks and newly registered vehicles is assured.

In order to depict the development of expenditures on the use of the existing fleet for each household over time, we introduce an appropriate consumption structure in the model: Each consumer has the possibility to substitute between public passenger transportation (PPT) and individual transportation (IT) in their mobility behavior.[3] Expenditures on IT include expenditures on purchases of new cars, and expenditures connected to the use of the vehicle stock (fuels incl. taxes, service and maintenance). The share between these expenditures adapts endogenously over time, according to the number of newly purchased vehicles and the size of the vehicle stocks.

Our modeling procedure is designed to appropriately depict the entry of a new technology. It simultaneously allows a distinction between expenditures on purchases and on the use of differently fuelled vehicle types, as well as an assessment of detailed preference-driven shifts between these vehicle technologies, taking account of the time lag that occurs in the stock development.

2 The DC Model

In this section we introduce the concept of a discrete choice model, and describe how we use such a DC model at an aggregate level to determine market shares of vehicel purchases among the 4 vehicle types in the CGE model.

The DC model for Austria, that is used here was estimated by Francisco Bahamonde Birke at DIW, in the course of WP3 of DEFINE. It is based on the representative household survey in Austria that was carried out in the course of the same WP in early 2013. The aggregation technique is described in a DEFINE working paper, Bahamonde-Birke and Hanappi (2015), which can be found on the DEFINE website[4], and is also a deliverable in DEFINE.

Using a discrete choice model within the CGE model allows us to analyse consumption behaviour from a micro perspective, and to derive demand for the choice alternatives (CV, HEV, PHEV and EV, indexed by i). In our combined modelling framework, we distinguish 9 agents, or household types (indexed by h), by education level and living area (degree of urbanisation). These distinctions are important due to the following. On the one hand, preferences and habits concerning transportation are clearly subject to regional differences. The degree of education, on the other hand, is used firstly as a proxy for income, which definitely has an effect on the affordability of more expensive xEVs, and secondly because we suspected environmental sensitivity to be dependent on the degree of education.

[2] See also Gruden (2008).

[3] The corresponding elasticities of substitution, σ^{mode}, were estimated for each agent on the basis of the results of the survey conducted within DEFINE.

[4] See `https://www.ihs.ac.at/projects/define/files/DEFINE_workingpaper_BirkeHanappi_vlsnprgk.pdf`.

β **entries**	**Households by living area**		
	Urban	**Suburban**	**Rural**
PP	-0.162	-0.152	-0.168
FC	-14.600	-22.300	-13.300
MC	-15.100	-14.200	-15.900
PS_{CV}	0.029	0.033	0.023
PS_{HEV}	0.017	0.017	0.018
PS_{PHEV}	0.025	0.022	0.018
PS_{EV}	-	0.010	0.007
RA	0.003	0.003	0.003
CS_{medium}	-	0.325	0.195
CS_{high}	0.707	0.705	0.558
$IM_{pub.tr.}$	0.436	-	-
MS_{CV}	0.702	0.529	-
MS_{HEV}	0.461	-	-
MS_{PHEV}	0.992	-	-
HS_{EV}	-	0.561	0.855
HS_{PHEV}	-	0.025	-
HS_{EV}	-	0.485	-
α_{CV}	-	-	-
α_{HEV}	0.288	-0.159	-1.120
α_{PHEV}	-0.624	-0.724	-0.698
α_{EV}	-0.279	-2.240	-1.450

Table 1: Marginal utility values of the vehicle attributes (β-entries)

For each of these aggregated household groups, a seperate multinominal logit model was estimated. The alternative specific attributes or variables in these models are purchase price (pp), fuel cost (fc), maintenance cost (mc), power (ps) and range of EVs (ra). The estimations yield for each agent a vector $\beta_{h,i}$ of shadow prices of each of these variables, explaining the representative indirect utility of choice alternative i for household h.

Multiplying the vector of shadow prices with a vector of initial levels $x_{h,i}$ of the variables yields for each household h the indirect utility $V_{h,i}$ of buying a car of type i,

$$V_{h,i} = \beta_{h,i} x_{h,i} + \alpha_{h,i}. \tag{1}$$

Here $\alpha_{h,i}$ is the alternative specific constant (ASC), or base-preference, that denotes that part of the utility of household h for alternative i, which is unexplained by the other variables. Table 1 provides values for the ASCs, and the marginal utility values of the vehicle attributes (components of $\beta_{h,i}$), while table 2 provides the levels of the vehicle attributes (components of $x_{h,i}$), as used in our scenario simulations.

With the help of the indirect utility, the probability $Prob_{h,i}$ of agent h to choose

Attributes	**Values**
PP_{CV}	25,502
PP_{HEV}	28,801
PP_{PHEV}	35,293
PP_{EV}	51,027
FC_{CV}	0.08
FC_{HEV}	0.07
FC_{PHEV}	0.05
FC_{EV}	0.04
MC_{CV}	0.06
MC_{HEV}	0.06
MC_{PHEV}	0.06
MC_{EV}	0.06
PS_{CV}	122
PS_{HEV}	160
PS_{PHEV}	186
PS_{EV}	146
RA	150
CS_{medium}	-
CS_{high}	-
$IM_{pub.tr.}$	-

Table 2: Attribute levels (initial steady state calibration)

alternative i, given the prior decision to purchase any car at all, is given as

$$Prob_{h,i} = \frac{e^{V_{h,j}}}{\sum_j e^{V_{h,j}}} \qquad \forall h, \forall i. \tag{2}$$

Equations (1) and (2) are referred to as a logit model, or discrete choice model in the literature (see e.g. Train (2003)). In the CGE model these probabilities, since they represent the aggregate level of the 9 agents, can be interpreted as market shares. The share of purchases of car i in total car purchases of household h, $\theta_{h,i}$, is hence

$$\theta_{h,i} := Prob_{h,i} \qquad \forall h, \forall i. \tag{3}$$

So once demand for overall car purchases is known for each agent, demand for cars of type i equals $\theta_{h,i}$ times this overall demand.

It shall be emphasized here, that these market shares are endogenous in the CGE model, as will be explained in the next section. Apart from the exogenous parameters, i.e. technological assumptions and the household preferences as estimated here, the market shares also depend on price developments, which are endogenously determined in the CGE model: the purchase prices, the fuel prices, taxes, and service and maintenance costs of the different vehicle types.

Within the CGE model, the resulting numbers of car purchases of each type feed into the build up of vehicle stocks per car type. Demand for fuel input, service and maintenance will be determined according to the development of these stocks over time.

3 The Hard Link between the CGE and the DC model

This chapter describes how we implement the DC model into the CGE model. It is structured into two sections. We first provide the theoretical considerations that allow us to combine CGE theory and micro-founded utility maximization of a representatitve agent with DC theory of multiple agents making discrete choices between non-homogenous goods. The second section provides a detailed outline of the technical implementation of this hard link between the DC and the CGE model. We provide a detailed recipie of how to include an aggregated DC model as sketched in section 2 within a CGE model formulated in MCP/GAMS.

Hard-linking the DC model into the CGE framework enables us to model car purchases as explicit preference-induced decisions by the representative agent. In our CGE model the representative agent was split up into 9 household types, distinguished by education level and living area. Each of them is associated with one of the 9 estimated DC models of section 2. Their preference structure also allows them to decide to use public transportation as a substitute to buying and/or driving a car. When a household decides to purchase a car, then the decision which type of car to buy occurs in a second stage. In the following we describe how this decision process is modelled and technically implemented.

3.1 Theoretical foundations of the Hard Link

As is standard practice in applied sectoral CGE models, also in our model each household's consumption structure is modelled as a nested CES function. Consumers can substitute between certain consumption goods as shown in figure 1. We make use of the CES functions in calibrated share form, as proposed by Rutherford (2002).

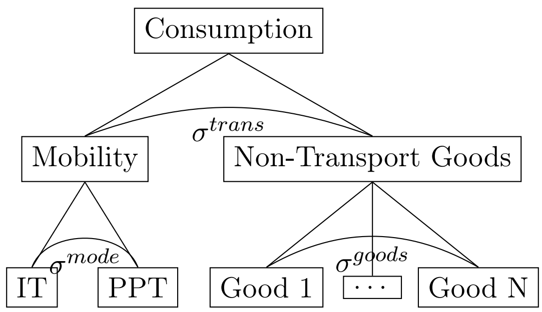


Figure 1: *Consumption structure of households (Nested CES functions)*

Similar as for public passenger transportation (PPT), and other consumption goods, one can think of the individual transport consumption composite (IT) as an economic activity, with a price that we shall call P_h^{IT}. This activity provides the aggregate good "individual transportation" to households, which includes all vehicle-type-specific mobility goods CV, HEV, PHEV, or EV. Here the term "mobility good" stands for purchase and use of these types of cars. Hence, from an accounting point of view, expenditures on IT include monetary flows connected to purchases of cars, as well as to the use of the vehicle stock, i.e. expenditures on fuels, taxes, service and maintenance.

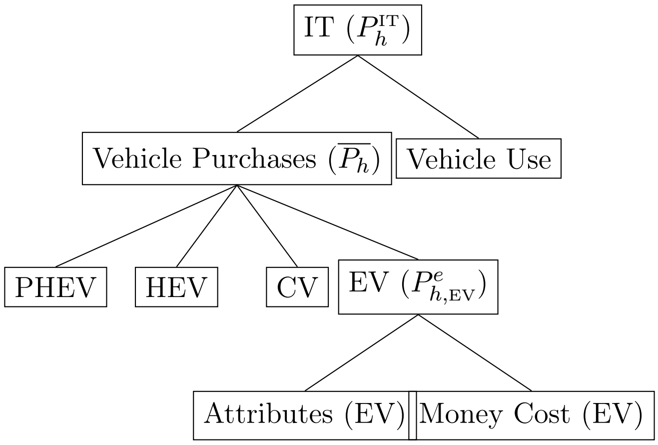


Figure 2: *Individual transport consumption structure (DC model of the purchase decision)*

Now the idea is to determine for each of the 9 agents, her demand for overall car purchases, i.e. demand for purchases of any kind of vehicle. Once we know this demand, we can use the DC model in order to split up this demand and determine the demand for purchases of each car type. The resulting numbers of new registrations per vehicle type per year will build up the vehicle stocks for each of the vehicle types. Finally, each agent's expenditures on the use of her vehicle stock is then assumed to be proportional to the size of this vehicle stock. In this way, we can distinguish between expenditures on purchases and use, for each agent, and in each time period.

In order to derive "demand for overall car purchases" for each consumer household, $\overline{D_h}$, we need a price for the abstract consumption good of aggregate car purchases per agent. We shall call this price the "aggregate price", or "price for overall car purchases", $\overline{P_h}$. Then we can derive unit final consumption demand for car purchases using Shephard's Lemma.

Usually in cases where many single goods (here different car types) are combined into a consumption bundle (here cars in general), such an aggregate price is derived in CGE models via a CES combination of the prices of the single components. However, the purpose of this paper is to model the choice between the different vehicle types as endogenously depending on more attributes than just on the purchase prices of the different car types, specifically on several vehicle-type-specific variables and on consumer-specific preferences. Hence a CES combination is not the appropriate method.

Following Truong and Hensher (2012) we use an effective price $P^e_{h,i}$ for each choice alternative i and each agent h, which accounts for all the attributes and characteristics

$x_{h,i}$, and can be interpreted as the consumer's perceived value of the vehicle at the purchase decision. We then derive the aggregate price for overall car purchases $\overline{P_h}$ with the help of the effective prices $P^e_{h,i}$. Demand for overall car purchases, $\overline{D_h}$, is determined according to Shephard's Lemma, and finally, the logit probabilities are used to determine demand for each vehicle type $D^{\mathrm{pur}}_{h,i}$.

Specifically, agent h's indirect utility of buying a car of type i, already introduced as $V_{h,i}$ in section 2, can be written as

$$V_{h,i} = \beta^{\mathrm{cm}}_{h,i} x^{\mathrm{cm}}_{h,i} + \beta^{\mathrm{cf}}_{h,i} x^{\mathrm{cf}}_{h,i} + \beta^{\mathrm{pp}}_{h,i} x^{\mathrm{pp}}_{h,i} + \sum_{\mathrm{rest}} (\beta^{\mathrm{rest}}_{h,i} x^{\mathrm{rest}}_{h,i}) + \alpha_{h,i} \qquad \forall h, \forall i, \tag{4}$$

for each choice alternative, where the superscript indices denote the single components of the vectors $x_{h,i}$ and $\beta_{h,i}$, purchase price (pp), fuel costs (cf) and maintenance costs (cm). In difference to Truong and Hensher (2012), we derive a money cost variable, $x^{\mathrm{money}}_{h,i}$, defined as

$$x^{\mathrm{money}}_{h,i} := \frac{\beta^{\mathrm{cm}}_{h,i}}{\beta^{\mathrm{money}}_{h,i}} x^{\mathrm{cm}}_{h,i} + \frac{\beta^{\mathrm{cf}}_{h,i}}{\beta^{\mathrm{money}}_{h,i}} x^{\mathrm{cf}}_{h,i} + \frac{\beta^{\mathrm{pp}}_{h,i}}{\beta^{\mathrm{money}}_{h,i}} x^{\mathrm{pp}}_{h,i} \qquad \forall h, \forall i, \tag{5}$$

where $\beta^{\mathrm{money}}_{h,i} := \beta^{\mathrm{cm}}_{h,i} + \beta^{\mathrm{cf}}_{h,i} + \beta^{\mathrm{pp}}_{h,i}$. Actually, these shadow prices do not depend on the index i, since they are shadow prices on characteristics of the household agents only. We assume households to have the same marginal propensity to spend on fuel, irrespective of which type of car they drive. Hence we have

$$\beta^{\mathrm{money}}_{h} := \beta^{\mathrm{money}}_{h,i} = \beta^{\mathrm{money}}_{h,j} \quad \forall i, j, \forall h, \tag{6}$$

the marginal utility value of money, which is naturally unique. Now $V_{h,i}$ can be expressed in terms of $\beta^{\mathrm{money}}_{h}$, as

$$V_{h,i} = \beta^{\mathrm{money}}_{h} x^{\mathrm{money}}_{h,i} + \sum_{rest} (\beta^{rest}_{h,i} x^{rest}_{h,i}) + \alpha_{h,i} \qquad \forall h, \forall i, \tag{7}$$

a formulation that distinguishes the input variables into a monetary variable and the other non-monetary variables. Here it is obvious that $\beta^{\mathrm{money}}_{h}$ is the marginal utility value of money, since it denotes the value of monetary costs compared to the value of other variables' contribution to household's utility of choice alternative i.

The effective price for vehicle purchases, as stated above, is an aggregate variable that includes all characteristics and attributes of a choice alternative, and translates them into monetary terms. So if the effective price $P^e_{h,i}$ of choice alternative i is known, the indirect utility function can be expressed as

$$V_{h,i} = \beta^{\mathrm{money}}_{h} P^e_{h,i} + \alpha_{h,i} \qquad \forall h, \forall i, \tag{8}$$

where $\alpha_{h,i}$ is the alternative specific constant.

Making use of this formulation and knowing the explicit form of the indirect utility function, (1), one can actually calculate the effective price for choice alternative i to be

$$P^e_{h,i} = \frac{V_{h,i} - \alpha_{h,i}}{\beta^{\text{money}}_h} = \sum_n \frac{\beta^n_{h,i}}{\beta^{\text{money}}_h} x^n_{h,i} \qquad \forall h, \forall i. \tag{9}$$

For each agent, we now derive with the help of the effective prices $P^e_{h,i}$, the aggregate price of purchasing any type of car $\overline{P_h}$, which will enable us to derive total demand for car purchases $\overline{D_h}$. The aggregation procedure can not follow a simple CES logic, since purchase shares of different vehicle types will change endogenously according to non-monetary variables. Hence, as proposed by Truong and Hensher (2012), one needs to go back to the indirect utility function and define the logsum, or inclusive value, $\overline{V_h}$ of all vehicle types as

$$\overline{V_h} := \ln \sum_{i \in I} \exp(V_{h,i}) \quad \forall h. \tag{10}$$

It represents total consumer surplus associated with all choices for a particular choice set, and indicates the expected maximum utility for these choices. The total differential of this inclusive value, i.e. its change due to an infinitesimal change in all attribute variables is denoted by

$$\mathrm{d}\overline{V_h} = \sum_{i \in I} Prob_{h,i} \; \mathrm{d}V_{h,i} \quad \forall h. \tag{11}$$

Substituting (8) for $V_{h,i}$ one gets

$$\begin{aligned} \mathrm{d}\overline{V_h} &= \sum_{i \in I} Prob_{h,i} \; \mathrm{d}(\alpha_{h,i} + \beta^{\text{money}}_h P^e_{h,i}) \\ &= \beta^{\text{money}}_h \sum_{i \in I} Prob_{h,i} \; \mathrm{d}P^e_{h,i} \quad \forall h, \end{aligned} \tag{12}$$

and defining the change in the aggregate price for car purchases $\overline{P_h}$ as

$$\mathrm{d}\overline{P_h} := \sum_{i \in I} Prob_{h,i} \; \mathrm{d}P^e_{h,i} \quad \forall h, \tag{13}$$

yields

$$\mathrm{d}\overline{V_h} = \beta^{\text{money}}_h \mathrm{d}\overline{P_h} \quad \forall h. \tag{14}$$

This represents economic intuition, since the marginal value of the utility of money (β^{money}_h) is by definition equal to the marginal change in utility due to a marginal change in the price for the good in question. However, the crucial point here is that $P^e_{h,i}$ includes not only "real" monetary costs as purchase price, fuel and maintenance costs, but also all non market attributes and their shadow prices by construction. Since the operator d is linear and since the integral of any function is unique up to a constant, by integrating (14) we have

$$\overline{P_h} = \frac{\overline{V_h}}{\beta^{\text{money}}_h} + c_h \quad \forall h, \tag{15}$$

The constant c_h is determined in the calibration procedure, in such a way that the equation holds with the initial values of the other variables and parameters. Here one can see from the definition of $\overline{V_h}$ that changes in the utilities of the choice alternatives determine changes in the aggregate price of purchasing a car, $\overline{P_h}$, as would be expected.

Overall demand for car purchases of any kind, $\overline{D_h}$, is derived in a standard manner according to Shephard's Lemma by differentiating the expenditure function of each household with respect to the aggregate price for car purchases

$$\overline{D_h} = \frac{\partial e(p_{x1}, p_{x2}, ..., \overline{P_h})}{\partial \overline{P_h}} \quad \forall h, \tag{16}$$

where $e(.)$ is the unit expenditure function of household h. This aggregate demand level is now split up between the choice alternatives according to the market shares as derived in (3). Demand for vehicle purchases of type i by agent h, $D^{\text{pur}}_{h,i}$, is hence equal to

$$D^{\text{pur}}_{h,i} := \overline{D_h} Prob_{h,i} \quad \forall h, \forall i. \tag{17}$$

With this method, we end up with the price $\overline{P_h}$, the demand $\overline{D_h}$ for overall car purchases, and the demand for purchases of each single vehicle type $D^{\text{pur}}_{h,i}$, depending on consumer preferences $\beta_{h,i}$ and vehicle attributes $x_{h,i}$, which can be exogenously varied in scenario simulations. However, these three variables, $\overline{P_h}$, $\overline{D_h}$ and $D^{\text{pur}}_{h,i}$, are all truly endogenous variables, since they depend on the money costs of each choice alternative in particular. This monetary cost is the sum of maintenance, purchase and fuel costs, all of which are endogenous variables in the CGE model, determined in the overall economic equilibrium. Hence, this representation of the purchase decisions reflects detailed consumer behaviour, and accounts for changes in prices and also exogenous variables, while it does not leave the borders of micro-founded economic theory.

Equation (16) is still very abstract. In order to explicitly arrive at the aggregate demand level for car purchases of any kind, $\overline{D_h}$, one needs to take into account the detailed expenditure structure of vehicle purchases and vehicle use. This is explicitly done in the following section.

3.2 Implementation of the Logit Module in the CGE Model

In this section we provide a detailed description of the technical implementation of the hard link between the DC and the CGE model. We show how to include an aggregated DC model as outlined in section 2 within a CGE model formulated in MCP/GAMS. In the course of this task we also introduce a detailed way of how to account for the development of the stocks of the different vehicle types. The time index is explicit in all equations of this chapter. For reasons of simplicity, we decided to explicitly include it in the description only where it is necessary, in the sense that time plays an active role, as it does in most of the equations of this section. In the previous section it was omitted, because most equations there were intratemproal equations, which hold in each period, but do not link different time periods. However, the time index is naturally implied in all equations of this report, since the model is intertemporal.

Before we begin to explain the imlementation, we want to remind the reader about which variables are given endogenously in the CGE structure, apart from the logit module, and which variables are being generated by the logit module.

The purchase price for vehicles of type i is given by a simple Leontief combination of the prices for the input goods cars (P^{C}) and engines (P^{E}),

$$P_i^{\mathrm{pur}}(t) = \theta_i^{\mathrm{CE}} P^{\mathrm{C}}(t) + (1 - \theta_i^{\mathrm{CE}}) P^{\mathrm{E}}(t) \quad \forall i, \forall t. \tag{18}$$

These goods are produced by the sectors[5] "cars" and "engineering" in the CGE mdoel. The cost combination is different for each car type i, but is assumed to stay constant over time for all types. The share parameter θ_i^{CE} is the vehicle type specific cost share between the two input goods. Any car of type i is sold at this price, and this price is not determined in the logit module.[6]

Similarly, P_i^{use} is the price of fuel and service inputs in vehicle use. It is the Leontief CES combination of the prices for "fuel" (P^F) and "service and maintenance" (P^S),

$$P_i^{\mathrm{use}}(t) = \theta_i^{\mathrm{FS}}(t) P^S(t) + (1 - \theta_i^{\mathrm{FS}}(t)) P_i^F(t) \quad \forall i. \tag{19}$$

Also here we assume that the use of these factors stay in constant proportion to each other over time. The price for fuel in (19) includes also the rate of fuel taxes.[7]

Now given these two prices, we use the logit module to determine the according demand varables, i.e. demand for vehicle purchases of type i by household h, $D_{h,i}^{\mathrm{pur}}$, as well as demand for the use of vehicles of type i by household h, $D_{h,i}^{\mathrm{use}}$. These demand variables will determine household expenditures, and the development of the size of the vehicle stock.

Equations (1), (10), and (15), as presented in the last section, form the first step of the logit module:

$$\begin{aligned} V_{h,i}(t) &= \beta_{h,i} x_{h,i}(t) + \alpha_{h,i} \qquad \forall h, \forall i, \forall t, \\ \overline{V_h}(t) &= \ln \sum_{i \in I} \exp(V_{h,i}(t)) \quad \forall h, \forall t, \\ \overline{P_h}(t) &= \frac{\overline{V_h}(t)}{\beta_h^{\mathrm{money}}} + c_h(t) \quad \forall h, \forall t. \end{aligned}$$

[5]The seperate cars sector was especially created within DEFINE.

[6]The purchase price should not be confused with the effective price mentioned in the previous chapter. The latter is necessary to determine demand for vehicles, since it is assumed to be influenced by the vehicle's attributes.

[7]The fuel tax rate is varied in scenarios, which leads to a change in the $\theta_i^{\mathrm{FS}}(t)$ share over time. This share is thus actually endogenous in our scenarios (as is Θ_h^{pur}, see below). However this does not have a structural implication on the model's functioning as a whole and is therefore not explained in further detail.

Basically, what happens in these three equations is that consumer preferences are translated into the abstract price for purchases of any kind of vehicle, $\overline{P_h}$. This translation is pretty mechanic; a rise in e.g. fuel costs of vehicles of type i would be represented in a rise of the value of the corresponding entry of the $x_{h,i}$ vector. This rise would influence the utility negatively (the corresponding β has a minus sign), and $\overline{P_h}$ would rise, since all operations are strictly monotone, and β_h^{money} also has a minus sign. It is clear that the price should rise, if an input cost rises. The constant $c_h(t)$ is chosen in such a way that the price $\overline{P_h}(t)$ equals the benchmark reference price path.[8]

In order to arrive at the corresponding demand for purchases of any kind of cars $\overline{D_h}$, see equation (16), which is in turn used to determine the demand for vehicle purchases of each type, we need to take a closer look at the household expenditure structure: The size of consumer expenditures connected to cars consist of expenditures on purchases of new cars, and on the use of existing cars (see 3). These develop quite differently from each other, since a rise in new purchases leads to a build up of a stock, that is, with some inertia. In the following, we will refer to expenditures on purchases of new cars as "flow-expenditures", denoting the "flow" of new cars that add to the vehicle stock. We will call expenditures on fuels, taxes and maintenance "stock-expenditures", since these are expenditures that occur to each household in direct proportion to the size of the vehicle stock owned.

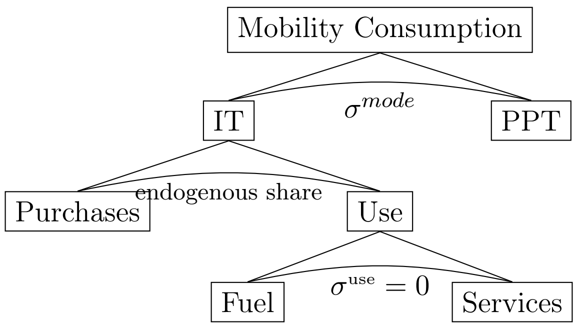


Figure 3: *Structure of households' expenditures on mobility.*

The amount spent on purchases and on the use makes up the total value of expenditures on individual transportaton (IT) in the household's overall consumption bundle. Unlike in other nests in the consumption function, here households shall clearly not be able to substitute between the two input components purchase and use of cars. Household's purchase decisions should be independent from the intensity at which they drive thier cars, and even more importantly, the size and hence also the use of the vehicle stocks develops according to the new purchases in the previous periods.

[8]It is standard practicse in CGE models to have all prices equal to unity in the base year, since one is typically interested in relative price changes only. The relative prices for goods and services all develop according to $(\frac{1}{1+r})^t$ in the benchmark steady state. More on this topic will be said in chapter 4.

Due to these lines of thought, we define the price for the IT composite as an *endogenously adapting Leontief composite* of the aggregate price for car purchases and the price for the use of existing cars,

$$P_h^{\mathrm{IT}}(t) \quad = \quad \Theta_h^{\mathrm{pur}}(t)\overline{P_h}(t) \quad + \quad (1-\Theta_h^{\mathrm{pur}}(t))\sum_i \theta_{h,i}^{st}(t)P_{h,i}^{\mathrm{use}}(t) \quad \forall h, \forall t. \tag{20}$$

Here the share paramter $\Theta_h^{\mathrm{pur}}(t)$ denotes the share of expenditures on car purchases in total expenditures for individual transportation for household h in period t. We use the capital greek letter Θ to denote the endogeneity of this share. This implies a qualitative change in the Leontief consumption nest over time; as new car purchases rise and fall, and as the vehicle stocks build up or shrink, also the expendiutres on, and hence the price for the overall IT composite changes. [9]

The share $\theta_{h,i}^{st}(t)$ in equation (20) is the share of the size of the stock of cars of type i in the total stock of vehicles owned by household h,

$$\theta_{h,i}^{st}(t) = \frac{st_i(t)}{\sum_j st_j(t)} \quad \forall h, \forall i, \forall t, \tag{21}$$

with

$$\sum_i \theta_{h,i}^{st}(t) = 1 \quad \forall h, \forall t. \tag{22}$$

This share is known at the beginning of each period t, since the vehicle stock at the beginning of each period, $st_i(t)$, is known too. We stick to the convention that vehicles are bought in the end of each period, and are only added to the stock in the next period. For this reason, we also know $D_{h,i}^{\mathrm{use}}(t)$, unit demand of household h for using vehicles of type i; since we assume the use of vehicles to develop in a constant relationship to the size of their stock, we have

$$D_{h,i}^{\mathrm{use}}(t) = \frac{st_i(t)}{st_i(0)} \quad \forall h, \forall i, \forall t. \tag{23}$$

Apart from $D_{h,i}^{\mathrm{pur}}(t)$, this variable is one of the two main variables that we wanted to determine in the logit module. However, its development over time clearly depends on the development of $D_{h,i}^{\mathrm{pur}}(t)$, since the size of the vehicle stock depends on the number of new purchases of vehicles. For the determination of $D_{h,i}^{\mathrm{pur}}(t)$, however, we need some more algebra.

The determination of the endogenous share paramter in equation (20), $\Theta_h^{\mathrm{pur}}(t)$, depends on both the beforementioned unit demand variables,

$$\Theta_h^{\mathrm{pur}}(t) = \frac{\sum_i e_{h,i}^{\mathrm{pur}}(0)D_{h,i}^{\mathrm{pur}}(t)}{\sum_j \left[e_{h,j}^{\mathrm{pur}}(0)D_{h,j}^{\mathrm{pur}}(t) + e_{h,j}^{\mathrm{use}}(0)D_{h,j}^{\mathrm{use}}(t)\right]} \qquad \forall h, \forall t. \tag{24}$$

[9] The share is exogenous in the first period, and endogenously adapts according to the households purchase decisions and the thereby induced vehicle stock developments over time.

Here $e^{\mathrm{pur}}_{h,i}(0)$ is the volume of expenditures on purchases of cars and $e^{\mathrm{use}}_{h,i}(0)$ denotes the volume of expenditures on fuel and services (which is associated with using the cars), both in the starting period. This share will hence rise in times when more new vehicles are bought, as compared to a steady state development of purchases and the size of the stock, and shrink in times when less new vehicles are bought.

The price for individual transportation, $P^{\mathrm{IT}}_h(t)$, is now used to determine overall demand for IT: differentiating the unit expenditure function of each household with respect to the price for IT yields, by Shephard's Lemma, unit demand for IT,

$$D^{\mathrm{IT}}_h(t) = \frac{\partial e(p_{x1}, p_{x2}, ..., P^{\mathrm{IT}}_h(t))}{\partial P^{\mathrm{IT}}_h(t)} \quad \forall h, \tag{25}$$

and unit demand for purchases of any kind of car is given as

$$\overline{D_h}(t) = D^{\mathrm{IT}}_h(t) \frac{\Theta^{\mathrm{pur}}_h(t)}{\Theta^{\mathrm{pur}}_h(0)} \quad \forall h. \tag{26}$$

Here we have introduced an additional step as compared to the previous chapter, where in (16), we directly derived $\overline{D_h}$ by Shephard's Lemma. However, the two approaches are equivalent, since the derivation of (20) with respect to $\overline{P_h}$, the only additional inner derivative appearing in (16), just yields the share Θ^{pur}_h.

In (26) $\Theta^{\mathrm{pur}}_h(0)$ is the base-year value of this share, which stays constant for all time periods in the benchmark steady state.[10] The reason for this share to be in the denominator in (26) is because all unit demand variables have to equal the reference growth path in the benchmark steady state: If the demand variables were expressed in real monetary terms, say $\overline{mD_h}$ and mD^{IT}_h, then (26) would become

$$\overline{mD_h}(t) = mD^{\mathrm{IT}}_h(t)\Theta^{\mathrm{pur}}_h(t) \quad \forall h, \forall t. \tag{27}$$

However, since in the benchmark steady state we have

$$\overline{D_h}(t) = \frac{\overline{mD_h}(t)}{\overline{mD_h}(0)} \qquad \text{and} \qquad D^{\mathrm{IT}}_h(t) = \frac{mD^{\mathrm{IT}}_h(t)}{mD^{\mathrm{IT}}_h(0)} \qquad \forall h, \forall t, \tag{28}$$

and, as a special case of (27),

$$\overline{mD_h}(0) = mD^{\mathrm{IT}}_h(0)\Theta^{\mathrm{pur}}_h(0) \quad \forall h, \tag{29}$$

it becomes clear that (26) is the correct formula to use for unit demand variables. More on the benchmark steady state and the evolution of unit demand variables is said in the next section on calibration (chapter 4).

Having derived unit demand for overall car purchases, $\overline{D_h}$, we can now use the share

[10]Only in scenarios, when the model departs from the benchmark steady state, this share will change it's value. See also chapter 4.

of purchases of vehicles of type i in total vehicle purchases of household h,

$$\theta_{h,i} = Prob_{h,i} = \frac{e^{V_{h,j}}}{\sum_j e^{V_{h,j}}} \qquad \forall h, \forall i,$$

as determined by the logit module (see equations (2) and (3)), to arrive at unit demand for purchases of vehicles of type i:

$$D^{\text{pur}}_{h,i}(t) = \overline{D_h}(t)\frac{\theta_{h,i}(t)}{\theta_{h,i}(0)} \quad \forall h. \tag{30}$$

As in equation (26), also here the initial value of the share appears in the denominator, since we use unit demand variables.

We now have determined for all periods t the two variables that we wanted to determine with the help of the logit module: unit demand for vehicle purchases of type i by household h, $D^{\text{pur}}_{h,i}(t)$, and unit demand for the use of vehicles of type i by household h, $D^{\text{use}}_{h,i}(t)$.

In what follows, we describe how we model the development of the vehicle stocks for the alternatives CV, HEV, PHEV and EV. We use a standard accumulation and depreciation process, and thereby account for the size of the vehicle stocks and for the new purchases in physical units, not in monetary units. This allows us to avoid issues with intertemporal price changes and their influence on the monetary value of the vehicle stock, when converting the money flows and stocks into physical units of cars. We also use cohort depreciation, i.e. we assume that vehicles that are bought have a fixed lifetime, and exceed from the vehicle stock when they reached that age. The average lifetime of a car is assumed to be 12 years.[11]

The vehicle stock $st_i(t)$ of vehicle type i equals last period's stock plus new registrations $nr_i(t)$ less depreciation of worn out cars $dc_i(t)$. We follow the convention that purchases of new vehicles and depreciation of old vehicles both take place at the end of each period, hence the stock in each period t is

$$st_i(t) = st_i(t-1) + nr_i(t-1) - dc_i(t-1) \quad \forall i, \forall t. \tag{31}$$

One might say that the level of new registrations is the core of the modelling framework. It is determined by the demand for purchases of new vehicles $D^{\text{pur}}_{h,i}(t)$, as described in the previous subsection, and determines the stock development. Specifically, new registrations are defined as

$$nr_i(t) = \frac{e^{\text{pur}}_{h,i}(0) D^{\text{pur}}_{h,i}(t)}{P^{\text{pur}}_i(t)} \quad \forall i, \forall t. \tag{32}$$

Here $e^{\text{pur}}_{h,i}(0)$ denotes the volume of expenditures on type i car purchases by household h in the starting period (hence the zero argument). It must be noted, that the number of new registrations of vehicles depends on the purchase price $P^{\text{pur}}_i(t)$ in two ways. Firstly, the

[11] See also Gruden (2008)

demand for purchases of new vehicles $D_{h,i}^{\text{pur}}(t)$ is formed taking account of this average monetary purchase price: Even if the effective price is used to derive this demand in (16), the purchase price $P_i^{\text{pur}}(t)$ enters, with all other vehicle attributes, the indirect utility $V_{h,i}$ (see e.g. (4)) which is at the core of the Logit module. Secondly, once the amount of money that will be spent on cars is determined, the purchase price for cars also determines the quantity of cars that are bought with that allocated amount of funds (that is the explicit representation of $P_i^{\text{pur}}(t)$ in (32)).

For depreciation of CVs, since we do not know the distribution of the age of cars among the current vehicle stock, we assume a constant depreciation for the first 12 periods in the model,

$$dc_{\text{CV}}(t) = st_{\text{CV}}(t)\delta_{\text{CV}} \text{ for } t \leq 12. \tag{33}$$

For other vehicle types, since we are still at the moment of introduction to the vehicle market, we do not assume depreciation for the first 12 years. After the 12th period, however, the exact amount of vehicles that was purchased 12 periods before depreciates:

$$dc_i(t) = nr_i(t-12) \text{ for } t > 12. \tag{34}$$

In this way a detailed stock-flow consistent accounting of the vehicle stocks, new registrations, and depreciation is assured.

As xEVs currently enter the market, and are at the beginning of their lifecycle as a technology, the vehicle stock is only increasing in the first years. This means that there is no depreciation of old cars yet, since they are newly bought and still below their average life expectancy. This is why stock-expenditures will, after an initial lag grow much stronger than flow-expenditures, however depending on the growth of new registrated vehicles. After some years, assuming the technology successfully entered the market, a stabilization of the procedure may be expected due to depreciation of old cars. Only then can stock and flow expenditures eventually reach the steady state growth rates of the economy, and grow at the same rate, as is more or less the case for CVs at the moment. [12] Depending on the extent that xEVs will enter the market, demand for new CVs may be expected to decrease, reducing the stock of CVs, again with a time lag.

4 Calibration and Validation

Calibrating a CGE model to real data involves many different tasks. The MERCI model has experienced a lot of development over the past years. At this point we want to give a short general overview of what it means to calibrate a model, and then focus and explain the details of the calibration procedure that are connected to the logit module, and the individual transportation sector of the model.

The starting point for calibrating CGE models is a Social Accounting Matrix (SAM). It depicts income and expendtiture folws between all agents and sectors in the model at a given point in time (here: 2008). The SAM that we used for our model was also

[12] More on steady state growth and the different growth rates of the vehicle purchases and stocks will be said in chapter 4

developed in the DEFINE model. A detailed report on the SAM and its construction is given in Deliverable 1.1. The SAM is constructed out of input output tables, EU SILC[13] and Labour Force Survey data, as well as data on vehicles which was specifically estimated from the vehicle consumption survey carried out in WP 3 of DEFINE (see Deliverables 3.1-3).

When calibrating dynamic CGE models, as MERCI, one first assumes the economy to be in a steady state, and calibrates the model so that all model equations hold for all time periods. Calibrating the model to a benchmark steady state means to choose all parameter values, and all inital values, so that all endogenous variables grow at the same rate. This implies that all demand variables grow at the same growth rate, and all prices develop according to the same price path. The structure of the economy does not change over time. One then also says that the model economy "is in the steady state".

It is standard practise in CGE models to have all prices equal to unity in the base year, since one is typically interested in relative price changes only. The relative prices for goods and services all develop according to the price reference path $pref(t)$in the benchmark steady state,

$$pref(t) = (\frac{1}{1+r})^t \quad \forall t, \tag{35}$$

where r is the real interest rate, which is exogenous. The reference price in period t is the expected present value of the price, i.e. discounted value from the representative agent's perspective, in the starting period. It is assumed in CGE models that consumption today is more important (hence has a higher value) to the representative agent than future consumption. Hence the $pref$ is a decreasing price path.

Also demand variables are typically used in the form of unit demand variables, i.e. they are normalized by their base year level. The unit demand variables then all develop according to the quantity reference level, $qref(t)$ in the benchmark steady state,

$$qref(t) = (1+gr)^t \quad \forall t, \tag{36}$$

where gr is the real growth rate, which is exogenous.

Since all levels of monetary flows between all agents and sectors are given in the SAM in real monetary terms, the values in the SAM can be used, in combination with the levels of unit demand and relative prices, to determine actual real prices and actual real monetary flows between agents and sectors in any period t.

After having successfully calibrated the model to the benchamark steady state, one typically implements realistic assumptions, such as resource constraints, and constructs a business as usual (BAU) scenario. The outcome of the simulation of this scenario does not necessarily have to be a steady state. Afterwards, counterfactual policy simulations are conducted, and compared to the outcomes of the BAU. Any differences in variables' levels are then the net general equilibrium effects of the policy eyperiment. Hence CGE models are typically not used to actually forecast levels of economic variables, but to accurately assess policies' influences on the level of economic variables.

[13]Statistics on Income and Living Conditions.

One difficulty in the calibration procedure was the fact that the estimated logit model which is included in the CGE model, see equations (1) and (2), yields market shares for vehicle purchases by household type which do not match the consumption shares by households in the SAM. This is due to the fact that for the projections of the vehicle stocks, a much more detailed version of the discrete choice model was used than the one implemented in the CGE model. In order to reach these more detailed market shares with the implemented version of the logit module, we used the alternative specific constants $\alpha_{h,i}$ in the households' estimated utility functions, equation (1), as an additional degree of freedom while calibrating the model.

The difficulty in calibrating our model to a steady state is the connection between stocks and new registrations of the different vehicle types. Since in a steady state, all variables must grow at the same rate, we desire the expenditures on vehicle use (fuel and maintenance costs) and those on vehicle purchases to grow at the same rate, the exogenous steady state growth rate gr. This implies vehicle stock sizes and the number of new registrations to grow at this rate as well,

$$st_i(t) = st_i(0)(1 + gr)^t \quad \forall i, \forall t, \tag{37}$$
$$nr_i(t) = nr_i(0)(1 + gr)^t \quad \forall i, \forall t. \tag{38}$$

Obviously, the vehicle stock in each period also has to be that of the preceeding period plus new registrations minus depreciated cars of the preceeding period, see equation (31).

Combining these conditions one obtains that the initial number of new registrations must be in a fixed relation to the vehicle stock,

$$nr_i(0) = st_i(0)(gr + \delta_i), \quad \forall i. \tag{39}$$

Here δ_i is the depreciation rate of the vehicle stock of type i, meaning that at the end of each period, the fraction δ_i of the stock of vehicles of type i depreciates.

The numbers of new registrations and stocks per vehicle type, as well as their average prices, were derived and estimated by Umweltbundesamt (UBA) Vienna within the DEFINE project. Clearly, average prices combined with physical units of new registrations imply expenditures on vehicle purchases. This calculation was used to construct total expenditures on vehicle purchases of each type in the social accounting matrix. These expenditures were divided between the different household types according to market shares that were computed by a very detailed version of the discrete choice model mentioned above, see equations (2) and (1). In order for vehicle stocks to develop in line with new registrations and depreciation, we used equation (39) to determine steady state depreciation rates for each vehicel type. This is the only degree of freedom, since for the first time period the other parameters (new registrations and the size of the vehicle stock), are given from data. Due to the fact that xEVs are yet in the phase of entering the market, xEV-stocks are extremely small in relation to new registrations of xEVs (compared with CVs). Hence depreciation rates for xEVs resulting from (39) are unrealistically high[14].

However, this is not a problem, since the initial steady state merely serves as an initial

[14]Steady state depreciation rates: CVs: 0.05, HEVs and PHEVs: 0.24, EVs: 0.26.

σ^{mode}	**Mode choice elasticities** Urban	Suburban	Rural
Low Skilled	0.15	0.31	0.32
Medium Skilled	0.17	0.41	0.46
High Skilled	0.15	0.26	0.40

Table 3: Cross-price elasticities between individual (IT) and public transport (PT).

"checkpoint" that ensures that the model is calibrated correctly. Any results of our policy scenarios are not compared to this initially calibrated steady state, but to a benchmark (BMK) scenario. This BMK scenario, or BMK growth path, differs from the initial steady state in that it depicts a realistic development of the economy without policy action. With respect to the vehicle stock, this means the following: Within the BMK scenario, and also in all policy scenarios, we do not account for xEV depreciation for the first 12 years, which is the assumed average lifetime of a car. After that, the exact number of vehicles bought 12 periods earlier depreciates. In our view, this is an extremely realistic depiction of depreciation, because xEV stocks were practically zero in 2008, and started to build up only after that. Clearly, this exact period-by-period depreciation accounting is more precise than using a constant depreciation rate. Especially in the feed-in phase of a new technology in a durable goods market that is subject to inertia, as is the case with cars, this is extremely important in order to assess stock developments as accurately as possible.

The model is not used to specifically forecast actual levels of economic variables, but to accurately assess policies' influences on the levels of economic variables. Model results, which are discussed in the next section, are always differences between variables' levels in one scenario and their levels in other scenarios.

In the course of WP3 of DEFINE, we also estimated demand elasticities for public transportation with the help of the micro dataset (see Deliverable 3.1). The values for these elatsticities are documented in Deliverables 3.2 and 3.3. In order to use these elasticities in the CGE model, we had to transform them into cross price elasticities, according to the forumals given in Rutherford (2002). This is the case since we use the calibrated share form of CES functions for unit cost functions, and derive unit demand from these unit cost functions. The transformed values of these cross price elasticities were used in the model in the "transport consumption" nest, see 3. The value is denoted with σ^{mode}, indicating the mode choice. It denotes the elasticity of substitution between individual transport and public passenger transportation. The values for these cross-price elasticities between individual transport (IT) and public transport (PT) are given in table 3.

The transformation formulas, and hence the values of the cross-price elasticities, also depend on the values of the base year consumption expenditure of each household, and on the values of the own-price demand elasticities of consumption composites in nests that appear higher in the consumption tree. Since we only had estimations for public transport and individual transport, we assumed the own price elasticity of demand for the IT-PT bundle 20% lower (in its absolute value) than that for IT.[15] We thereby implicitly assume that households rather substitute within this nest (i.e. from IT to PT) if IT's price rises, and rather not use less overall transport.

In order to validate the model's stability we performed a sensitivity analysis. The benefit of such a validation is twofold. On the one hand this procedure ensures that the selection of parameter values is such, that the model's solution is not close to a singularity, and that the results are stable. On the other hand, it helps the modeller to find such a set of elasticities, if the initially chosen set of parameters yields unstable results. For a stable model, a slight change in parameter values of crucial elasticities should neither yield a significant change in the size of the model variables, nor a qualitative change in direction of the results. Performing a sensitivity analysis hence helps the modeller to find a set of elasticities, where these conditions are satisfied.

We simulated our BAU and our EM+ scenarios multiple times with a structural change in all values of elasticities. Thereby we varied the values of the elasticities by +/-25%, +/-50%, +/-100%, +/-150%, +/-200%, and +/-300%.

Depending on the initial value of each elasticity a rise in e.g. +300% may not be very realistic. However, for the simulation runs with elasticity values in a realistic range, the changes in the variable's values were also in a realistic order of magnitude. The quality of results, i.e. the directions of variables' reactions to scenario simulations in the BAU and EM+, was not reversed by any alteration of elasticities. Hence the results were accepted to be robust. A complete documentation of our results would exceed the scope of this report, due to the magnitude of results generated by the process. The most volatile examples are, however, worth reporting at this point:

Among the results that we obtained from the sensitivity analysis, the most notweorthy is a variation in terms of the elasticities of consumption (for all households). Results of this simulation reacted slightly more sensitive than e.g. a variation in terms of elasticities of production. This is not really surprising since this kind of CGE models are typically demand-driven. With regard to production, a variation in the elasticity between energy and electricity inputs had a slightly stronger impact than variations of other elasticities in production.

To give a concrete example, we compared the GDP levels in an ordinary EM+ scenario-run (i.e. without a variation of any elasticities) with the GDP levels of all our sensitivity analysis simulations of the EM+ scenario (i.e. with variations of all elasticities in the range described above). The deviation of the change in GDP in 2030 stayed within a range of +/- 20 % in all our successful simulation runs: While with the standard values, the main result was minus 1 bln Euro in 2030 (compared to the BAU), and with variations of elasticities, it was at most at 1.2 bln Euro or 0.85 bln Euro.

[15] The values for these demand elasticities were between -0.1 and -0.15, and hence in a range that is accepted in the literature.

5 A Set of Simulation Results and Case Studies

5.1 Simulation Results for Austria: Economic Costs and Benefits of Electromobility

5.1.1 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 %, EAA (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 CO_2 emissions under supportable economic 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 directly 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 ("Mineraloelsteuer" or MoeSt) on gasoline and diesel for the individual transport sector, the new registration tax for cars in Austria[16] (NoVA), taxes on consumption, labour and capital, as well as different energy taxes for households and firms are explicitly considered in the model.

5.1.2 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, CO_2 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. This benchmark growth path describes an economy in which there is a very small shift-in of xEVs, barely of significance for the vehicle market, since basic preferences of households do not change, and the fuel cost and price effects have very little influence on the households' mobility preferences. There is also no build-up of charging infrastructure assumed in this benchmark growth path.

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, Ibesich et al. (2014), see also section 2 of the DEFINE Synthesis report.[17] The macro CGE model at this point is primarily used to investigate the according overall economic costs of the increased penetration of electric vehicles.[18]

[16] 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. Currently there is an additional 50 Euro penalty for each g/km CO_2 emissions between 180g/km and 220g/km, and 75 Euro for each g/km above that.

[17] See `https://www.ihs.ac.at/projects/define/files/DEFINE_SynthesisReportEN_final.pdf` for the DEFINE synthesis report.

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

5.1.3 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 DEFINE Synthesis report, 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 and by ca. 10 % to the service sector.[19] 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 that does not include an expansion of electromobility, as described above. With this comparison, we want to assess the effect of electromobility on the development of relevant macroeconomic indicators such as government revenue and the gross domestic product (GDP).

5.1.4 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

[19] Assumptions to the sectoral allocation of the provision of charging infrastructure are based on calculations conducted within the project ECONGRID, Bliem et al. (2013).

(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 inputs[20] 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[21]. 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 sce-nario, a rather slight reduction of 0.03 percentage points from the balanced growth path.

Relating to the figure of 1 million tons of CO_2 emission reduction as calculated by the Environment Agency Austria for 2030 (see Ibesich et al. (2014)), the economic net costs[22] for saving a ton of direct CO_2 emissions amount to 120 Euros.[23] However, in this scenario already more than 44 % of new registrations are electric vehicles (PHEVs

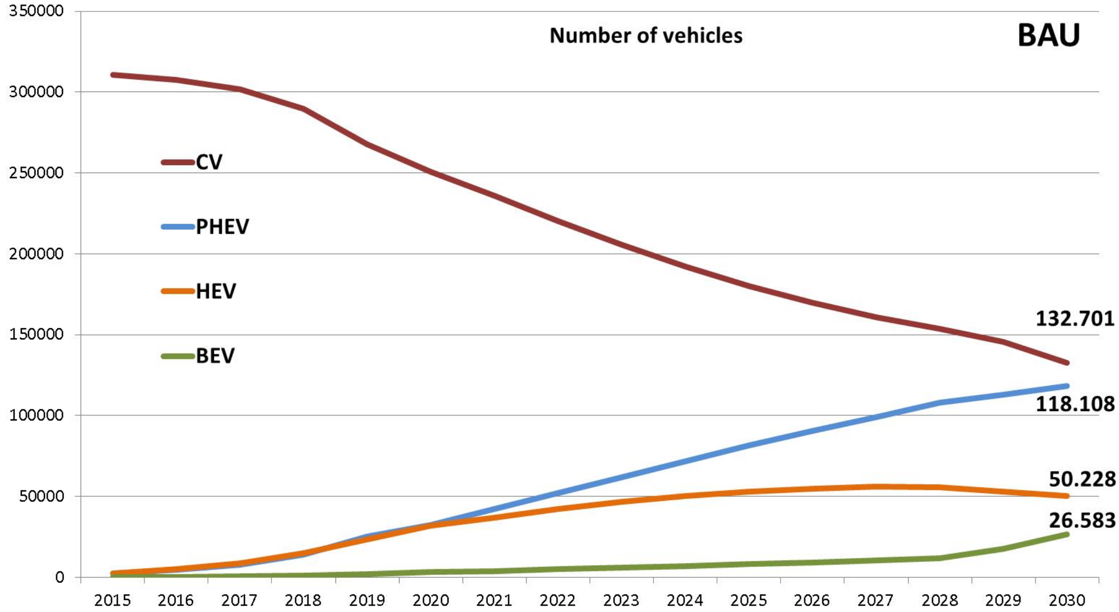
[20]See Miess et al. (2014) for the sectoral structure of the model and assumptions for the construction of the vectors of intermediate inputs for the different vehicle types. Conventional vehicles, according to assumptions by IHS, almost exclusively require intermediate inputs from the sector "Motor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

[21]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.

[22]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.

[23]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.

Figure 4: Development of New Registrations in Cars 2015 - 2030 (Austria)



Source: Model calculations by IHS Vienna

or BEVs) in 2030. Thereby, one can assume that under continuation of this trend (see Figure 4 for the development of new registrations in cars until 2030) CO_2 emissions in the transport sector will be substantially further reduced in the time span after 2030.

5.1.5 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

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 and 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).[24]

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

[24]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.

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 Ibesich et al. (2014)) naturally differ.

5.1.6 Results - EM+

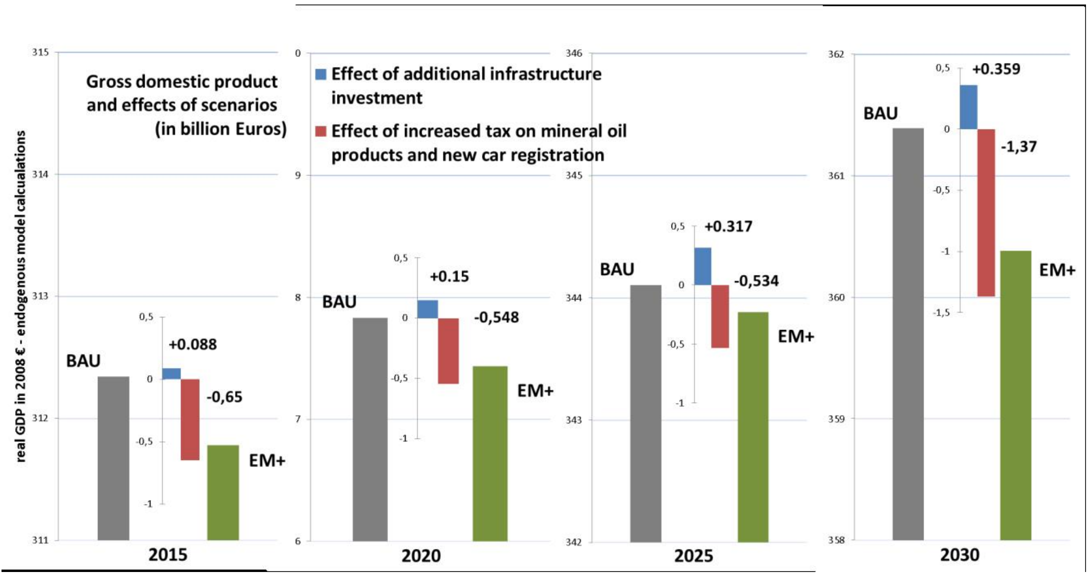
Also in this scenario the infrastructure investments induce positive growth effects. The positive net effects lie between an additional raise in GDP by 88 million Euros (0.03 %) in 2015 and 360 million Euros (0.1 %) in 2030, clearly more than in the BAU scenario.

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.[25] 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

[25]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 5: Gross Domestic Product - BAU and EM+, positive and negative effects in billion Euros p.a. (Austria)



Source: Model calculations by IHS Vienna

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 5[26]). 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.

Figure 5 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).

[26]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.

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.

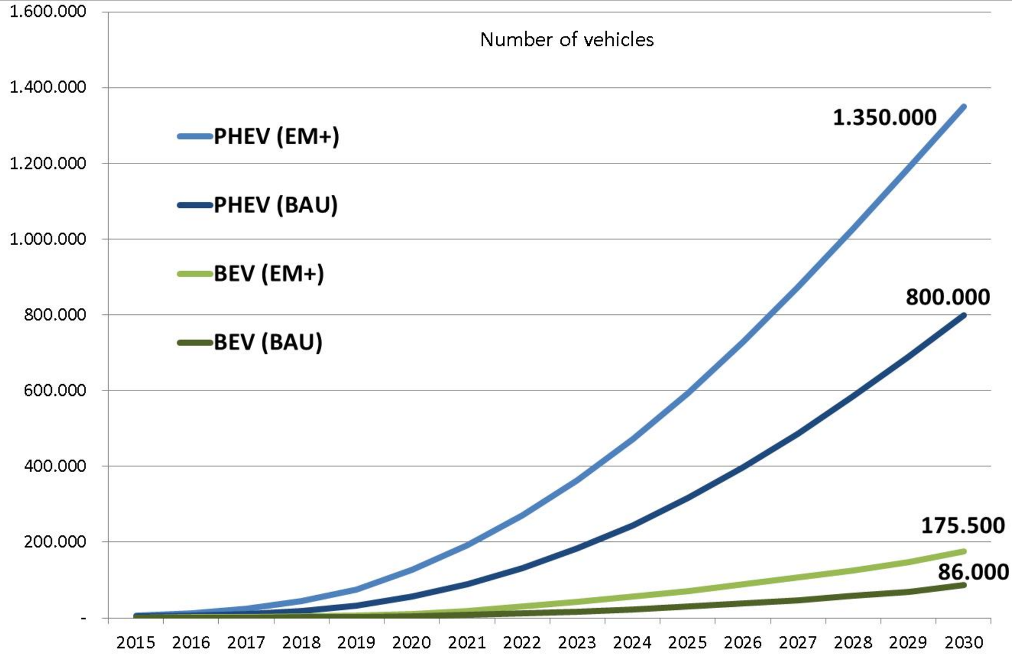
Altogether, according to results of the IHS macro model, the increase in mineral oil and new car registration taxes as well as the higher availability of charging stations, has significantly positive effects on new car purchases of electric vehicles in comparison to the BAU scenario. The number of electric 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 the EM+ scenario (see Figure 6). 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.

The reduction in CO_2 emissions of 1.2 million tons as calculated by the Environment Agency Austria, see Ibesich et al. (2014), would be much higher according to these figures due to the higher market penetration rate of electric vehicles.[27] The share of newly registered electric vehicles in total new registrations already reaches 68 % in 2030, see Figure 7. 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 corre-sponding part of CO_2 emissions attributed to Austria will be assigned to one of its neighbours. Thereby, Austrian traffic-induced CO_2 emissions could be

[27] 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.

Figure 6: Comparison vehicle stock BAU and EM+ in numbers of vehicles (Austria)



Source: Model calculations by IHS Vienna

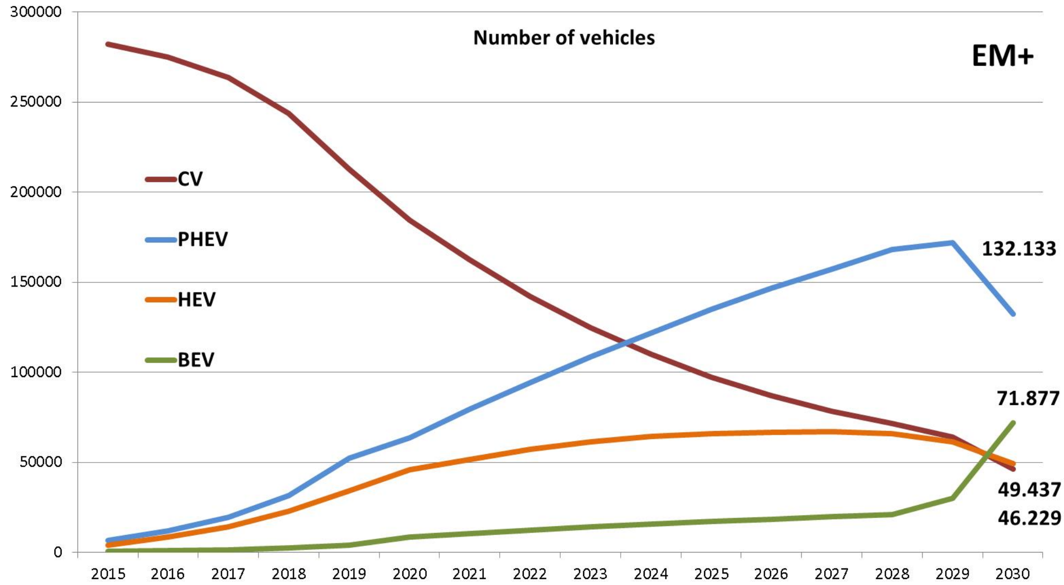
reduced by almost 30 % (cf. Kromp-Kolb et al. 2014, S. 76).[28] In relation to current EU climate targets and corresponding prices for CO_2 and thus possible government savings, this reduction could entail further positive economic effects, since government spending that would have to be used for the purchase of CO_2 certificates or any other payments due to falling short of emission targets could be directed to other purposes.

5.1.7 Conclusions for Austrian Model Simulations

Altogether, it has been shown that electromobility can make a significant contribution to the reduction of CO_2 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 Ibesich et al. (2014). In the BAU scenario as well as in the EM+ scenario investments in charging infrastructure have expansive economic effects. Thereby, an example is provided showing that the ecologisation of society can also contribute positively to growth.

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

Figure 7: Development of new registrations in number of vehicles in the EM+ scenario (Austria)



Source: Model calculations by IHS Vienna

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 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 CO_2 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.

5.2 Simulation Results for Germany

A further objective in DEFINE was to calibrate the CGE model to German data (macro data - SAM - and electricity market data) and then to implement scenarios for Germany. The SAM (Social Accounting Matrix) was delivered by the German Institute for Economic Research (DIW Berlin) and was taken as input data by the Institute for Advanced Studies (IHS).

Electricity market data was taken as input by the Technical University of Vienna, Totschnig and Litzlbauer (2015),[29] and DIW Berlin, Schill and Gerbaulet (2014).[30] Scenario input was taken from scenario building by the Oeko - Institut as reported in Kasten and Hacker (2014).[31]

5.2.1 Scenario Assumptions for BAU and EM+ Scenarios for Germany

Scenario building for Germany was very similar to Austria, mostly to keep the highest measure of comparability between the simulations for the two countries. As laid down in (Kasten and Hacker, 2014, p.12), two scenarios were developed analogously to Austria with the following assumptions:

- The Business-As-Usual (BAU) scenario assumes no relevant changes in legislation and the continuation of current policies. No special measures for market success of electromobility are applied in this scenario.
- The Electromobility+ (EM+) scenario shows a more favourable environment for market success of electromobility. Policies that are advantageous for electromobility are assumed.

Comparable policy measures to Austria were depicted in Germany, see (Kasten and Hacker, 2014, p.12):

- more ambitious CO_2 emission targets of the EU CO_2 regulation on new passenger cars,
- higher energy taxes on fossil fuel, and
- implementation of a feebate system to support ultra-low emission vehicles.

Specifically, assumptions on specific CO_2 emissions by conventional cars were made as provided in Table 4, which is taken from (Kasten and Hacker, 2014, p.15).

[29] See the combined report on TU Vienna DEFINE Deliverables available at `https://www.ihs.ac.at/projects/define/files/DEFINE_deliverable-2-7_Combined_TUWIEN_Final.pdf`

[30] See the DIW Berlin combined report on electricity market modelling available at `https://www.ihs.ac.at/projects/define/files/DEFINE---DIW-Berlin-Final-Report---final_corr_20140915.pdf`

[31] See the combined project report by the Oeko - Institut, available at `https://www.ihs.ac.at/projects/define/files/DEFINE-Oeko-english-version.pdf`

Table 4: Assumptions of Average Specific CO_2 Emission of Conventional Cars, 2010 - 2030

Year	Scenario	$e_{target,all,EU}$ g CO2/km	xEV effect g CO2/km	$e_{CV,EU}$ g CO2/km	$e_{CV,Germany}$ g CO2/km
2010	BMK	-		140.3	151.2
2020	(BAU/EM+)	95	5	100	107.8
2030	(BAU)	72.5	10	82.5	88.9
2030	(EM+)	60	12.5	72.5	78.1

Source: Calculations by Oeko - Institut

Fees and rebates taken as input for CGE modelling can be found in Table 5, see (Kasten and Hacker, 2014, p.15).

Table 5: Assumptions of Fees and Rebates of the Feebate System in EM+ Scenario

Year	Fee for conventional cars ($Euro_{2010}$)			Rebate ($Euro_{2010}$)	
	small	mid size	large	BEV	PHEV
2020	569	625	698	2140	1070
2030	338	386	449	549	275

Source: Calculations by Oeko - Institut

The underlying increases in energy prices due to a higher taxation of fossil fuels are provided in Table 6 below, as given in (Kasten and Hacker, 2014, p.16).

Prices for charging infrastructure and average amount of investment into charging infrastructure per vehicle were assumed analogously to Austria, to keep this important macro figure comparable across countries (see Chapters 5.1.3 and 5.1.5 above).

The calibration procedure was the same as in Austria (see also chapter 5.1.2):

Firstly, the model is calibrated to a steady state growth path of 1 %, which features measures already implemented and agreed on by German politics, but does *not* include a shift-in of electric vehicles as assumed in the BAU scenario in Kasten and Hacker (2014), chapter 3.

The BAU scenario of the CGE model then is calibrated to the amount of total vehicle new registrations and vehicle stock by car technology (CV, PHEV, BEV) as assumed in Kasten and Hacker (2014). The economic effects of the EM+ scenario are then compared to the BAU scenario in the CGE model.

Table 6: Assumptions of Energy Retail Prices for Car Users

Scenario	Fuel	Year	Production /miscel-laneous costs $Euro_{2010}$ /GJ	Energy Tax $Euro_{2010}$ /GJ	Value Added Tax $Euro_{2010}$ /GJ	Retail price $Euro_{2010}$ /GJ	Retail price $Euro_{2010}$ /l
BAU	gasoline	2020	23,6	17,3	7,8	48,7	1,57
		2030	31,1	14,8	8,7	54,6	1,77
	diesel	2020	24,6	11,3	6,8	42,6	1,52
		2030	30,8	9,6	7,7	48,2	1,72
	electricity	2020	52,5	4,9	10,9	68,2	
		2030	56,7	18,5	14,3	89,5	
EM+	gasoline	2020	23,6	20,6	8,4	52,6	1,70
		2030	31,1	28,7	11,4	71,2	2,30
	diesel	2020	24,6	20,9	8,6	54,1	1,93
		2030	30,8	29,1	11,4	71,4	2,55
	electricity	2020	52,5	4,9	10,9	68,2	
		2030	56,7	18,5	14,3	89,5	

Source: Calculations by Oeko - Institut

Important Remark As the Oeko - Institut did *not model* **HEVs (Hybrid Electric Vehicles)**, these are not shown here (they factor into the fuel efficiency of CVs).

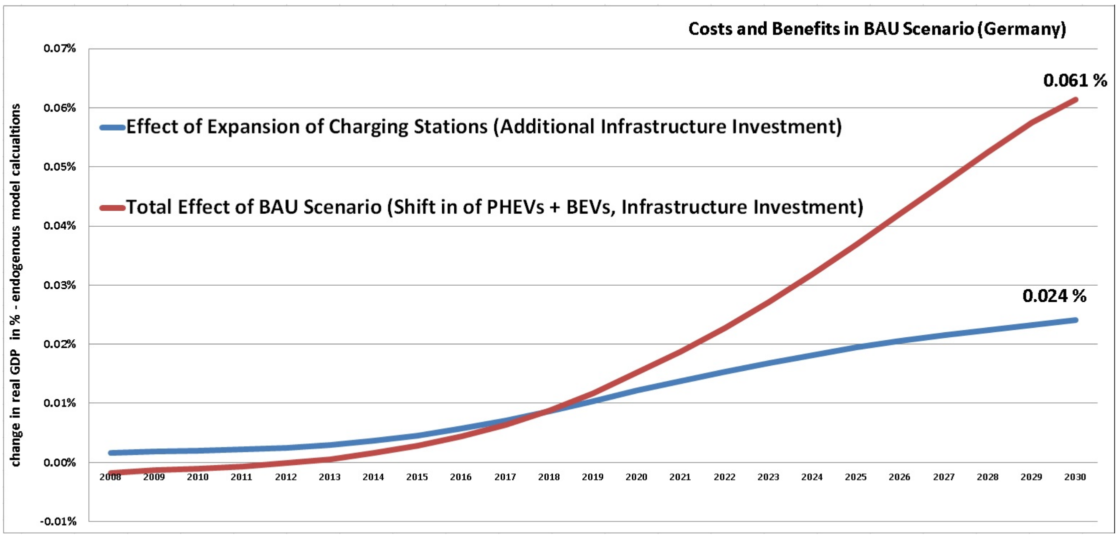
5.2.2 Results of the BAU Scenario for Germany

As was to be expected due to different industrial structure, among others, the effects of the shift-in of PHEVs and BEVs are different in Germany as compared to Austria (see Figure 8 below, and Chapter 5.1.4 above).

Whereas the effect of the additional infrastructure investment is qualitatively the same in Germany as in Austria (expansive growth effects) up to about 0.024 % of German GDP in 2030 (about 812 mln. Euro), the shift-in of PHEVs and BEVs causes qualitatively different economic effects.

Whereas Austria is rather a supplier of automobile parts - to a high extent to the German automobile industry, see e.g. Sihn et al. (2013) - much of the BEVs and PHEVs are produced in Germany itself, as can be inferred from German national accounting data (Input-Output tables). Therefore, while a higher share of electric vehicles in total vehicles purchases raises the import share of the Austrian economy and increases the costs for

Figure 8: Gross Domestic Product - BAU, positive and negative effects in % deviation from Benchmark (BMK) (Germany)



Source: Model calculations by IHS Vienna

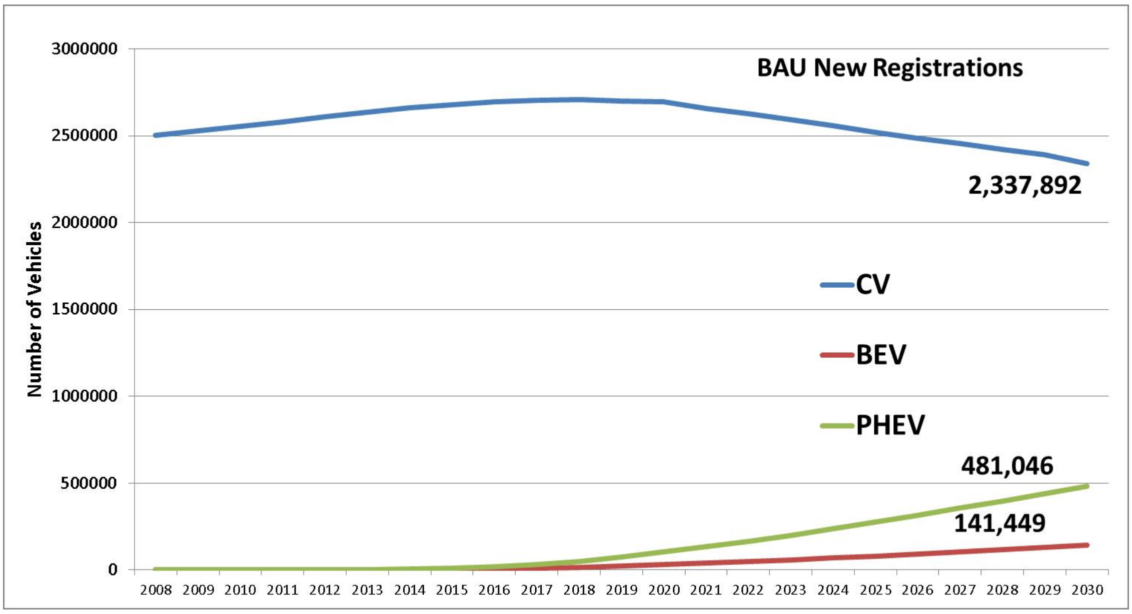
households for the bundle "individual transport" (cf. Chapter 5.1.4 above), in Germany the higher expenditures of households for individual transport (electric vehicles have a higher purchase price on average than CVs) translate into a higher economic activity. This demonstrates the importance of intermediate industrial structure when assessing the national economic effects of the shift-in of a technological innovation, as assessed in the hybrid micro-macro linked CGE model constructed by IHS for DEFINE.

Thus, while in Austria the shift-in of xEVs (PHEVs + BEVs = xEVs) causes costs of about 0.03 % of Austrian GDP in 2030, in Germany the *benefits* for GDP of a shift-in of electric vehicles reach up to an increase of GDP of about 0.037 % (about 1.26 bln. Euro). Initially, the shift-in of xEVs has slightly negative effects of less than 100 mln. Euros due to the intertemporal substitution behaviour by households (consumption deferred to later periods), the turning point to positive GDP effects is the year 2018.

Altogether, due to the reasons sketched above and as can also be inferred from Figure 8, total effects of the BAU are positive for Germany: + 0.061 % GDP in 2030 (about 2.07 bln. Euro) as compared to the reference growth path.

Compared to Austria, however, the change in the vehicle market is less pronounced in Germany as regarding electromobility (see Figure 9). The amount of BEVs plus PHEVs only reaches about 21 % of total new registrations (as compared to 44 % of total in Austria, see Chapter 5.1.4).

Figure 9: Development of New Registrations in Cars 2015 - 2030 (Germany)



Source: Model calculations by IHS Vienna

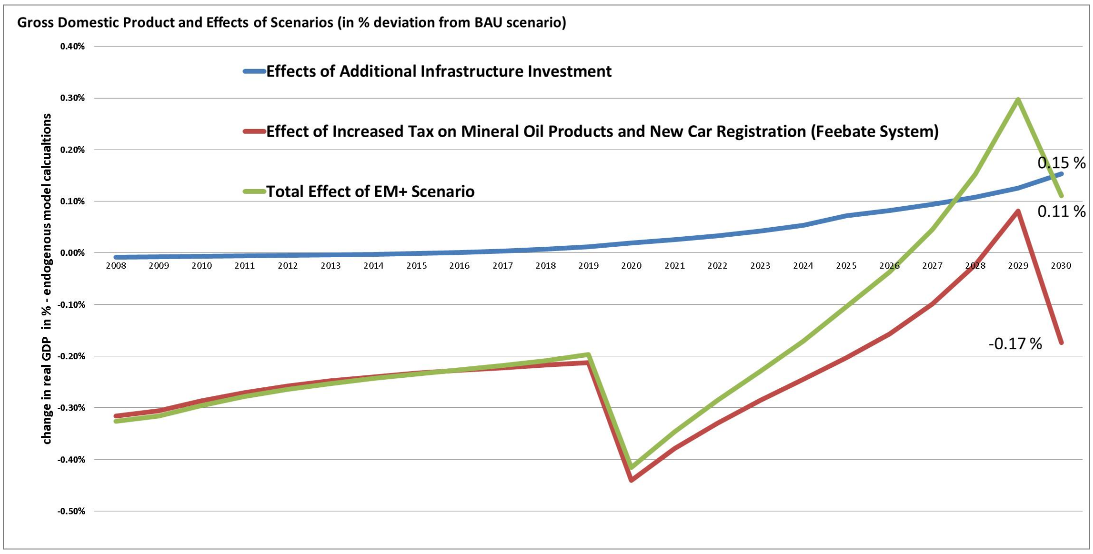
Conclusion BAU Scenario Germany Concluding for the BAU scenario, even though the effects of a shift-in of electric vehicles on GDP are positive due to the different industrial structure in Germany as compared to Austria, the market penetration is less pronounced. Here, one can see the *benefits of the micro-macro link* for the CGE model: the relation between the preference structure of the German population as regarding the introduction of electromobility and the imposed measures in the BAU is different than in Austria. On the one hand, the measures implemented in Germany in the BAU are less supportive of e-mobility compared to Austria (e.g. no feebate system), on the other hand preferences might additionally be more conservative as regarding the uptake of electromobility. This method therefore enables to relate political incentive measures to the preferences of the population on a macroeconomic level, and we can always view the vehicle market from the perspective of the potential *customers* of xEVs under a systemic perspective.

5.2.3 Results of EM+ Scenario for Germany (compared to BAU)

As described above in Chapter 5.2.1, the EM+ scenario features stricter CO_2 emission standards for the car fleet, the introduction of a feebate system to incentivize electric mobility, and higher taxes on fossil fuel inputs for CVs.

These measures, similar to the Austrian simulations, induce a fall in economic growth at the times of the tax raises in the years 2019 and 2029 (see Figure 10 - red line). The fall in GDP at these times is quite pronounced with more than 0.2 % as compared to the BAU reference scenario (about 6 bln. Euros), and results from the decreased consumption

Figure 10: Gross Domestic Product - EM+, positive and negative effects in % deviation from BAU (Germany)



Source: Model calculations by IHS Vienna

of households due to the additional tax burden reducing disposable household income. However, after the first tax increase in 2019, the effect reverses over the years, and in the year 2028 even becomes slightly positive, until the next tax increase in 2029.

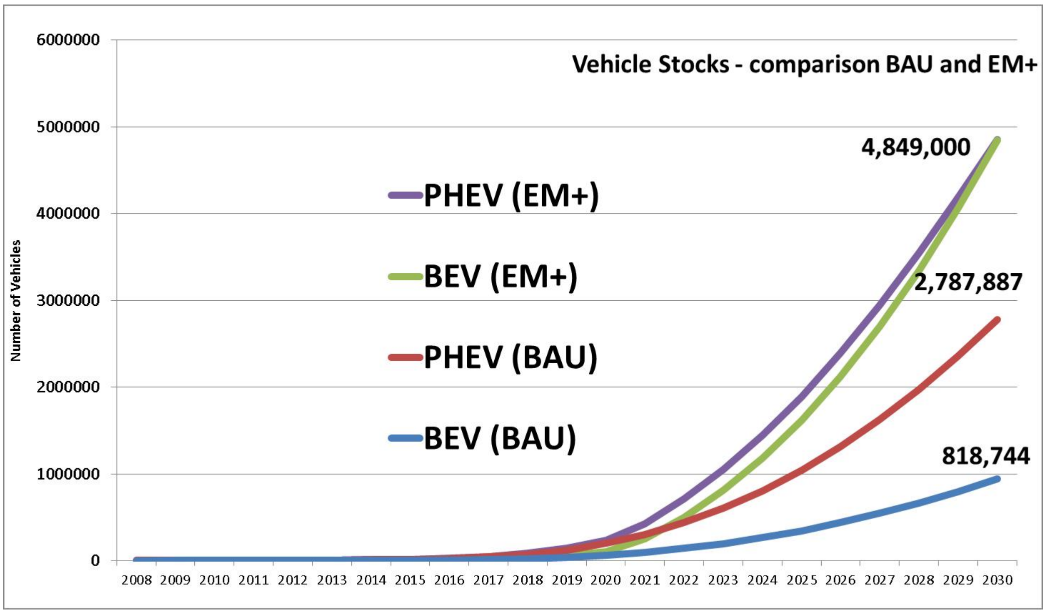
The initial shock of the tax and price increases regarding conventional cars and mineral oil slowly fades out due to the compensative effects of household substitution behaviour and the additional revenues received for the sale of xEVs (higher average price and higher number of sold xEVs due to the tax incentives), which accrue mainly to the domestic German car industry. Together with the positive growth effects resulting from the additional investments in charging infrastructure assumed in the EM+ scenario, total growth effects turn positive in the year 2026, and remain so despite the drop due to the additional tax increase in 2029.

Until 2030, therefore, the total effect on GDP in the EM+ scenario amounts to a plus of 0.11 % of German GDP (ca. 3.73 bln Euros) due to these two opposite effects, but after an additional tax shock in 2029.

As can be seen in Figure 11, the effects on the stocks of xEVs are remarkable: in 2030, we have almost 10 mln. xEVs, with an equal share of BEVs and PHEVs. This is almost triple the amount of xEVs in the BAU scenario (about 3.6 mln xEVs). It can be seen, that the tax incentives have a higher impact in Germany than in Austria and act more in favour of BEVs, which is also due to the different preferences of the German population.

However, the share of xEVs in total car stock remains higher in Austria (28 %) as compared to Germany (18.4 %). This is due to the result of the BAU scenario - the initial uptake of xEVs in the BAU scenario based on current political measures is much

Figure 11: Comparison vehicle stock BAU and EM+ in numbers of vehicles (Germany)



Source: Model calculations by IHS Vienna

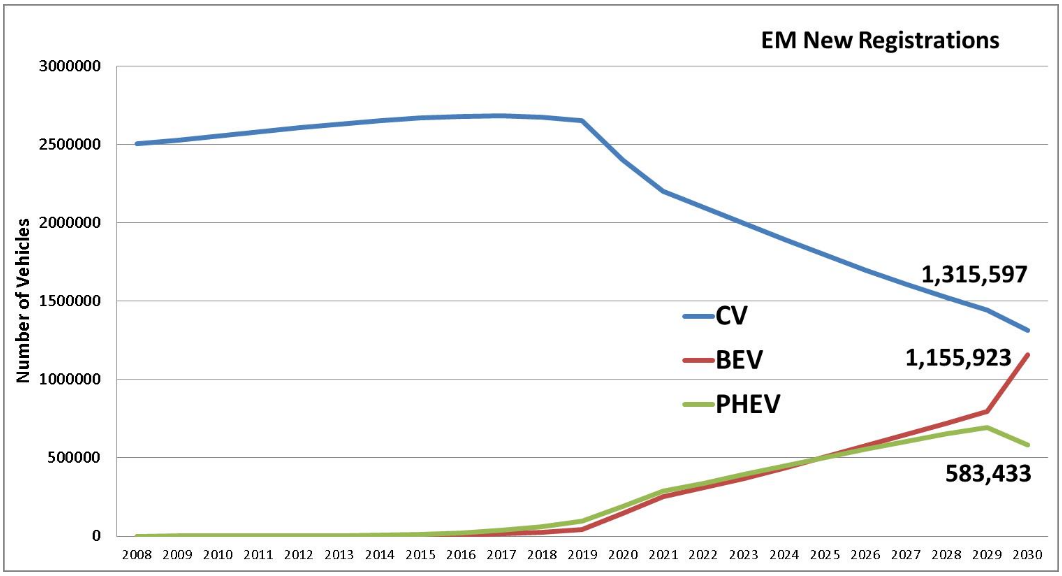
stronger in Austria, while the effects of the assumed tax incentives (in the EM+ scenario) are higher in Germany.

A closer look at new registrations (Figure 12) reveals that xEVs have a lower share in total new registrations in Germany (57 %) than in Austria (68 %). Whereas in Austria the preference structure seems to favour PHEVs, in Germany BEVs overtake PHEVs in total sales in the year 2025. Addtionally, due to the higher availability of charging stations in the year 2030, which is modelled to have a positive influence especially on the utility of BEVs, BEV sales steeply increase in this year to almost twice the number of PHEVs. This result underlines the different vehicle markets structures of Germany and Austria. Total xEV sales overtake CV sales not before the year 2029, about 3 years later than in Austria (comparing the difference between CV and HEV sales taken together to total xEV sales for the latter).

Conclusion EM+ Scenario Germany To conclude, the German vehicle market reacts less strongly in the BAU scenario as regarding the shift-in of xEVs. The explanation for this mostly lies in the measures to foster electromobility already in place in Austria (feebate system already in the BAU scenario) and the higher base preferences for PHEVs in Austria.

However, the growth effects of the shift-in of xEVs are positive in Germany after the year 2017, increasing to almost 0.1 % of GDP in 2030 in the BAU scenario. This results continues to hold in the EM+ scenario, where the increased amount of xEVs in total

Figure 12: Development of new registrations in number of vehicles in the EM+ scenario (Germany)



Source: Model calculations by IHS Vienna

car sales induces positive growth effects after 2028 before the next tax increase, which is assumed to be in 2029 in the EM+ scenario. Furthermore, the positive growth effects of the additional infrastructure investments show a very similar structure as it Austria: a steady increase in relation to the rising total expenditures on this infrastructure.

The reaction of the German car customers to the scenario measures is stronger in the EM+ scenario compared to Austria. This leads to a steeper increase of total xEV sales in the EM+ scenario for Germany - where the number of xEVs almost triples in 2030 as compared to the BAU - than in Austria, where the number of xEVs nearly doubles in the EM+ scenario.

Overall, the tax incentive measures simulated in DEFINE seem to have strong effects on the uptake of xEVs in Germany and Austria. Therefore, from the point of transport legislation, the results of this analysis show that they seem to be a suitable choice to foster the introduction of electromobility under supportable economic costs (Austria) or even slight growth effects after the year 2025 (Germany).

References

Bahamonde-Birke, F. J. and Hanappi, T. (2015). The potential of electromobility in austria. an analysis based on hybrid choice models. *DEFINE Working Paper.*

Böhringer, C. and Rutherford, T. (2008). Combining bottom-up and top-down. *Energy Economics, 30*, 2:574–596.

Bliem, M., Friedl, B., Aigner, M., Schmautzer, E., Haber, A., and Bitzan, G. (2013). Econgrid: Smart grids und volkswirtschaftliche effekte: Gesamtwirtschaftliche bewertung von smart grids lösungen (overall economic effects of smart grid solutions). *Final report of the project ECONGRID funded by the Austrian Climate and Energy Fund.*

Brons, M., Nijkamp, P., Pels, E., and Rietveld, P. (2008). A meta analysis of the price elasticity of gasoline demand a sur approach. *Energy Economics*, 30:2105–2122.

EAA (2014). Environment agency austria (eaa): Klimaschutzbericht 2014 (climate protection report 2014). *Austrian Climate Protection Reports.*

Gruden, D. (2008). *Umweltschutz in der Automobilindustrie*, chapter 8, pages 289–327. Vieweg und Teubner.

Hanappi, T., Lichtblau, G., Müllbacher, S., Ortner, R., Plankensteiner, B., Pötscher, F., Reitzinger, S., Schuh, U., and Stix, S. (2012). Elektromobilität in Österreich - determinanten für die kaufentscheidung von alternativ betriebenen fahrzeugen: Ein diskretes entscheidungsexperiment. *Final Report of Project ELMAR funded by the Austrian Climate and Energy Fund.*

Huetter, D. and Stigler, H. (2012). Kosten und bepreisungsmodelle einer flächendeckenden ladeinfrastruktur für e-mobilität in Österreich (costs and pricing models of a comprehensive charging infrastructure foe e-mobility in austria). *12. Symposium Energieinnovation, 15.-17.2.2012, Graz.*

Ibesich, N., Kasten, P., Ortner, R., Pötscher, F., and Stix, S. (2014). Scenarios on potential user groups and market potential of electric vehicles for austria up to 2030. *DEFINE Project Report.*

Karplus, V. J., Paltsev, S., Babiker, M., Heywood, J., and Reilly, J. M. (2012). Applying engineering and fleet detail to represent passenger vehicle transport in a computable general equilibium model. *Economic Modelling*, 30:295 – 305.

Karplus, V. J., Paltsev, S., and Reilly, J. M. (2010). Prospects for plug-in hybrid electric vehicles in the united states and japan: A general equilibrium analysis. *Transportation Research Part A*, 44:620 – 641.

Kasten, P. and Hacker, F. (2014). Two electromobility scenarios for germany: Market development and their impact on co2 emissions of passenger cars in define. *DEFINE Project Report.*

Kloess, M. and Müller, A. (2011). Simulating the impact of policy, energy prices and technological progress on the passenger car fleet in austria - a model based analsis 2010 - 2050. *Energy Policy*, 39:5045 – 5062.

Öko Institut (2011). Optum: Optimierung der umweltentlastungspotenziale von elektrofahrzeugen - integrierte betrachtung von fahrzeugnutzung und energiewirtschaft. *Final Report for the OPTUM project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.*

Link, C., Raich, U., Sammer, G., and Stark, J. (2012). Modeling demand for electric cars - a methodical approach. *Procedia - Social and Behavioral Sciences*, 48:1958–1970.

Miess, M., Schmelzer, S., and Janke, J. (2014). Report on improvements in the hybrid general equilibrium core model. *DEFINE Project Report.*

Plötz, P., Gnann, T., Kühn, A., and Wietschel, M. F. I. (2013). Markthochlaufszenarien für elektrofahrzeuge. *Study commissioned by the National Academy of Science and Engineering and Working Group 7 of the National Platform for Electromobility (NPE)zi.*

Rutherford, T. (2002). Lecture notes on constant elasticity functions. http://www.gamsworld.eu/mpsge/debreu/ces.pdf.

Rutherford, T. F. (1995). Extension of gams for complementarity problems arising in applied economic analysis. *Journal of Economic Dynamics and Control*, 19:1299–1324.

Schill, W.-P. and Gerbaulet, C. (2014). Power system impacts of electric vehicles in germany. *DEFINE Project Report.*

Sihn, W., Palm, D., and Gommel, H. (2013). Chancen und risiken der österreichischen fahrzeugindustrie. die österreichische fahrzeugindustrie - auf crashkurs? (chances and risks of the austrian automobile industry. the austrian automobile industry on a crash course?). *Study by the Fraunhofer Institute and the Vienna University of Technology.*

Thiel, C., Perujo, A., and Mercier, A. (2010). Cost and co2 aspects of future vehicle options in europe under new energy policy scenarios. *Energy Policy*, 38:7142 – 7151.

Totschnig, G. and Litzlbauer, M. (2015). Simulation of the economic and technical impacts of different electric vehicle charging strategies on the power market and the power grid. *DEFINE Project Report.*

Train, K. (2003). *Discrete Choice Methods with Simulation.* Cambridge University Press. Second edition: 2009.

Truong, P. and Hensher, D. A. (2012). Linking discrete choice to continuous demand within the framework of a computable general equilibrium model. *Transportation Research Part B*, 46:1177–1201.

WIFO (2011). Energy transition 2012-2020-2050: Strategies for the transition to low energy and low emission structures. *Project funded by the Austrian climate and energy fund in the framework of the call Energy of the Future.*