Supplementary Information

TECHNICAL DOCUMENTATION OF THE HYBRID CGE-DC MODEL

Section A provides a technical documentation of the hybrid CGE-DC model, while Section B describes the discrete choice modelling and Section C summarizes the quantification of environmental damage, i.e. the external costs.

A. TECHNICAL DOCUMENTATION OF THE CGE-DC MODEL

A.1 Model structure

The hybrid CGE model with the discrete choice (DC) implementation further explores the objective of linking bottom-up (BU) to top-down (TD) models in energy and environmental policy applications. Uniquely, we use the hard-linked integrated structure proposed by Böhringer and Rutherford (2008) to include fine grained detail on technological change driven by consumption choices based on a detailed preference structure elicited by a survey and estimated by DC models that are described in detail in Bahamonde-Birke and Hanappi (2016). Thus, we explicitly consider the endogenous and demand-driven uptake of electromobility as an abatement technology whose penetration rate is based on consumer choice in a hybrid modeling structure as a novel contribution to the literature. This hybrid modeling structure allows us to couple a consumer-oriented bottom-up model such as the DC model and, additionally, a technology-based BU model of the electricity system according to least cost optimisation, to a top-down general equilibrium (GE) model of the economy. To directly integrate these BU models into the GE model as a hard link, we follow the approach proposed by Böhringer and Rutherford (2008) that shows how to spell out an Arrow-Debreu economy as a mixed complementarity problem (MCP), and how technological detail can be fully integrated into the GE framework in this approach. Due to the flexibility of this approach and following the methodology proposed by Truong and Hensher (2012), we can further directly integrate the DC model as described in section A.7.

Böhringer and Rutherford (2008) demonstrate how complementarity can be exploited to cast an economic equilibrium as an MCP. In particular, the complementarity format facilitates weak inequalities and logical connections between prices and market conditions to re-formulate general equilibrium conditions. These properties permit the modeler to integrate bottom-up activity analysis directly within a top-down representation of the broader economy. Apart from accommodating technological explicitness in an economy-wide framework, the MCP approach relaxes integrability conditions that are inherent to economic models formulated as an optimization problem (Pressman, 1970; Takayma and Judge, 1971), which allows us to solve larger and more complex models. This re-formulation of the competitive economic equilibrium allows us to hard-link BU models to TD models in a single modelling MCP framework. Numerical solution of such a highly complex model is facilitated by the flexible formulation as an MCP in GAMS[1], see (Rutherford, 1995). With this model formulation as an MCP, it becomes possible to formulate large and complex models, calibrate them to empirical data and conduct applied policy analysis with a model based on solid theoretical

[1]For more information on the GAMS (General Algebraic Modelling System) software package, please visit www.gams.com and see Brooke et al. (1996).

foundations. The following section gives a short overview of these theoretical foundations of our model. For a comprehensive depiction, please see Böhringer and Rutherford (2008).

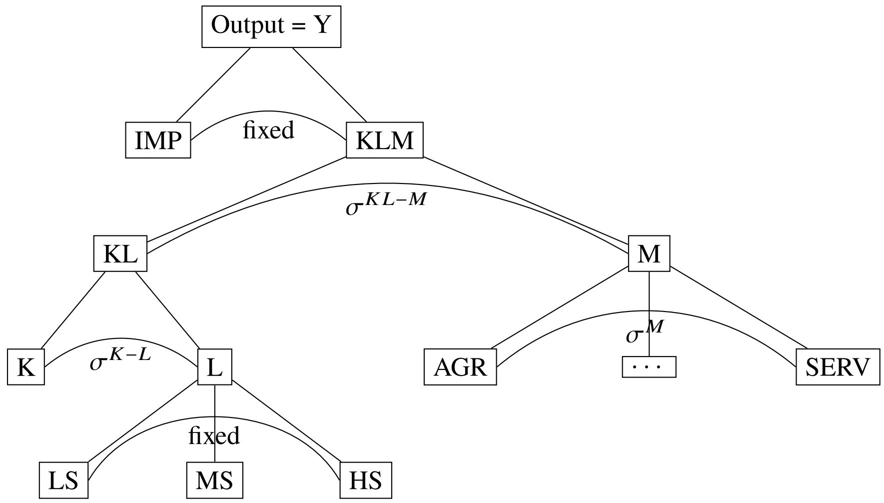
A.2 Production side and zero profit conditions

Production by sectors (firms) The producing sectors (firms) minimise their costs subject to constant elasticity of substitution (CES) functions, which determine the price-dependent use of factors and intermediate inputs for each sector (Böhringer and Rutherford, 2008). This relation is embodied in the zero profit conditions. In other words, producing sectors either produce cost-minimally under a zero profit condition, or the activity is slack, i.e. it does not produce any output at all. According to Böhringer and Rutherford (2008), this can be written as

$$\begin{aligned}\Pi^{Y}_{t,i}\text{ (unit profit of macro sector i at time t)} &= p^{Y}_{t,i}\text{ (output price of good)}\\ &\quad - unit\ costs\text{ (market value of inputs for unit production)} \leq 0,\end{aligned}$$

The structure of all zero profit conditions in the core CGE model follows this pattern according to the tree structure shown in Figure A. The producing sectors need intermediate inputs as well as inputs of the factors capital and labor to produce consumption goods according to a standard nested CES production structure. As can be obtained from Figure A, this input structure resembles an inverse tree. The lowest end of each branch represents an input good; the entries at the crossroads represent bundles of the input goods.

Figure A: The Nesting Structure of Producing Sectors



Note: In this nesting structure, output Y is a composite of imported goods (IMP) and a nest of capital (K), labour (L) and material (M), KLM. Here for reasons of simplicity, while still maintaining a small open economy assumption as appropriate for the Austrian economy, we assume that domestic production and imports develop according to a fixed share in production. The only exception here is that we have introduced a supply elasticity for the export of mineral oil products that we have applied to the oil sector in our model (η^{MO}), to capture changes in "tank tourism" in our model due to changes in the mineral oil tax. This elasticity has been set to a value especially calculated by an expert partner in the DEFINE project consortium (Environment Agency Austria). On the next lower level of nested production, firms can substitute between a capital and labour composite (nest KL) and an energy and material (M) nest for domestic production with the elasticity σ^{KL-M}. Then again, in the different nests, the sectors can substitute between capital and labour (nest KL, elasticity σ^{K-L}), and between the material composite M consisting of all sectors named in table E with the elasticity σ^{KL-M}. For the material composite, the sectors can choose between different material inputs in the material nest M, with the elasticity σ^{M}. The labour market is intentionally kept simple with a fixed relation between low-skilled (LS), medium-skilled (MS) and high-skilled (HS) labour. However, the share of income by skill group is important due to heterogeneous consumer preferences for these different household types regarding vehicle choice between alternatively fuelled vehicles.

To give one example, the zero profit condition for the producing sectors reads as follows:

$$\Pi^{Y}_{t,i} = PY_{t,i} - \textit{total unit cost} \leq 0 \Leftrightarrow$$

$$\eta_{imp_{t,i}} \cdot PIM_t + (1-\eta_{imp_{t,i}}) \cdot \left[\left(\theta_{klm_i} \cdot KL_{t,i}^{1-\sigma^{KL-M_i}} + (1-\theta_{klm_i}) \cdot M_{t,i}^{1-\sigma^{KL-M_i}} \right)^{\frac{1}{1-\sigma^{KL-M_i}}} \right] \geq PY_{t,i} \quad (1)$$

where

$PY_{t,i}$	is the output price of the sectoral good
PIM_t	is the fixed world market price of the good
$\eta_{imp_{t,i}}$	is the exogenous share of imports
θ_{klm_i}	is the share of the capital and labour composite in total sectoral production
$1-\theta_{klm_i}$	is then the share of energy, electricity and material in total production (as all shares add up to one)
$KL_{t,i}$	is the composite of capital and labour as shown in figure A
$M_{t,i}$	is the material composite bundle (intermediate inputs) as shown in figure A

σ^{KL-M_i}	is the elasticity of substitution between the composites described above
Y_i	is the associated complementary variable

The composites themselves, now, are of all of CES, analogous to the top next and according to the nesting structure given in Figure A.

Table A: Elasticities of substitution used in the CGE model

Attributes	Values
$\sigma^{\text{C-LS}}$	1.4
σ^{t}	0.5
$\sigma^{\text{KL-M}}$	0.3
$\sigma^{\text{K-L}}$	0.4
σ^{M}	0.5
η^{MO}	-0.23

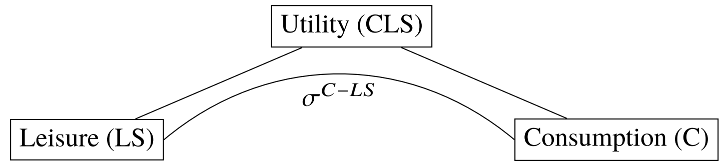
Note: C-LS = substitution between consumption and leisure in household welfare, t = intertemporal elasticity of substitution for household, KL-M = substitution between capital-labour composite and intermediate input goods composite in production, K-L = substitution between capital and labour in production, M = substitution between all intermediate input goods in production, MO = supply elasticity of mineral oil products due to changes in the Austrian mineral oil tax

A.3 Household sector

We distinguish nine types of consumer households (indexed by h) by three levels of education (low, medium, high) and three degrees of urbanisation (rural, suburban, urban). These distinctions are important for our framework due to the fact that preferences and habits concerning transportation are clearly subject to regional differences. Moreover, education is used as a proxy for income and environmental attitudes, which both may increase preferences for using environmentally friendly and advanced technologies. Household consumption decisions are modelled through a standard nested CES function. In their consumption decision, all consumers have different values of elasticities and different initial levels of consumption according to their level of income that are estimated from the specifically designed survey data (Bahamonde-Birke and Hanappi, 2016). Table B shows the values for these elasticities.

In the top nest of the period-by-period utility maximization, households can substitute between consumption and leisure according to an elasticity (σ^{C-LS}), as further illustrated in Figure B below. This trade-off between consumption in leisure in turn influences households' labour supply decision in an MCP formulation according to the framework developed by Böhringer and Rutherford (2008), see equation (4) below.

Figure B: Household Optimization at the top nest - consumption leisure trade off



The period-by-period utility function of a household agent h according to the above tree branch illustration in Figure B thus reads as follows:

$$\Pi_{h,t}^{CLS} \leq 0 \Leftrightarrow$$

$$\left[\theta cls_c \cdot PC_t^{1-\sigma^{C-LS}} + (1-\theta cls_c) \cdot PLS_{h,t}^{1-\sigma^{C-LS}}\right]^{\frac{1}{1-\sigma^{C-LS}}} \geq PCLS_{h,t} \quad (2)$$

where

θcls_c	is the share in consumption in the consumption and leisure composite
$PC_{h,t}$	is the price of consumption for household h
σ^{C-LS}	is the elasticity of substitution between consumption and leisure
$PLS_{h,t}$	is the price of leisure for household h
$PCLS_{h,t}$	is the price of full consumption including leisure for household h
$CLS_{h,t}$	full household consumption of household h including leisure is the complementary variable

Finally, households h maximize their total intertemopral utility representing their total welfare by allocating their consumption-leisure bundle optimally over time with an intertemporal elasticity of substitution

$$\Pi_h^W \leq 0 \Leftrightarrow \left[\sum_t \left(\theta wcls_{h,t} \cdot \frac{PCLS_{h,t}}{pref_t}\right)^{1-\sigma^t}\right]^{\frac{1}{1-\sigma^t}} \geq PW_h \quad (3)$$

where

Π_h^W	is the intertemporal household total utility for household h
$\theta wcls_t$	is the share of household welfare obtained in time t for household h
$PCLS_{h,t}$	is the price of full consumption including leisure at time t for household h
$pref_t$	is the price reference path, a discount factor that is applied to all prices in the economy (exponentially)
σ^t	denotes the intertemporal elasticity of substitution of households
PW_h	is the intertemporal price of welfare for household h
W_h	welfare is the associated complementary variable for household h

Table B: Cross-price elasticities in household consumption

σ^{trans}	Substitution between T-composite and M-composite: **Urban**	**Suburban**	**Rural**
LS	0.12	0.16	0.16
MS	0.12	0.18	0.18
HS	0.10	0.14	0.16

σ^{othtrans}	Substitution between ITPT-composite and OT-composite: **Urban**	**Suburban**	**Rural**
LS	0.22	0.48	0.32
MS	0.28	0.48	0.43
HS	0.16	0.23	0.23

σ^{mode}	Substitution between IT and PPT: **Urban**	**Suburban**	**Rural**
LS	0.15	0.31	0.32
MS	0.17	0.41	0.46
HS	0.15	0.26	0.40

σ^{goods}	Substitution between other consumption goods: **Urban**	**Suburban**	**Rural**
LS, MS, HS	0.4	0.4	0.4

Note: LS = Low Skilled, MS = Medium Skilled, HS = High Skilled, T = transport, IT = individual transport, PT = public transport, OT = other transport (planes etc.), M = material (consumption goods)
The values for the cross price elasticities σ^{trans}, σ^{othtrans}, and σ^{mode} were calculated using initial consumption shares and demand elasticities that were estimated on the basis of discrete choice experiments carried out together with the representative survey for Austria (Bahamonde-Birke and Hanappi, 2016).

A.4 Government sector

Our model features a detailed depiction of the governmental tax and transfer system in Austria, see Table F depicting the SAM used for model calibration. Apart from expenditures on the fixed bundle of consumption goods (government consumption), the government agent spends money on unemployment payments, pensions and other transfers. Government income is determined by tax flows from both households and firms: the government taxes wages, capital, consumption, energy, electricity, mineral oil, as well as new vehicle registration (differentiated by vehicle type). The decision of the government agent is to adjust taxes endogenously in order to ensure that government income equals expenditures (zero deficit rule). This automatic zero deficit rule is especially relevant for counterfactual scenarios featuring government subsidies of different sectors, since taxes of the right amount are increased endogenously in the model in order to refinance these expenditures budget-neutrally. A special feature of our model is an additional elasticity that decreases government revenue due to mineral oil products because of “tank tourism”, i.e. foreigners purchasing fuel in Austria because of lower taxes. We calibrate this elasticity due to expert input from the DEFINE project consortium partner Environment Agency Austria (EAA).[2]

[2]This revenue elasticity η^{MOrev} is calibrated to a value of -0.156.

A.5 Market clearing

The balance of supply and demand is assured by the flexible prices on competitive markets (Böhringer and Rutherford, 2008). These flexible prices are determined in concordance with the zero profit conditions. The interdependence between zero profit and market clearance conditions is thus mutual: prices and quantities are determined simultaneously by the zero profit and market clearance conditions. Each condition puts a restraining factor on the other. If a sector makes negative profit, nothing is produced, thus quantities are zero, and supply will equal demand.

To give an example, the market clearance condition for *labour* for a household h in this model economy is given by:

$$\bar{Z}_{h,t} - \frac{\partial \Pi^W}{\partial PLS_{h,t}} \cdot W = LSP_{h,t} \geq \sum_i \frac{\partial \Pi_t^{Y_i}}{\partial PL_{h,t}} \cdot Y_{t,i} + \sum_{tec} a_{t,tec}^L \cdot ELE_{t,tec} \tag{4}$$

where

$\bar{Z}_t$	is the total endowment of time per year by household h
$\frac{\partial \Pi_h^W}{\partial PLS_{h,t}}$	is unit demand for leisure at time t for household h
$LSP_{h,t}$	is the level of labour supply by the household at time t, which is equal to total household time endowment minus the demand for leisure for household h
$\frac{\partial \Pi_t^{Y_i}}{\partial PL_t}$	is unit labour input required by sector i at time t for household h
$Y_{t,i}$	is the level of production of sector i at time t for household h
$a_{t,tec}^L \cdot ELE_{t,tec}$	is unit labour input required by technology tec for electricity production at time t

Here, the price for labour $PL_{h,t}$ is the associated complementary variable.

Complementary slackness If supply permanently exceeds demand, prices will be zero. Only in the case of zero but nonnegative profit and equality of supply and demand do we have positive quantities and positive prices for a sector. As all goods and factor markets then have to clear, we get a system of interdependent endogenous prices and quantities constituting our model economy.

A.6 Passenger vehicle stock-flow accounting model

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 vehicles $dc_i(t)$. 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

$$st_i(t) = st_i(t-1) + nr_i(t-1) - dc_i(t-1) \quad \forall i, \forall t. \tag{5}$$

New vehicle registrations are determined from the unit demand for purchases of new vehicles $D_{h,i}^{\text{pur}}(t)$, see (32), and are defined as

$$nr_i(t) = \frac{e_{h,i}^{\text{pur}}(0) D_{h,i}^{\text{pur}}(t)}{P_i^{\text{pur}}(t) p_i^{av}(t)} \quad \forall i, \forall t, \tag{6}$$

where $e_{h,i}^{\text{pur}}(0)$ denotes the volume of expenditures on type i vehicle purchases by household h in the starting period, and $p_i^{av}(t)$ is the exogenous average monetary price[3] for a vehicle of technology i.

[3]Any prices in the model are unit prices. In equation (6), we need a price that denotes euro per vehicle, in order to

We assume a constant depreciation rate for CVs of $\delta_{\text{CV}} = 5.85\%$ for the first 12 periods in the model. For the other vehicle types, since these markets are not yet matured, we do not assume any depreciation for the first 12 years[4]. Subsequently, the vehicles that were registered 13 periods before are depreciating for all technologies.

$$\begin{aligned} dc_i(t) &= st_{\text{CV}}(t)\delta_{\text{CV}} \text{ for } t \leq 12, i = CV; \\ &= 0 \text{ for } t \leq 12, i = AFVs; \\ &= nr_i(t-12) \text{ for } t > 12. \end{aligned} \tag{7}$$

Table C shows the attributes of vehicles in the business-as-usual (BAU) scenario used in the model.

Table C: Attributes of vehicles in BAU

2015	**CV**	**HEV**	**PHEV**	**BEV**
purchase price [€]	25 502	28 823	35 138	48 417
power [PS]	118	181	181	143
fuel costs [€/km]	0.089	0.082	0.053	0.045
maintenance costs [€/km]	0.06	0.06	0.06	0.06
range [km]	>500	>500	>500	150
service station availability [%]	100	100	100	private hubs
2020	**CV**	**HEV**	**PHEV**	**BEV**
purchase price [€]	26 248	28 117	32 853	45 988
power [PS]	118	181	181	143
fuel costs [€/km]	0.092	0.085	0.055	0.051
maintenance costs [€/km]	0.06	0.06	0.06	0.06
range [km]	>500	>500	>500	150
service station availability [%]	100	100	100	private hubs
2030	**CV**	**HEV**	**PHEV**	**BEV**
purchase price [€]	26 924	27 502	29 778	40 022
power [PS]	118	181	181	143
fuel costs [€/km]	0.095	0.089	0.054	0.051
maintenance costs [€/km]	0.06	0.06	0.06	0.06
range [km]	>500	>500	>500	150
service station availability [%]	100	100	100	private hubs

Note: pp = purchase price, fc = fuel cost, mc = maintenance cost, ep = engine power, ra = driving range of BEV, cs = charging station availability, ms, hs = two-way interaction terms with medium and high level of education and vehicle technologies, ASC = alternative specific constant

A.7 Integration of the discrete choice model into the core CGE model

Following Truong and Hensher (2012), the DC model is used to derive the demand for overall vehicle purchases $\overline{D_h}$, and aggregate vehicle choice probabilities, which are used to split up the demand for overall vehicle purchases into demand for the vehicle purchase choice alternatives.

The deterministic part of the indirect utility $V_{h,i}$ of buying a vehicle of type i is given in

calculate numbers of cars. The values of $p_i^{av}(t)$ are derived by projections based on the vehicle technology database described in Ibesich et al. (2014).

[4]This is a simplifying assumption abstracting from potentially higher depreciation rates for EVs partly reported in the literature, and is mostly due to the lack of reliable data available to measure average lifetimes of EVs.

equation (8), with $x_{h,i}$ being the vector of initial levels for the attributes (see e.g. Train (2003))[5].

$$V_{h,i} = \beta^{\text{mc}}_{h,i}x^{\text{mc}}_{h,i} + \beta^{\text{fc}}_{h,i}x^{\text{fc}}_{h,i} + \beta^{\text{pp}}_{h,i}x^{\text{pp}}_{h,i} + \beta^{\text{ep}}_{h,i}x^{\text{ep}}_{h,i} + \beta^{\text{ra}}_{h,i}x^{\text{ra}}_{h,i} + \alpha_{h,i} \qquad \forall h, \forall i, \tag{8}$$

where purchase price (pp), fuel cost (fc), maintenance cost (mc), engine power (ep), and driving range of BEVs (ra) are the exogenous vehicle specific attributes, $\beta_{h,i}$ represents marginal utilities of these attributes, and $\alpha_{h,i}$ is the alternative (i.e. technology) specific constant, or base-preference, denoting a part of the utility for all other characteristics of a given alternative not explicitly described in the DC model[6].

Following a random utility model (McFadden, 1981) and assuming the error term ϵ is i.i.d standard type I extreme value, the probability $\mathbb{P}_{h,i}$ of agent h to choose alternative i, given the prior decision to purchase any vehicle at all, is given as

$$\mathbb{P}_{h,i} = \frac{exp(V_{h,i})}{\sum_i exp(V_{h,i})} \qquad \forall h, \forall i. \tag{9}$$

Thus, also the probability to choose alternative i contributes to the likelihood to choose alternative i in the conditional logit model (Train, 2003). In the CGE model, these probabilities are interpreted as market shares of vehicles. The endogenous share of purchases of vehicle i in the total vehicle purchases of household h, $\theta_{h,i}$, is hence

$$\theta_{h,i} := \mathbb{P}_{h,i} \qquad \forall h, \forall i. \tag{10}$$

In contrast to Truong and Hensher (2012), (8) contains three monetary variables instead of one. Thus, we introduce an aggregated money cost variable, $x^{\text{money}}_{h,i}$, defined as the shadow-price weighted average of all monetary variables

$$x^{\text{money}}_{h,i} := \frac{\beta^{\text{mc}}_{h,i}}{\beta^{\text{money}}_{h,i}}x^{\text{mc}}_{h,i} + \frac{\beta^{\text{fc}}_{h,i}}{\beta^{\text{money}}_{h,i}}x^{\text{fc}}_{h,i} + \frac{\beta^{\text{pp}}_{h,i}}{\beta^{\text{money}}_{h,i}}x^{\text{pp}}_{h,i} \qquad \forall h, \forall i, \tag{11}$$

where we define $\beta^{\text{money}}_{h,i} := \beta^{\text{mc}}_{h,i} + \beta^{\text{fc}}_{h,i} + \beta^{\text{pp}}_{h,i}$ as the unique marginal utility of money for each agent h. Expressing $V_{h,i}$ in terms of β^{money}_{h} and (11) yields

$$V_{h,i} = \beta^{\text{money}}_{h,i}x^{\text{money}}_{h,i} + \sum_{other}(\beta^{other}_{h,i}x^{other}_{h,i}) + \alpha_{h,i} \qquad \forall h, \forall i, \tag{12}$$

where the index *other* stands for other non-monetary variables and coefficients.

Since $\beta^{\text{money}}_{h,i}$ is generally unique for each agent (the disutility of any euro spent is the same for all goods), it does not depend on technology and the subscript i can be omitted,

$$\beta^{\text{money}}_{h} := \beta^{\text{money}}_{h,i} = \beta^{\text{money}}_{h,j} \quad \forall i, j, \forall h. \tag{13}$$

Following Truong and Hensher (2012), we set an effective price $P^{e}_{h,i}$[7] as an abstract aggregate price variable inferred from $V_{h,i}$. Using this concept, the indirect utility function could be rewritten as:

$$V_{h,i} = \beta^{\text{money}}_{h}P^{e}_{h,i} + \alpha_{h,i} \qquad \forall h, \forall i.^{8} \tag{14}$$

[5]For each of the nine aggregated household groups, a separate conditional multinomial logit model was estimated based on consumer preferences data elicited through a specially designed representative survey within which 1,449 Austrian respondents were interviewed (Bahamonde-Birke and Hanappi, 2016).

[6]Table G reports the estimates of the utility parameters, while Table H provides levels of the vehicle attributes $x_{h,i}$, as used in our scenario simulations.

[7]The effective price $P^{e}_{h,i}$ can be interpreted as the consumer's perceived value of the vehicle at the purchase decision.

[8]Contrary to (12) with $x^{\text{money}}_{h,i}$ including only monetary attributes, $P^{e}_{h,i}$ in (14) includes all attributes.

Rearranging (14) and using (8) for $V_{h,i}$, we get the effective price as the sum of the implicit willingness to pay (defined as $\frac{\beta^n_{h,i}}{\beta^{\text{money}}_h}$) for each attribute $x^n_{h,i}$ times its value:

$$P^e_{h,i} = \sum_n \frac{\beta^n_{h,i}}{\beta^{\text{money}}_h} x^n_{h,i} \qquad \forall h, \forall i, \tag{15}$$

where the index n runs over all vehicle attributes.

To derive the aggregate price $\overline{P_h}$ of purchasing any type of vehicle i, we follow Truong and Hensher (2012)) and define the logsum, or inclusive value, $\overline{V_h}$ of all vehicle types as

$$\overline{V_h} := \ln \sum_{i \in I} \exp(V_{h,i}) \quad \forall h. \tag{16}$$

The aggregation procedure cannot follow a simple CES logic, since purchase shares of different vehicle types will change endogenously, also according to non-monetary vehicle attributes. The logsum represents total consumer surplus associated with all choices for a particular choice set, and indicates the expected maximum utility for these choices. Using (9), the total differential of this inclusive value equals

$$\mathrm{d}\overline{V_h} = \sum_{i \in I} \mathbb{P}_{h,i}\, \mathrm{d}V_{h,i} \quad \forall h. \tag{17}$$

Substituting (14) for $V_{h,i}$ yields

$$\begin{aligned} \mathrm{d}\overline{V_h} &= \sum_{i \in I} \mathbb{P}_{h,i}\, \mathrm{d}(\alpha_{h,i} + \beta^{\text{money}}_h P^e_{h,i}) \\ &= \beta^{\text{money}}_h \sum_{i \in I} \mathbb{P}_{h,i}\, \mathrm{d}P^e_{h,i} \quad \forall h, \end{aligned} \tag{18}$$

and defining the change in the aggregate price for vehicle purchases $\overline{P_h}$ as the sum of the probability-weighted changes in the vehicle types' effective prices

$$\mathrm{d}\overline{P_h} := \sum_{i \in I} \mathbb{P}_{h,i}\, \mathrm{d}P^e_{h,i} \quad \forall h, \tag{19}$$

yields

$$\mathrm{d}\overline{V_h} = \beta^{\text{money}}_h \mathrm{d}\overline{P_h} \quad \forall h. \tag{20}$$

By integrating (20) we have

$$\overline{P_h} = \frac{\overline{V_h}}{\beta^{\text{money}}_h} + c_h \quad \forall h, \tag{21}$$

The constant c_h is determined in the calibration procedure such that the equation holds with the initial values of the other variables and parameters.

We now define the price for the IT composite as an *endogenously adapting Leontief composite* of $\overline{P_h}$ and the price for the use of existing vehicles,

$$P^{\text{IT}}_h(t) \quad = \quad \Theta^{\text{pur}}_h(t)\overline{P_h}(t) \quad + \quad (1 - \Theta^{\text{pur}}_h(t)) \sum_i \theta^{st}_{h,i}(t) P^{\text{use}}_{h,i}(t) \quad \forall h, \forall t. \tag{22}$$

$\Theta^{\text{pur}}_h(t)$ denotes the endogenous share parameter of monetary expenditures on vehicle purchases in total expenditures for IT for household h in period t. This implies a qualitative change in the Leontief consumption nest over time; as new vehicle purchases rise and fall, and as the vehicle stocks build up or shrink, also the expenditures on, and hence the price for, the overall IT composite changes.[9] The determination of the endogenous share parameter $\Theta_h^{\text{pur}}(t)$ in equation (22) depends on both the aforementioned unit demand variables,

$$\Theta_h^{\text{pur}}(t) = \frac{\sum_i e_{h,i}^{\text{pur}}(0) D_{h,i}^{\text{pur}}(t)}{\sum_j \left[e_{h,j}^{\text{pur}}(0) D_{h,j}^{\text{pur}}(t) + e_{h,j}^{\text{use}}(0) D_{h,j}^{\text{use}}(t)\right]} \qquad \forall h, \forall t, \tag{23}$$

where $e_{h,i}^{\text{use}}(0)$ denotes monetary expenditures on fuel and services in the starting period.

We assume the use of vehicles $D_{h,i}^{\text{use}}(t)$ to develop in a constant relationship to the size of their stock. Thus, the change in $D_{h,i}^{\text{use}}(t)$ will be determined by the change in the stock as

$$D_{h,i}^{\text{use}}(t) = \frac{st_i(t)}{st_i(0)} \quad \forall h, \forall i, \forall t. \tag{24}$$

$D_{h,i}^{\text{use}}(t)$ is further modified by a demand elasticity for fuel use that depends on the level of the mineral oil tax in Austria, η^{fuel}. We calibrate this elasticity according to the literature Brons et al. (2008), where we use the short term value of -0.34. The share $\Theta_h^{\text{pur}}(t)$ 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, shrink in times when fewer new vehicles are bought, and will be influenced by the level of mineral oil taxes.

The share $\theta_{h,i}^{st}(t)$ in equation (22) is the share of the size of the stock of vehicles of type i in the total stock of vehicles owned by household h,

$$\theta_{h,i}^{st}(t) = \frac{st_i(t)}{\sum_j st_j(t)} \quad \forall h, \forall i, \forall t, \tag{25}$$

with

$$\sum_i \theta_{h,i}^{st}(t) = 1 \quad \forall h, \forall t. \tag{26}$$

This share is known at the beginning of each period t, since the vehicle stock $st_i(t)$ is known at the beginning of each period by our convention, see equation (5).

The price for individual transportation, $P_h^{\text{IT}}(t)$, can be used to determine overall demand for IT in the standard manner by Shephard's Lemma: differentiating the unit expenditure function $\hat{e}_h$ of each household with respect to the price for IT yields unit demand for IT,

$$D_h^{\text{IT}}(t) = \frac{\partial \hat{e}_h(p_{x1}, p_{x2}, ..., P_h^{\text{IT}}(t))}{\partial P_h^{\text{IT}}(t)} \quad \forall h. \tag{27}$$

This can also be done at one deeper level, and yields unit demand for purchases of any kind of vehicle as

$$\overline{D_h}(t) = D_h^{\text{IT}}(t) \frac{\Theta_h^{\text{pur}}(t)}{\Theta_h^{\text{pur}}(0)} \quad \forall h, \tag{28}$$

since the only additional inner derivative when applying Shephard's Lemma at this level (differentiating (22) with respect to $\overline{P_h}$) just yields the share Θ_h^{pur}. $\Theta_h^{\text{pur}}(0)$ is the base-year value of this share, which remains constant for all time periods. The reason for this share to be in the denominator in (28) is because all unit demand variables have to equal the reference growth path in the initial steady state: If the demand variables were expressed in real monetary terms, say $\overline{\mathbb{D}_h}$ and $\mathbb{D}_h^{\text{IT}}$, then (28) would become

$$\overline{\mathbb{D}_h}(t) = \mathbb{D}_h^{\text{IT}}(t) \Theta_h^{\text{pur}}(t) \quad \forall h, \forall t, \tag{29}$$

[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.

since Θ_h^{pur} is a monetary expenditure share. However, since in the initial steady state we have

$$\overline{D_h}(t) = \frac{\overline{\mathbb{D}_h}(t)}{\overline{\mathbb{D}_h}(0)} \qquad \text{and} \qquad D_h^{\text{IT}}(t) = \frac{\mathbb{D}_h^{\text{IT}}(t)}{\mathbb{D}_h^{\text{IT}}(0)} \qquad \forall h, \forall t, \tag{30}$$

and, as a special case of (29),

$$\overline{\mathbb{D}_h}(0) = \mathbb{D}_h^{\text{IT}}(0)\Theta_h^{\text{pur}}(0) \quad \forall h, \tag{31}$$

it becomes clear that (28) is the correct formula to use for unit demand variables.

Combining (28) with (9) and (10) yields the unit demand for purchases of vehicles of type i:

$$D_{h,i}^{\text{pur}}(t) = \overline{D_h}(t)\frac{\theta_{h,i}(t)}{\theta_{h,i}(0)} \quad \forall h. \tag{32}$$

The price $\overline{P_h}$, the demand $\overline{D_h}$ for overall vehicle purchases, and the demand for purchases of each vehicle type $D_{h,i}^{\text{pur}}$, depend on exogenous 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 $D_{h,i}^{\text{pur}}$, are also 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 price variables in the CGE model, determined in the overall economic equilibrium.

A.8 Hard-linking of CGE and electricity BU models

In the bottom-up model, as in Böhringer and Rutherford (2008), we solve the following linear optimisation problem

$$min \sum_{tec} \bar{c}_{tec} y_{tec} \tag{33}$$

subject to

$$\sum_{tec} a_{j,tec} y_{tec} = \bar{d}_j \{energy\ goods\} \tag{34}$$

$$\sum_{tec} b_{k,tec} y_{tec} \leq \kappa_k \{energy\ resources\} \tag{35}$$

$$y_{tec} \geq 0 \tag{36}$$

where

y_{tec}	denotes the activity level of the energy technology tec,
$a_{j,tec}$	stands for the "netput" of energy good j by technology tec,
$\bar{c}_{tec} y_{tec}$	is the exogenous, constant marginal unit cost of producing the energy good by technology tec,
$\bar{d}_j$	denotes the market demand for energy good j (which is derived from the top-down general equilibrium part of the model),
$b_{k,tec} y_{tec}$	represents the unit demand for the energy resource k by technology tec, and
κ_k	stands for the aggregate supply of the energy resource k.

The complementarity conditions between Lagrange multipliers and constraints are used to solve the linear problem along with the top-down macroeconomic equilibrium of the overall economy. This is done by including the market price for a unit of electricity, the shadow price of the capacity constraint and the shadow price of the resource constraint as additional variables, and by adding equations (34) and (35) as additional zero profit or market clearance conditions.

Specifically, in this model the electricity sector is divided into seven technologies: hydro power, wind, solar, biomass, coal, oil, and gas, all of which produce electricity subject to different input structures, resource constraints, and production costs. In total, aggregate produced electricity has to meet consumption demand for electricity.

Table D shows the data used for the calibration of the BU electricity model.

Table D: Technology Data used to calibrate the bottom-up electricity market module of the hybrid model (base year 2008, values in €1000)

Values in 1000 Euro	wind	pv	water_ps	water_run	biomass	biogas	gas_sewage	coal_black	gas_natural	Total
AGR	-7	0	-61	-48	-1,699	-324	-178	-8	-15	-2,339
FERR	-140	-1	-1,140	-892	-45	-9	-5	-85	-135	-2,452
CHEM	-107	0	-1,127	-882	-26	-5	-3	-78	-113	-2,340
ENG	-18,170	-145	-148,628	-116,297	-9,744	-1,859	-1,020	-16,382	-26,571	-338,815
CARS	-200	0	-1,674	-1,310	-24	-5	-3	-100	-98	-3,413
CV	0	0	0	0	0	0	0	0	0	0
HEV	0	0	0	0	0	0	0	0	0	0
PHEV	0	0	0	0	0	0	0	0	0	0
EV	0	0	0	0	0	0	0	0	0	0
VEH	0	0	0	0	0	0	0	0	0	0
OTHER	-452	-1	-3,677	-2,877	-103	-20	-11	-212	-229	-7,583
BUI1	-4,162	-7	-33,739	-26,400	-271	-52	-28	-1,119	-1,301	-67,079
BUI2	-2,200	-44	-17,926	-14,027	-2,908	-555	-304	-3,697	-7,283	-48,944
PT	-76	-1	-627	-490	-47	-9	-5	-365	-626	-2,245
NCST	-713	-1	-5,782	-4,524	-199	-38	-21	-995	-819	-13,091
FT	1,760	-1	-1,457	-1,140	-105	-20	-11	-688	-1,517	-3,181
RnD	-490	-1	-3,969	-3,106	-73	-14	-8	-274	-281	-8,215
SERV	-43,607	-512	-341,469	-267,190	-34,733	-6,626	-3,635	-50,576	-109,060	-857,409
CAR_SERV	-317	0	-3,638	-2,846	-59	-11	-6	-215	-131	-7,225
ELE	**136,229**	**2,269**	**1,074,131**	**1,976,823**	**265,387**	**38,943**	**37,765**	**657,861**	**844,215**	**5,033,624**
ELE_INF	0	0	0	0	0	0	0	0	0	0
LDH	0	0	0	0	0	0	0	0	0	0
GAS	-22,530	-504	-183,747	-143,777	-33,628	-6,415	-3,519	-42,185	-83,759	-520,064
COAL	-2	-2	-13	-11	-124	-24	-13	-78,595	-291	-79,073
CRUDE	-19,004	-706	-154,784	-121,115	-47,097	-8,984	-4,928	-74,740	-509,774	-941,133
FUEL	-1,704	-43	-13,103	-10,253	-2,856	-545	-299	-3,547	-7,126	-39,476
OWNINT	0	0	0	0	0	0	0	0	0	0
labor	-14,185	-236	-111,848	-205,845	-27,635	-4,055	-3,932	-68,502	-87,907	-524,147
capital	-3,032	-18	-8,106	-104,890	-31,320	-2,511	-6,011	-92,486	-7,179	-255,554
fixed factor	-6,891	-44	-37,615	-948,903	-72,691	-6,865	-13,826	-223,010	0	-1,309,846

Data on electricity production and energy balances were provided by Statistics Austria and E-Control Austria. These data were then amended by technology-specific 2008 supply-use data for electricity production taken from the EXIOBASE database (CREEA, 2013)

A.9 Benchmark and business-as-usual scenario

All relative prices for goods and services develop according to the benchmark price reference path $pref(t)$,

$$pref(t) = \left(\frac{1}{1+r}\right)^t \quad \forall t, \tag{37}$$

where r is the real exogenous interest rate. 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. Moreover, the unit demand variables develop according to the benchmark quantity reference level, $qref(t)$,

$$qref(t) = (1+gr)^t \quad \forall t, \tag{38}$$

where gr is the real exogenous growth rate. 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.

The exogenous steady state growth rate gr also applies for the growth of expenditures on vehicle use (fuel and maintenance costs) and vehicle purchases. Hence, the growth paths of vehicle stock sizes and new registration numbers are

$$st_i(t) = st_i(0)\,(1+gr)^t \quad \forall i, \forall t, \tag{39}$$

$$nr_i(t) = nr_i(0)\,(1+gr)^t \quad \forall i, \forall t. \tag{40}$$

According to (5), the vehicle stock in each period is equal to the preceding period's vehicle stock plus new registrations minus depreciated cars of the preceding period. Combining these conditions yields the initial number of new registrations in a fixed relation to the vehicle stock as

$$nr_i(0) = st_i(0)(gr + \delta_i) \quad \forall i, \tag{41}$$

where 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.

A.10 Social Accounting matrix

The overview of production sectors included in the CGE model is available in Table E while the full SAM is shown in Table F.

Table E: Summary of producing sectors included in the Social Accounting matrix

Abbreviation	Sector name	Link to bottom-up modeling
AGR	Agriculture, forestry, fishing	
FERR	Basic metals, nuclear fuels	
CHEM	Chemical products, pharmaceutics	
ENG	Metal products, engineering	→ HEV, PHEV, BEV
CAR	Vehicles production and trade	→ CV, HEV, PHEV, BEV
VEH	Other transport equipment	
OTHER	Other production and mining	
BUI1	Building construction, civil engineering	
BUI2	Specialised construction activities	
PPT	Public passenger transport	
NCST	Other passenger transport	
FT	Freight transport	
RnD	Research and Development	
SERV	Services	
CAR SERV	Car services	→ CV, HEV, PHEV, BEV
ELE	Electricity production	→ ELE INF, Electricity BU model
ELE INF	Electricity trans and distribution	→ PHEV, BEV
LDH	Steam and AC supply	
GAS	Gas production and distribution	
COAL	Mining of coal and lignite	
CRUDE	Crude oil and gas extraction	
FUEL	Fuel for transport purposes	
OWNINIT	Intermediate inputs within sector	
	...rows in final demand	
CV	Conventional vehicle	→ Vehicle stock-flow model
HEV	Hybrid vehicle	→ Vehicle stock-flow model
PHEV	Plug-in hybrid vehicle	→ Vehicle stock-flow model
BEV	Battery electric vehicle	→ Vehicle stock-flow model

Table F: The Social Accounting matrix to calibrate the model (calibration year 2008), in € million (PART I)

	AGR	FERR	CHEM	ENG	CARS	CV	HEV	PHEV	BEV	VEH	OTHER	BUI1	BUI2	PT	NCST	FT	RnD	SERV	CAR_SERV	ELE
AGR	10,817	0	-17	0	-4	0	0	0	0	0	-5,339	-5	-7	-2	0	-1	0	-328	0	-2
FERR	0	24,634	-52	-4,713	-441	0	0	0	0	-173	-1,265	-218	-401	0	0	0	0	-12	-2	-2
CHEM	-286	-170	22,158	-818	-45	0	0	0	0	-31	-3,075	-14	-210	-2	-1	-3	-72	-1,438	-3	-2
ENG	-337	-623	-101	84,131	-2,905	0	-2	-2	0	-476	-1,456	-566	-2,471	-169	-203	-187	-46	-3,356	-322	-339
CARS	-36	-4	-54	-251	33,927	-7,490	-9	-6	-1	-77	-117	-152	-53	-112	-54	-181	-8	-1,524	-227	-3
CV	0	0	0	0	0	14,175	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HEV	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
BEV	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
VEH	0	0	0	-277	-17	0	0	0	0	9,684	0	0	0	-18	-37	-9	0	-618	0	0
OTHER	-643	-135	-726	-1,490	-789	0	0	0	0	-153	82,266	-3,234	-2,560	-50	-21	-65	-61	-7,598	-71	-8
BUI1	-28	-17	-15	-91	-10	0	0	0	0	-2	-95	25,210	-458	-13	-1	-11	-1	-1,236	-2	-67
BUI2	-72	-147	-94	-327	-111	0	0	0	0	-12	-704	-2,226	21,288	-64	-5	-55	-27	-5,717	-24	-49
PT	-12	-52	-23	-70	-20	0	0	0	0	-6	-219	-15	-10	5,251	-8	-405	-2	-545	-1	-2
NCST	-1	-35	-22	-143	-38	0	0	0	0	-9	-144	-30	-50	-12	5,012	-39	-10	-1,372	-6	-13
FT	-12	-267	-210	-489	-129	0	0	0	0	-33	-1,739	-165	-104	-73	-6	12,200	-1	-1,971	-9	-3
RnD	0	-26	-103	-452	-172	0	0	0	0	-13	-107	-2	-3	-6	-2	-11	2,999	-340	-1	-8
SERV	-550	-2,453	-1,094	-7,480	-2,876	0	0	0	0	-471	-9,350	-2,967	-3,200	-1,175	-1,563	-1,853	-457	303,633	-405	-857
CAR_SERV	-16	-3	-3	-58	-567	-1,490	-1	0	0	-20	-62	-20	-60	-224	-1	-115	-1	-403	3,184	-7
ELE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,034
ELE_INF	-84	-323	-225	-214	-74	0	0	0	0	-6	-711	-30	-57	-248	-7	-127	-8	-1,646	-15	0
LDH	-3	-22	-20	-12	-8	0	0	0	0	-4	-35	-2	-3	0	-2	0	-1	-254	-1	0
GAS	-7	-254	-219	-67	-21	0	0	0	0	-4	-542	-13	-25	-31	-3	-16	-4	-645	-3	-520
COAL	-4	0	-37	-2	-1	0	0	0	0	0	-39	0	0	0	0	0	0	-62	0	-79
CRUDE	-73	-1,510	-777	-102	-53	0	0	0	0	-3	-281	-187	-118	-51	-439	-428	-4	-1,570	-4	-941
FUEL	-178	-20	-17	-44	-6	-2,816	-1	0	0	-1	-165	-172	-17	-82	-96	-426	-2	-529	-10	-39
OWNINT	-2,116	-5,012	-3,417	-15,520	-4,525	0	0	0	0	-1,190	-13,094	-5,357	-2,313	-170	-298	-696	-296	-78,925	-128	0
LS	-42	-163	-88	-1,089	-238	0	0	0	0	-58	-902	-574	-754	-130	-43	-190	-83	-6,532	-125	-91
MS	-284	-1,179	-633	-7,881	-1,771	0	0	0	0	-422	-6,856	-3,105	-4,080	-1,295	-432	-1,894	-685	-57,168	-1,066	-360
HS	-75	-310	-166	-2,069	-483	0	0	0	0	-111	-2,028	-541	-711	-145	-48	-211	-363	-29,317	-340	-74
Imports	-2,779	-9,804	-12,401	-34,452	-12,492	0	0	0	0	-5,968	-27,547	-519	-268	-285	-1,582	-3,842	-771	-16,125	-6	0
Capital	-3,024	-2,028	-1,595	-5,969	-6,120	0	0	0	0	-437	-6,195	-4,945	-3,337	-810	-69	-1,057	-93	-83,802	-402	-1,565
Labour tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capital tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HETAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FETAX	-2	-39	-23	-4	-2	0	0	0	0	0	-20	-4	-3	-2	-10	-10	0	-55	0	0
HELETAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FELETAX	-5	-19	-13	-13	-4	0	0	0	0	0	-43	-2	-3	-15	0	-8	0	-99	-1	0
PENSION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minoil Tax	-150	-17	-14	-37	-5	-2,379	-1	0	0	-1	-140	-145	-14	-69	-81	-360	-2	-446	-8	0
TCAR CV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCAR HEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCAR PHEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCAR BEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHTAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UEBEN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHTRANS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Legend: LS = low-skilled labour, MS = medium-skilled labour, HS = high-skilled labour, HETAX = tax on energy (fossil fuels) paid by households, FETAX = tax on energy (fossil fuels) paid by firms, HELETAX = tax on electricity paid by households, FELETAX = tax on electricity paid by firms, PENSION = pension benefits paid by the government, Minoil tax = mineral oil tax paid on fuel input for vehicles, TCAR CV,HEV,PHEV,BEV = new registration taxes/rebates paid/received for different vehicle types, CONSTAX = consumption (value added) tax paid on household consumption, OTHTAX = other taxes attributed paid by the household sector (data consistency), UEBEN = unemployment benefits, OTHTRANS = other transfers from government to household sector.

contd.: The Social Accounting matrix to calibrate the model (calibration year 2008), in € million (PART II)

	ELE_INF	LDH	GAS	COAL	CRUDE	FUEL	OWNINT	U-LS	SU-LS	R-LS	U-MS	SU-MS	R-MS	U-HS	SU-HS	R-HS	GOVT	INV	ROW
AGR	-22	0	0	0	0	0	-2,116	-101	-76	-136	-470	-326	-517	-227	-111	-137	0	0	-873
FERR	-1	-3	-1	0	0	0	-5,012	0	0	0	-1	-1	-1	-1	0	0	0	-293	-12,042
CHEM	0	-1	0	0	-77	-66	-3,417	-65	-48	-87	-300	-208	-330	-144	-71	-88	-1,392	-60	-9,635
ENG	-108	-74	-60	0	-87	-17	-15,520	-132	-99	-177	-610	-423	-671	-294	-145	-178	-28	-13,900	-38,048
CARS	0	-1	-1	0	-2	0	-4,525	0	0	0	0	0	0	0	0	0	0	0	-19,038
CV	0	0	0	0	0	0	0	-230	-976	-747	-3,034	-3,661	-4,471	-488	-278	-288	0	0	0
HEV	0	0	0	0	0	0	0	0	-1	0	-3	-3	-5	-1	0	0	0	0	0
PHEV	0	0	0	0	0	0	0	0	0	0	-2	-2	-3	-1	0	0	0	0	0
BEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEH	0	0	0	0	0	0	-1,190	-14	-11	-19	-65	-45	-72	-32	-16	-19	-12	-1,348	-5,866
OTHER	0	-5	-1	0	-9	-3	-13,094	-821	-615	-1,104	-3,801	-2,636	-4,181	-1,833	-902	-1,112	-273	-4,410	-29,861
BUI1	0	-17	-15	0	-30	-3	-5,357	0	0	0	0	0	0	0	0	0	0	-17,060	-681
BUI2	-13	-16	-14	0	-27	-20	-2,313	-66	-50	-89	-307	-213	-337	-148	-73	-90	0	-7,677	-203
PT	-91	-2	-18	0	-11	-6	-170	-257	-103	-94	-976	-291	-317	-180	-51	-26	-287	0	-979
NCST	0	-1	-4	0	-4	-2	-298	-70	-52	-94	-322	-223	-354	-155	-76	-94	-1	-3	-1,334
FT	-55	-1	-11	0	-41	-28	-696	-67	-50	-90	-308	-214	-339	-149	-73	-90	-147	-68	-4,564
RnD	0	-4	-2	0	-2	0	-296	0	0	0	0	0	0	0	0	0	-136	-8	-1,305
SERV	-65	-144	-343	0	-245	-122	-78,925	-4,447	-3,334	-5,985	-20,599	-14,286	-22,659	-9,932	-4,887	-6,023	-53,301	-11,402	-30,183
CAR_SERV	-3	0	-1	0	-1	0	-128	0	0	0	0	0	0	0	0	0	0	0	0
ELE	-5,034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ELE_INF	24,249	-36	-15	0	-6	-1	-15,602	-148	-111	-199	-686	-476	-755	-331	-163	-201	0	0	-1,746
LDH	-4	832	-1	0	-1	0	-21	-21	-16	-28	-97	-67	-107	-47	-23	-28	0	0	-5
GAS	0	-100	3,884	0	-5	0	-1,370	-1	-1	-2	-6	-4	-7	-3	-2	-2	0	-1	-4
COAL	0	0	-79	481	-77	-68	0	-1	-1	-1	-3	-2	-4	-2	-1	-1	0	-16	-2
CRUDE	-33	-52	-995	0	14,027	-1,392	-1,651	-10	-8	-14	-47	-33	-52	-23	-11	-14	0	0	-3,151
FUEL	-11	-9	-6	0	-3	4,652	-2	0	0	0	0	0	0	0	0	0	0	0	0
OWNINT	-15,602	-21	-1,370	0	-1,651	-2	151,702	0	0	0	0	0	0	0	0	0	0	0	0
LS	-34	-9	-23	0	-14	-5	0	4,738	2,922	3,527	0	0	0	0	0	0	0	0	0
MS	-544	-68	-169	-1	-103	-34	0	0	0	0	31,718	23,630	34,682	0	0	0	0	0	0
HS	-164	-18	-44	0	-27	-9	0	0	0	0	0	0	0	16,895	9,406	10,951	0	0	0
imports	-1,531	-55	-368	-476	-10,914	-2,795	0	0	0	0	0	0	0	0	0	0	0	0	144,980
capital	-926	-187	-339	-1	-688	-78	0	418	1,410	1,453	10,392	6,869	14,442	9,054	4,000	4,844	0	56,245	14,540
LTAX	0	0	0	0	0	0	0	-1,937	-1,195	-1,442	-14,162	-10,551	-15,485	-7,981	-4,443	-5,173	62,371	0	0
KTAX	0	0	0	0	0	0	0	-82	-278	-286	-2,048	-1,354	-2,846	-1,784	-788	-955	10,423	0	0
HETAX	0	0	0	0	0	0	0	-7	-5	-9	-32	-22	-36	-16	-8	-9	144	0	0
FETAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	174	0	0
HELETAX	0	0	0	0	0	0	0	-37	-28	-50	-171	-118	-188	-82	-41	-50	764	0	0
FELETAX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	226	0	0
PENSION	0	0	0	0	0	0	0	2,092	2,162	5,013	9,671	6,930	7,268	3,506	1,751	2,083	-40,475	0	0
MoeSt	-9	-7	-5	0	-3	0	0	0	0	0	0	0	0	0	0	0	3,894	0	0
TCAR_CV	0	0	0	0	0	0	0	-37	-156	-119	-484	-584	-713	-78	-44	-46	2,260	0	0
TCAR_HEV	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	0	0	0	3	0	0
TCAR_PHEV	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	2	0	0
TCAR_BEV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTAX	0	0	0	0	0	0	0	-943	-707	-1,269	-4,367	-3,029	-4,804	-2,106	-1,036	-1,277	19,537	0	0
OTHTAX	0	0	0	0	0	0	0	-294	-220	-395	-1,361	-944	-1,497	-656	-323	-398	6,087	0	0
UEBEN	0	0	0	0	0	0	0	177	109	132	310	231	339	78	43	50	-1,469	0	0
OTHTRANS	0	0	0	0	0	0	0	2,361	1,536	2,314	2,175	2,058	4,023	-2,842	-1,632	-1,628	-8,366	0	0

Legend: LS = low-skilled labour, MS = medium-skilled labour, HS = high-skilled labour, HETAX = tax on energy (fossil fuels) paid by households, FETAX = tax on energy (fossil fuels) paid by firms, HELETAX = tax on electricity paid by households, FELETAX = tax on electricity paid by firms, PENSION = pension benefits paid by the government, Minoil tax = mineral oil tax paid on fuel input for vehicles, TCAR CV,HEV,PHEV,BEV = new registration taxes/rebates paid/received for different vehicle types, CONSTAX = consumption (value added) tax paid on household consumption, OTHTAX = other taxes attributed paid by the household sector (data consistency), UEBEN = unemployment benefits, OTHTRANS = other transfers from government to household sector, U-LS,SU-LS,R-LS, ..., SU-HS,R-HS = nine household types of urban (U), sub-urban (SU), rural (R) type crossed with low-skilled (LS), medium-skilled (MS) and high-skilled (HS) skill levels, GOVT = government expenditures and receipts, INV = investment, ROW = rest of world

A.11 Sensitivity analysis

In order to validate the model's stability, we performed a sensitivity analysis, which ensures that the selection of parameter values does not lead to unstable results and singularity in the model's solution.[10] 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 the direction of the results.

The simulations of MODEST and EM+ scenarios were repeated several times with a structural change in all values of elasticities. Therefore, 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 of e.g. +300% may not be very realistic. However, for the simulation runs with elasticity values in a realistic range, the changes in the variables' values were also in a realistic order of magnitude. Qualitatively speaking, the directions of variables' reactions to scenario simulations are not reversed by any alteration of elasticities. Hence, our results can be perceived as robust. Among the most reactive parameters are consumption elasticities (for all households) since our hybrid CGE model is mostly 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. A comparison of the GDP levels in an ordinary EM+ scenario-run (i.e. without a variation of any elasticities) with the GDP levels of all sensitivity analysis simulations of the EM+ scenario yielded a deviation in 2030 within the range of +/- 20%.

B. DISCRETE CHOICE MODEL

Market shares of newly purchased vehicles are given by the probabilities (Truong and Hensher, 2012) that can be derived from the estimates of indirect utility parameters. Specifically, in our model, we use responses of survey participants from a discrete choice experiment that has been designed for this purpose within the EU funded project ERA-NET DEFINE (see Hanappi and Mayr (2013) for details)[11]. Survey participants were asked to choose the best vehicle among four different technologies (conventional vehicle – CV, plug-in hybrid-electric – PHEV, hybrid-electric – HEV, and battery electric vehicle BEV) that are described by several monetary (purchase price, fuel costs, maintenance costs) and non-monetary attributes (driving range, engine power, availability of charging stations, and policy incentives such as a Park and Ride subscription, investment subsidies to support private charging stations, and a one-year-ticket for public transportation).

Respondents' choices reveal their preferences and can be modelled using the random utility framework (McFadden, 1974). Indirect utility of individual i associated with choosing alternative j of the available alternatives in choice task t can be expressed as:

$$U_{i,jt} = X_{ijt} + COSTS_{ijt}b + (I_i - PRICE_{ijt})a + \epsilon_{i,jt} \tag{42}$$

where the first components represent a deterministic part of utility, described by a non-monetary vehicle's attributes (X), fuel and maintenance costs ($COSTS$), and vehicle purchase price ($PRICE$) subtracted from an individual's income, I. The vectors b and c, and a are coefficients to be estimated. The stochastic error j captures individual- and alternative-specific factors that remain unobserved by the analyst and it is assumed to be IID standard type I extreme value. It implies that the probability

[10] Detailed results from the sensitivity analysis are available from the authors upon request.

[11] Apart from the discrete choice experiment, the questionnaire also included questions on socio-economic background, mobility behaviour and attitudes, car ownership and car purchase, frequency and purpose of car use, and detailed information on recent and recurring trips (Hanappi and Mayr, 2013)

that alternative k is chosen from a set of a alternatives is

$$Pr(k|J) = \frac{exp(X_{ikt}c + COSTS_{ikt}b + (I_i - PRICE_{ikt})a)}{\sum_{j=1}^{J} exp(X_{ijt}c + COSTS_{ijt}b + (I_i - PRICE_{ijt})a)} \tag{43}$$

This probability contributes to the likelihood in a conditional logit model (Train, 2003)[12] where y_{ijt} is a dummy taking the value 1 if an alternative is chosen in choice task t, and 0 otherwise. The coefficients a, b, and c are estimated by maximum likelihood.

Data were collected through a web-based survey carried out in Austria in February 2013. The survey participants were sampled from an online panel using quotas and this sample is representative with regard to gender and the age structure, nine federal states in Austria and the degree of urbanization (rural, sub-urban and urban). Due to the specific research focus, individuals from households without a car are under-represented while those from households with more than one car are slightly over-represented (Bahamonde-Birke and Hanappi, 2016).

The overall sample of 1,449 respondents were selected at random into two subgroups. A discrete choice experiment on vehicle purchase was assigned to one of them, whilst also restricting this subsample to only individuals with a driver's license and an intention to buy a new vehicle in the near future. This subgroup consists of 787 respondents and each respondent in this subgroup received nine choice tasks, yielding 7,083 responses that are used in econometric estimation.

Three conditional logit models are estimated separately – for respondents living in rural (n=280), sub-urban (n=261), and urban areas (n=246), while controlling for education level in interaction with the alternative-specific constants. As expected, the coefficients for all qualitative attributes are positive, while the coefficients for all monetary attributes are negative and significant at any convenient level. The degree of urbanisation does not affect how respondents are responsive to purchase price and fuel and maintenance costs, with only an exception for individuals living in a sub-urban area, who are more responsive to fuel costs indicating their higher demand on commuting. Except for this segment, the coefficients for fuel costs and maintenance costs are very close to each other. Respondents also share the same preference for increasing driving range, with implied willingness to pay at about 18 euro per km, which is comparable to other estimates found in other EU countries (Ščasný et al., 2018). Engine power is a more important attribute for conventional vehicles than for the alternative technologies. The probability to purchase PHEV and BEV is increased if the availability of charging stations is high, although respondents living in sub-urban and rural areas also appreciate a medium-level of stations. Higher education increases the probability to buy alternative technologies – the preference for hybrid vehicles is higher in less urbanized areas, while the preference for BEVs is higher in sub-urban areas.

[12]Since the labelled choice experiment includes four attributes and each respondent is asked to select the best alternative nine times, the log likelihood function is $LL = \sum_{i=1}^{N} \sum_{t=1}^{9} \sum_{j=1}^{4} y_{ijt} \cdot ln\left(Pr_{ijt}\right)$

Table G: Conditional logit estimates for various degree of urbanization, preference-space.

β entries	Households by living area: Urban	Suburban	Rural
Purchase price [€ 1,000]	-0.162	-0.152	-0.168
Fuel costs [€/100km]	-14.600	-22.300	-13.300
Maintenance costs [€/100km]	-15.100	-14.200	-15.900
Power x CV	0.029	0.033	0.023
Power x HEV	0.017	0.017	0.018
Power x PHEV	0.025	0.022	0.018
Power x BEV	-	0.010	0.007
Range x BEV [km]	0.00295	0.00272	0.00307
Charging stations medium x BEV	-	0.325	0.195
Charging stations high x BEV	0.707	0.705	0.558
Medium skilled x HEV	0.702	0.529	-
Medium skilled x PHEV	0.461	-	-
Medium skilled x BEV	0.992	-	-
High skilled x HEV	-	0.561	0.855
High skilled x PHEV	-	0.025	-
High skilled x BEV	-	0.485	-
ASC HEV	0.288	-0.159	-1.120
ASV PHEV	-0.624	-0.724	-0.698
ASV BEV	-0.279	-2.240	-1.450

Table H: Attribute levels (initial steady state calibration)

Attributes	Values
Purchase price CV [€ 1,000]	25.502
Purchase price HEV [€ 1,000]	28.801
Purchase price PHEV [€ 1,000]	35.293
Purchase price BEV [€ 1,000]	51.027
Fuel costs CV [€/100km]	0.08
Fuel costs HEV [€/100km]	0.07
Fuel costs PHEV [€/100km]	0.05
Fuel costs BEV [€/100km]	0.04
Maintenance costs CV [€/100km]	0.06
Maintenance costs HEV [€/100km]	0.06
Maintenance costs PHEV [€/100km]	0.06
Maintenance costs BEV [€/100km]	0.06
Power x CV	122
Power x HEV	160
Power x PHEV	186
Power x BEV	146
Range x BEV [km]	150
Charging stations medium x BEV	0
Charging stations high x BEV	0

After controlling for the monetary and non-monetary vehicle's attributes, all alternative specific constants (ASC) for the alternative technologies remain negative and significant, indicating a positive preference for conventional technology. As might be expected from mere economic intuition, people living in sub-urban areas share the strongest disutility related to BEV. The ASC for hybrid vehicles is positive for people living in urban areas, while people from other two segments seem to favor HEV compared to CV. There is no such disparity in preferences among the three levels of urbanization in the case of PHEV, which might be related to the higher range of PHEVs as compared to BEVs.

C. EXTERNE'S IMPACT PATHWAY ANALYSIS

The Impact Pathway Analysis (IPA) is an analytical bottom-up procedure examining the sequence of processes through which polluting emissions result in damage to firms and individuals. The IPA comprises four basic steps: (i) selection of the reference emission source, determination of the technology used and of the harmful emissions released, (ii) calculation of difference in pollutant concentrations between a reference and a case scenario for all affected regions using atmospheric dispersion models, (iii) estimation of physical impacts on human health, buildings and materials, biodiversity, and crop yields from exposure using concentration-response functions, and (iv) economic valuation of these physical impacts (Bickel and Rainer, 2005; Rabl et al., 2014). We specifically use the approach as being developed within a series of EU funded research projects - ExternE - the approach that is similar to US Air Pollution Emission Experiments and Policy integrated assessment model.

Chemical transport and atmospheric modelling is embodied in the EcoSense tool developed within several EC-funded projects. The tool uses three models of air quality: (1) the Industrial Source ComplexModel for transport of primary air pollutants on a local scale delaminated by 100×100 km around the power plant, (2) the EMEP/MSCWest Eulerian dispersion model for modelling transport and chemical transformation of primary pollutants on a regional scale covering all Europe, and (3) the Northern-hemispheric model which serves for an estimation of the intercontinental influence primary and secondary pollutants (secondary inorganic aerosols, tropospheric ozone) (Preiss and Klotz, 2008).

Health impacts include new cases of illness, developmental impairments, and premature mortality, which is the most important among them. Effects on building include accelerated corrosion and soiling of facades, while the loss of biodiversity is assessed through 'Potential Disappeared Fraction' of species linked to acidification and eutrophication. Valuation methods are used to translate the physical impacts into monetary impacts, using either direct costs (cost of illness, effect on crop yield, restoration of building materials or biodiversity loss) and indirect costs measured through the willingness-to-pay approach, i.e. compensating/equivalent surplus.

In our quantification of the external costs, we use country-specific impacts expressed in 2005 euro per ton of emission of pollutant, as estimated in Preiss and Klotz (2008). We assume the social cost of carbon to be € 20 per ton of CO_2, as being used in the impact assessments based on the ExternE projects. Table I describes the unit external costs per ton of emissions SO_2, NOx, PM_{coarse}, PM2.5, NMVOC, NH_3 and CO_2 released in Austria.

Table I: Average damage factors for air quality and GHG pollutants - Austria (euro2005 per ton)

	SO_2	NO_x	NH_3	NMVOC	PM_{coarse}	PM2.5	CO_2
Health effects	7,719	9,533	11,711	1,015	1,202	29,556	
Loss of biodiversity	507	1,638	6,869	-85	0	0	
Crop yield	-89	570	-103	126	0	0	
Materials	357	144	0	0	0	0	
Health effects due to North Hemispheric modelling	278	131	2.7	358	2.1	158	
Climate change	-	-	-	-	-	-	20
TOTAL	8,772	12,016	18,480	1,414	1,204	29,714	20

Note: PM_{coarse} indicates particulate matters with an aerodynamic diameter between 2.5 and 10 µm. Unit damage cost due to other non-CO_2 green-house gasses is € 420 per t CH_4 and € 6,200 per t of N_2O assuming 21, and 310 GWP factors, respectively.

We use four data sources to determine emissions in our model:

- First, direct emissions stemming from domestic economic production are endogenously determined by the hybrid CGE model through the emission-output coefficients. The emission factor for each economic sector is derived from the EXIOBASE 2.2 database as compiled within the CREEA project. The originally derived 200 product categories and 163 industry sectors from the CREE matrix are merged into the 22 sectors used in the CGE model. Economic values in both CREEA database and the SAM are recorded in basic prices, which makes our link consistent.

- Second, direct emissions due to fuel use in vehicles can be quantified by at least two approaches. Emission factors can be derived from the EXIOBASE CREEA database, as describe above in the case of economic sectors. If direct emissions are linked to FUEL output (4,610 million euro in 2008), as determined by our hybrid CGE model, we get the external costs at 125 million euro. Alternatively, the emission factors can be derived from TREMOVE database that resulted in the external cost attributable to fuel used in passenger and freight transport at 1,636 million euro (excluding indirect impacts due to CO_2 w2t). Ščasný et al. (2015) validated this approach and recommended to use the latter one. We use the emission factors for GHGs (CO_2, CO_2 w2t, CH4, N2O) and air quality pollutants (SO_2, NO_x, NH_3, NMVOC, PM2.5 and PM_{coarse}) that are expressed in tones per euro of pre-tax expenditures on fuel. These factors are then multiplied by fuel use in passenger cars and by freight transport. Fuel use is endogenously determined for each scenario and each year by the hybrid CGE model. To avoid double-counting, we subtract direct emissions attributable to FUEL sector, relying on the former approach linked to EXIOBASE factors.

- Third, similarly, as in the case of vehicle use, direct external costs associated with electricity generation can be based on two different sources. A first approach can be based on the EXIOBASE-based emission-factors that represent a technology-invariant average emission intensity of generating electricity. Alternatively, damage factors can be derived per kWh of electricity generated in various technologies, accounting for life cycle emissions. In order to consider the technology-mix that may vary over time and across scenarios, we prefer to use CASES database on the external costs of electricity generating technologies, as derived within EU funded CASES project (excluding the up-stream impacts due to construction). In our approach we link electricity production by different technology, as endogenously determined in the bottom-up electricity part of the hybrid model, see Table J. In order to avoid double-counting, we subtract direct emissions computed for ELE sector, using the approach based on the EXIOBASE database.

Table J: External costs of electricity generation due to operation and fuel use in Austria, €c/kWh.

Technology	Electricity model (hybrid CGE)	Environmental	Health	Climate change	Total
hydro run of river	water_run	0.0015	0.0164	0.0077	0.0256
natural gas combined cycle	gas_sewage	0.0715	0.4204	0.8967	1.3886
hard coal condensing power plant	coal_black	0.1593	1.2457	1.7176	3.1226
biomass (woodchips) CHP	biomass	0.0665	0.4266	0.1157	0.6089
biogas	biogas	0.153	1.8103	0.5879	2.5511
wind	wind	0.003	0.0377	0.0117	0.0524
hydropower, pump storage	water_ps	0.0004	0.0045	0.0018	0.0067
solar PV open space	pv	0.0129	0.1749	0.0522	0.24
natural gas, gas turbine	gas_natural	0.1079	0.6303	1.3416	2.0798

- Lastly, indirect emissions attributable to all imported goods produced worldwide are calculated using the MRIO data for total imported products, including total emissions embodied in the imports. Footprints are calculated using the product-by-product MRIO model under an industry technology assumption (similar to Weinzettel et al. (2012, 2014)). To derive the emission factors for imported goods we consider economic value of net imports only, i.e. economic value of exported imports are excluded.

Table K shows the difference between domestic emissions in EM+ and BAU across the model years, while Table L presents total (domestic+indirect) emissions. Table M presents the detailed results for the equivalent variation as a measure of welfare change for scenarios EM+ and TARGET95 for the nine household types and the whole observed period.

Table K: Difference EM+ minus BAU, domestic emissions, kt, CO_2 and GHG in mil. t

	CO_2, mt	GHG, mt	SO_2	NO_X	NH_3	CO	NMVOC	PM10	PM2.5	TSP
2008	-0.14	-0.14	-0.07	-0.2	0	-0.47	-0.13	-0.02	-0.03	-0.04
2009	-0.16	-0.17	-0.1	-0.34	0	-0.71	-0.18	-0.03	-0.04	-0.06
2010	-0.22	-0.23	-0.1	-0.44	0	-0.92	-0.2	-0.04	-0.05	-0.06
2011	-0.25	-0.26	-0.11	-0.51	0	-1	-0.22	-0.04	-0.05	-0.07
2012	-0.3	-0.31	-0.12	-0.57	0	-1.12	-0.25	-0.05	-0.06	-0.07
2013	-0.32	-0.34	-0.13	-0.63	0	-1.2	-0.28	-0.05	-0.07	-0.09
2014	-0.37	-0.38	-0.12	-0.69	0	-1.22	-0.29	-0.05	-0.07	-0.09
2015	-1.14	-1.22	-0.35	-2.58	-0.02	-2.36	-0.79	-0.12	-0.13	-0.16
2016	-1.19	-1.27	-0.35	-2.52	-0.02	-2.32	-0.82	-0.12	-0.13	-0.17
2017	-1.23	-1.31	-0.33	-2.45	-0.02	-2.17	-0.83	-0.11	-0.14	-0.17
2018	-1.25	-1.33	-0.3	-2.39	-0.02	-1.93	-0.83	-0.11	-0.13	-0.17
2019	-1.96	-2.1	-0.47	-3.8	-0.03	-2.43	-1.27	-0.14	-0.17	-0.22
2020	-1.96	-2.1	-0.42	-3.74	-0.03	-2.06	-1.27	-0.13	-0.17	-0.21
2021	-1.95	-2.09	-0.38	-3.72	-0.03	-1.82	-1.28	-0.13	-0.17	-0.2
2022	-1.92	-2.06	-0.34	-3.71	-0.03	-1.55	-1.27	-0.12	-0.16	-0.18
2023	-1.88	-2.02	-0.29	-3.69	-0.03	-1.32	-1.27	-0.11	-0.15	-0.17
2024	-1.82	-1.96	-0.25	-3.68	-0.03	-1.1	-1.26	-0.1	-0.14	-0.15
2025	-1.72	-1.85	-0.2	-3.61	-0.03	-0.73	-1.21	-0.09	-0.12	-0.12
2026	-1.61	-1.75	-0.17	-3.62	-0.03	-0.6	-1.22	-0.09	-0.11	-0.11
2027	-1.51	-1.64	-0.15	-3.66	-0.03	-0.59	-1.24	-0.09	-0.11	-0.1
2028	-1.38	-1.52	-0.13	-3.69	-0.03	-0.58	-1.25	-0.09	-0.11	-0.1
2029	-1.23	-1.36	-0.1	-3.74	-0.03	-0.53	-1.27	-0.09	-0.11	-0.1
2030	-1.08	-1.21	-0.04	-3.81	-0.03	-0.38	-1.34	-0.09	-0.13	-0.11
2008-2030	-26.61	-28.63	-5.02	-57.79	-0.42	-29.12	-19.98	-2.02	-2.54	-2.89

Table L: Difference EM+ minus BAU, total (domestic+indirect) emissions, kt, CO_2 and GHG in mil. t

	CO_2, mt	GHG, mt	SO_2	NO_X	NH_3	CO	NMVOC	PM10	PM2.5	TSP
2008	-0.22	-0.24	-0.36	-0.48	0	-0.87	-0.41	-0.06	-0.06	-0.08
2009	-0.28	-0.31	-0.46	-0.69	0	-1.2	-0.57	-0.08	-0.08	-0.11
2010	-0.34	-0.38	-0.46	-0.79	0	-1.4	-0.62	-0.09	-0.08	-0.11
2011	-0.36	-0.4	-0.47	-0.87	0	-1.47	-0.66	-0.09	-0.09	-0.12
2012	-0.42	-0.47	-0.5	-0.95	0	-1.62	-0.74	-0.1	-0.09	-0.13
2013	-0.45	-0.5	-0.53	-1.04	0	-1.71	-0.8	-0.11	-0.1	-0.14
2014	-0.49	-0.54	-0.52	-1.11	0	-1.7	-0.84	-0.11	-0.11	-0.14
2015	-1.44	-1.69	-1.28	-3.69	-0.02	-3.23	-3.13	-0.24	-0.21	-0.29
2016	-1.48	-1.74	-1.23	-3.61	-0.02	-3.12	-3.2	-0.23	-0.22	-0.29
2017	-1.49	-1.75	-1.13	-3.48	-0.02	-2.83	-3.22	-0.21	-0.21	-0.28
2018	-1.46	-1.72	-0.93	-3.33	-0.02	-2.31	-3.21	-0.19	-0.2	-0.26
2019	-2.27	-2.72	-1.4	-5.26	-0.03	-2.9	-5.36	-0.26	-0.27	-0.35
2020	-2.18	-2.62	-1.1	-5.03	-0.03	-2.14	-5.32	-0.22	-0.25	-0.31
2021	-2.1	-2.54	-0.89	-4.89	-0.03	-1.64	-5.3	-0.19	-0.24	-0.28
2022	-2	-2.44	-0.66	-4.74	-0.03	-1.1	-5.24	-0.16	-0.21	-0.24
2023	-1.9	-2.33	-0.46	-4.61	-0.03	-0.64	-5.18	-0.14	-0.19	-0.2
2024	-1.76	-2.18	-0.26	-4.47	-0.03	-0.19	-5.11	-0.11	-0.17	-0.16
2025	-1.57	-1.98	-0.02	-4.25	-0.03	0.43	-4.94	-0.08	-0.13	-0.09
2026	-1.42	-1.82	0.06	-4.21	-0.03	0.63	-4.91	-0.07	-0.12	-0.07
2027	-1.27	-1.67	0.09	-4.24	-0.03	0.62	-4.89	-0.07	-0.12	-0.06
2028	-1.12	-1.51	0.07	-4.29	-0.03	0.56	-4.89	-0.08	-0.12	-0.05
2029	-0.92	-1.3	0.09	-4.34	-0.03	0.57	-4.88	-0.09	-0.13	-0.03
2030	-0.69	-1.06	0.31	-4.34	-0.04	0.93	-4.92	-0.08	-0.14	-0.03
2008-30	-27.61	-33.9	-12.06	-74.7	-0.49	-26.3	-78.35	-3.05	-3.56	-3.81

Table M: Equivalent variation across household types in EM+ and TARGET95 scenarios

	All	LS_U	LS_S	LS_R	MS_U	MS_S	MS_R	HS_U	HS_S	HS_R
EM+										
2008	-94	7	-20	-4	-23	-47	14	-11	-6	-6
2009	-73	7	-18	-3	-15	-40	15	-10	-5	-5
2010	-79	6	-16	-4	-19	-38	13	-10	-5	-5
2011	-83	5	-15	-4	-19	-37	10	-11	-6	-6
2012	-99	4	-15	-5	-22	-38	2	-12	-6	-7
2013	-158	2	-17	-7	-35	-49	-20	-15	-7	-9
2014	-248	-1	-20	-12	-54	-68	-54	-19	-9	-12
2015	-410	-6	-26	-19	-88	-107	-106	-27	-13	-18
2016	-643	-14	-36	-30	-139	-162	-190	-38	-9	-26
2017	-967	-24	-48	-44	-205	-235	-297	-51	-25	-36
2018	-1475	-38	-70	-68	-313	-356	-468	-73	-36	-52
2019	-2297	-60	-108	-107	-487	-559	-738	-109	-53	-77
2020	-2993	-77	-144	-139	-636	-747	-951	-137	-69	-94
2021	-3491	-89	-169	-165	-743	-868	-1115	-158	-78	-108
2022	-3950	-99	-192	-189	-843	-978	-1265	-177	-87	-120
2023	-4319	-108	-211	-210	-923	-1067	-1385	-192	-94	-130
2024	-4590	-113	-225	-226	-983	-1131	-1473	-203	-99	-137
2025	-4756	-115	-235	-236	-1020	-1172	-1530	-207	-100	-139
2026	-4864	-118	-242	-244	-1044	-1196	-1565	-212	-102	-141
2027	-4905	-118	-245	-248	-1054	-1203	-1578	-213	-102	-142
2028	-4890	-117	-245	-249	-1053	-1197	-1574	-213	-101	-141
2029	-4890	-116	-246	-254	-1055	-1195	-1570	-213	-101	-140
2030	-5205	-12	-267	-290	-1171	-1292	-1680	-236	-108	-148
Total	-55 479	-1194	-2830	-2757	-11944	-13782	-17505	-2547	-1221	-1699
TARGET95										
2008	-120	0	-24	-16	-22	-39	26	-22	-10	-13
2009	-154	-4	-24	-20	-38	-55	27	-17	-13	-10
2010	-198	-4	-26	-22	-43	-64	11	-27	-13	-10
2011	-547	-9	-49	-37	-112	-152	-108	-38	-19	-22
2012	-550	-9	-48	-36	-126	-147	-109	-36	-18	-21
2013	-532	-9	-46	-36	-122	-141	-104	-36	-18	-21
2014	-528	-10	-47	-35	-119	-137	-104	-36	-18	-21
2015	-769	-14	-62	-47	-164	-203	-186	-44	-25	-25
2016	-729	-11	-60	-45	-159	-183	-181	-43	-22	-25
2017	-696	-12	-58	-45	-155	-177	-163	-43	-22	-21
2018	-631	-10	-53	-40	-140	-162	-145	-38	-19	-22
2019	-772	-13	-62	-45	-164	-201	-199	-41	-23	-24
2020	-767	-13	-60	-43	-167	-198	-200	-42	-21	-23
2021	-824	-14	-61	-45	-177	-214	-225	-43	-22	-24
2022	-1065	-19	-75	-56	-224	-278	-304	-50	-27	-31
2023	-1197	-22	-81	-62	-253	-311	-350	-54	-29	-34
2024	-1316	-24	-87	-69	-282	-341	-386	-60	-32	-35
2025	-1387	-24	-92	-73	-292	-363	-418	-59	-32	-35
2026	-1756	-31	-115	-90	-373	-456	-536	-72	-40	-43
2027	-1868	-33	-122	-97	-398	-483	-572	-77	-42	-46
2028	-1949	-35	-127	-102	-416	-502	-598	-79	-43	-48
2029	-2002	-36	-130	-103	-427	-514	-616	-80	-45	-50
2030	-2228	-40	-144	-115	-474	-567	-692	-90	-50	-56
Total	-22 585	-396	-1653	-1279	-4847	-5888	-6132	-1127	-603	-660

Note: LS, MS, and HS denote low, medium, and high skilled segment of households, while the subscripts U, S, and R describe urban, suburban, and rural residence, respectively.

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