Development of an Evaluation Framework for the Introduction of Electromobility

Electromobility+

Project:

Development of an Evaluation Framework for the Introduction of Electromobility

WP9 Quantification of Environmental Benefits

Deliverable 9.1: Report on External Costs of electricity generation and vehicle use

Deliverable 9.2: Soft link between environmental assessment and the hybrid general equilibrium model

Due date of deliverable: 28 February 2015

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Abstract

We quantify environmental benefits attributable to air quality and GHGs pollutants due to electro-mobility. We link ExternE's Impact Pathway Analysis and the hybrid CGE model in order to relate predicted effects on economy to external costs. To quantify the external costs, environmental and health effects attributable to direct and indirect emissions stemming from domestic economic production, imports, fuel use and electricity production over the period 2008-2030 are estimated. As a result, total external costs and year-by-year differences for business-as-usual and EM+ scenario are computed for Austria. We find that EM+ scenario generates overall smaller externalities, but the year-by-year differences are very small in absolute magnitude, corresponding to about 0.3% reduction in relative terms. Different sectors contribute to the total value of external costs, however. EM+ generates small benefits due to changes in the structure of domestic economic sectors, while changes in vehicle fleet and fuel use solely result in about 2.5 times larger benefits. Annual environmental benefits of EM+ are about 80 to 90 million euros after the year 2025. EM+ scenario also leads to changes in electricity market that would result in damage, rather than benefits, of value about 10 to 33 million euros. This environmental damage is however not sufficiently large to counterbalance the environmental benefits, and hence EM+ is environment-improving policy yielding overall total net benefits.

Keywords: external costs; ancillary benefits; ExternE; Impact Pathway Analysis; emission factors

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1 Introduction

The aim of the Work Package 9 is twofold. First, we develop an approach for quantification of external costs of policy scenario on electro-mobility. Doing that, we gather appropriate emission data and the damage factors for the benefit quantification and link the benefit assessment to the hybrid general equilibrium model. Second, we apply this approach to quantify the external costs due to EM+ policy scenario and compared these benefits with business as usual level.

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

Specifically, we consider the environmental and health effects attributable to direct emissions stemming from domestic economic production and derive the emission-output factors, indirect emissions attributable to all imported goods produced worldwide and derive the emission-import factors, direct emissions released by vehicles and derive the emission-fuel use factors, and direct external costs associated with electricity generation when the damage factors per kWh electricity generated in various technologies are utilized.

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

Summing all the external costs across domestic production in economic sectors, fuel use, and electricity production, we get total value of external costs that amount about 27 billion euros in the reference year and 33 billion euros in 2030. This value also includes impacts attributable to net imports embodied through indirect emissions Total value of externality corresponds to about 4% of total economic value of Austrian economy in 2008. EM+ scenario generates lower externalities but the year-by-year differences are overall very small in absolute magnitude, about 100 million euros smaller than in BAU in 2030, which is 0.3% less in relative terms. We get qualitatively similar results for the externalities attributable to direct emissions, but they correspond about 1.3% of total economic value of Austrian economy.

Different sectors contribute to the total outcome on externalities attributable to direct emissions differently. We find that EM+ will generate small benefits due to changes in the structure of domestic economic sectors, while changes in vehicle fleet and hence fuel use solely will result in about 2.5 times larger benefits than the change in overall economy structure. Annual environmental benefits of EM+ are about 80 to 90 million euros after 2025. However, EM+ scenario would also lead to changes in electricity market that would result on the contrary in damage of value about 10 to 33 million euros in the same period as the benefits would be generated. This environmental damage is however not sufficiently large to counterbalance the environmental benefits, yielding overall net benefits.

We note that our conclusion for Austria cannot be generally supported, since the overall result on the effect of electromobility on external costs will strongly depend on the technology mix to generate electricity. Positive finding for Austria is partly determined by environmentally-friendly technology mix to generate electricity, whereas more polluting electricity generating technology mix might switch environmental benefits of electromobility towards environmental damage.

The structure of this report is as follows. Chapter 2 describes our method and this chapter presents Deliverable 9.2 of DEFINE project. Chapter 3 applies this method to quantify the external costs of electromobility, specifically of EM+ scenario in Austria. This chapter presents actually Deliverable 9.1 of DEFINE.

2 The Method

2.1 The ExternE Impact Pathway Analysis

Environmental benefits due to electro-mobility are quantified using Impact Pathway Analysis (IPA) developed within the most recent ExternE projects (Externalities of Energy)[1]. The IPA is an analytical procedure examining the sequence of processes through which polluting emissions result into external damages. The method allows estimating the marginal physical impact and the marginal cost of pollution from any emission source, as a function the technology and of the location of the plant.

The IPA comprises four basic steps:

i. selection of the reference power plant, determination of the technology used and of harmful emissions released,
ii. calculation of changes in pollutant concentration for all affected regions using atmospheric dispersion models,
iii. estimation of physical impacts from exposure using concentration-response functions, and
iv. economic valuation of impacts using direct costs (effect on crop yield, damage on building materials or biodiversity) or compensating/equivalent surplus measured through the willingness-to-pay approach.

The ExternE's IPA method is very similar to an integrated assessment model used in the American studies to connect emissions to changes in concentrations, human exposures, physical effects and monetary damages by the Air Pollution Emission Experiments and Policy model (APEEP, see for instance, Muller and Mendelsohn 2007, 2009; Muller et al. 2011; Grossman et al. 2011).

The ExternE and IPA is widely accepted method for deriving benefits of new governmental proposals, programs or policies in Europe or in order to derive new sustainability indicators. For instance, Holland et al. (2011) performed cost-benefit analysis of Scenarios for Cost-Effective Emission Controls after 2020, Holland et al. (2014) conducted CBA on the EU's Thematic Strategy on Air Pollution (TSAP) and Pye et al (2008) analysed cost and benefits of Proposed Revisions to the National Emission Ceilings Directive. Each of them based their assessment of environmental impacts

[1] The European Commission in collaboration with the US Department of Energy launched a joint research projects to assess the energy-related externalities in 1991 (European Commission 1995; ORNL and RFF 1995). Following a detailed bottom-up methodology relying on impact pathway approach, the EU/US studies provided estimates of marginal external costs of electricity production from a wide range of energy technologies at various locations. The EC provided additional funding over the years to improve the ExternE accounting framework and to expand it to new EU member states and to other non-EU countries. The ExternE IPA framework that we use has been recently updated within the NEEDS project (http://www.needs-project.org/). For more information on ExternE see http://www.externe.info.

and benefit on the ExternE's IPA approach. Similarly, Maliszewska et al. (2010) or Ecorys & CASE (2012) used the ExternE to quantify environmental impacts of a Free Trade Agreement between the European Union and The Russian Federation or between the European Union and Georgia and Moldova, respectively.

The ExternE's IPA has been particularly widely used to assess the external costs of energy technologies (Sundqvist and Söderholm 2002; Sundqvist et al., 2004; Spadaro and Rabl 2007; Pietrapertosa et al. 2009), but more recently this method has been also applied to quantify benefits in other sectors (see, for instance, results of MethodEx or EXIOPOL EU funded projects). Maca et al. (2012) compare the external costs and current regulation in order to derive the rate of external cost internalisation in countries of Central and Eastern Europe. Weinzettell et al. (2012) quantify the production-based and consumption-based external costs of electricity production in Europe in order to provide better sustainable indicator of environmental impacts.

The results from the ExternE's IPA have been frequently used in a policy impact assessment by means of various macro models as well. Rafaj and Kypreos (2007) or Rečka and Ščasný (2013) analysed impacts of various policies on energy system by linear optimisation or partial equilibrium models. Using macro-econometric E3ME model, Barker and Rosendhal (2000) estimate the co-benefits from SO2, NOx and PM10 reduction as an effect of carbon tax for Western Europe, and Ščasný et al. (2009) estimate the impact of energy taxation and emission charges that reflect the external costs for the Czech Republic. Again utilizing the ExternE's results, as an example, Van Regemorter (2008) assess the macroeconomic impacts of NEC Scenarios with CGE GEM-E3 model, and Kiulia et al. (forthcoming) analyse economic impact and environmental benefits by CGE model applied on the Czech economy. Ščasný et al. (2015) then link integrated assessment model WITCH and the ExternE's IPA to quantify ancillary benefits of carbon mitigation policies in Europe, when the ancillary benefits are quantified by ExternE's IPA.

The IPA procedure has been incorporated into EcoSense tool – the integrated atmospheric dispersion and exposure assessment model –, which was developed mainly within the NEEDS EU funded project (Preiss and Klotz 2008). EcoSense tool uses air transport models to control changes in the atmospheric concentration of pollutants at each local, regional and global level. Specifically, it uses three models of air quality: (i) the Industrial Source Complex Model for transport of primary air pollutants on a local scale delaminated by 100 x 100 km around the power plant, (ii) the EMEP/MSC-West Eulerian dispersion model for modelling transport and chemical transformation of primary pollutants on a regional scale covering all Europe, and (iii) the N-Hemispheric Model which served for estimation of the intercontinental influence primary and secondary pollutants.

The model then determines a range of impacts on human health, buildings, biodiversity, and crop yields using concentration-response functions. The quantification of economic impact of micro-pollutants is based on generic estimates of marginal costs – i.e. the same damage value regardless which country releases the micro-pollutant – as estimated in the ExternE project series (especially NEEDS). The loss of ecosystems is assessed using a measure of Potential Disappeared Fraction of species (Frischnecht and Steiner 2006) linked to acidification and eutrophication. Concentration-response functions are utilized to estimate the economic loss from mortality and morbidity, from agricultural productivity losses and for damages to building materials. Valuation methods of welfare economics are used to translate the physical impacts into monetary impacts.

Impacts on human health, mainly on mortality, are the most important among all impacts. In order to establish a causal relationship between pollution and human morbidity and mortality, ExternE uses concentration-response functions calibrated using a large number of epidemiological and toxicological studies. At the beginning of the ExternE project the CRFs of all European countries were calibrated using studies for the United States. The European functions have been re-calibrated using epidemiological and toxicological studies for Europe. The economic loss due to increased mortality is estimated using the Value of Life Year (VOLY) (Desaigues' et al. 2011), reflecting recent changes in the ExternE methodology. Previously, ExternE used a uniform Value of Statistical Life (VSL) to value excess mortality. Several studies have argued that the VSL is appropriate to value the loss of – usually large – losses of life expectancy from fatal accidents but it should not be used to estimate the – usually smaller – impact of pollution on life expectancy, especially of elderlies (Rabl et al. 2014). Regardless which one of the two metrics is used, they should be both based on the willingness to pay for a small reduction in risk of dying (Hammitt 2007). In the ExternE's IPA, the VOLY for so called acute and chronic mortality is set at €60,000, or €40,000, respectively, and these values have been also recommended to be used in cost–benefit analyses of EU-level policies using the external costs.

Morbidity increases medical costs and causes a loss of productivity, but it also causes large disutility from pain, suffering and other inconveniences. We follow here the valuation of additional morbidity proposed in the NEEDS update of ExternE. Their values range from 1 € for each use of bronchodilator to 200,000 € per new case of chronic bronchitis.

Crop losses are valued at the international market prices. The impacts on building materials are assessed using replacement and maintenance costs, and the assessment of biodiversity impacts is based on restoration costs.

In our quantification, we use country-specific impact expressed in 2005 Euro per ton of emission of pollutant, as estimated in the project NEEDS. Table 1 describes the unit external costs per ton of emissions released from emission sources in Austria, based on damage factors derived within NEEDS project (Preiss and Klotz 2008). We include the most common air pollutants (SO2, NOx, PM2.5, PM10, NMVOC, NH3) in our assessment of damage.

Table 1. Average damage factors for air quality and GHG pollutants - Austria (Euro2005 per ton)

	SO_2	NOX	NH3	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

Note: PM_{coarse} indicates particulate matters with an aerodynamic diameter between 2.5 and 10 µm. Unit damage cost due to other non-CO2 green-house gasses is 420 € per t CH4 and 6,200 € per t of N_2O assuming 21 and 310 GWP factors.

An important part of the external costs are associated with climate change impacts. External costs due to climate change may be expressed considering two different conceptual approaches. First, the costs of carbon might be based on abatement costs of reaching certain policy target, i.e. the cost of action. An indication about the abatement costs can provide actual or forecast market permit price, or it can result from *ex ante* modelling (see, for instance, Carraro and Faveli 2009 for a review). However, this approach provides correct damage estimates only if policy target is also socially optimal, i.e. when the marginal abatement costs are equal to marginal external benefits.

Following to welfare economics, quantified impacts of climate change should be rather based on marginal damage costs of carbon, commonly referred to as the Social Costs of Carbon (SCC). These costs present a difference in net benefit streams over long time period estimated for a scenario with and without a release of a certain volume of carbon emission and expressed in present values using discounting. Both of these discounted streams of net benefits result from an integrated assessment model, such as FUND or DICE, which usually differ in a range of impacts covered, time span covered or climate sensitivity assumed (Tol 2009). Apart from the given model structure, there are at least two key parameters of integrated assessment models that can drive the differences in climate change damage estimation: it is the utility discount rate (i.e. pure rate of time preference) and equity weights which both have to be arbitrarily chosen by an analyst, (see e.g. OECD 2008, or Heal 2009 for more details).

Since Social Cost of Carbon estimations require using a mix of positive and normative approaches in modelling, there cannot be one generally agreed value of Social Cost of Carbon. For instance, a review of SSC estimates by Tol (2005) reports the mean of SSC at €26 per tonne of CO_2 and median equal to €4; if peer reviewed studies are considered only the mean goes at €14. Stern (2007) in his review suggests the Social Cost of Carbon would start around €20-24 if the target were between 450-

550 ppm CO2-eq., and the cost of inaction might have a value of €68 per ton of CO_2 (that is, if we follow business as usual trajectory).

To quantify damages associated with climate change impacts in our study, we consider the central value of ***20 € per ton of CO_2***, as it had been used in the impact assessments being based on ExternE so far.[2]

In climate change impact assessment, we particularly follow the recommendation of the large-scale integrated project NEEDS (Preiss and Kloz 2009) that reports the value of 19 € per ton of CO_2 as the central value of SCC. This recommendation is based on probabilistic estimate of SCC by the FUND model assuming 1 % pure rate of time preference, world average equity weighting and using 1 % trimmed mean of SCC estimates (Anthoff 2008). The resulting value of SCC equals to 20.3 € per ton of CO_2. The value of around 20 € is also close enough to the marginal abatement cost estimates; for instance, Carraro and Faveli (2009) analyse CO_2 price uncertainty in detail and suggest the mean value of €21 per tonne of CO2 avoided in 2009 or €31 per tonne of CO2 avoided in 2012. Capros and Mantzos (2000) report a range of SCC values between 5 and 38 € per tonne of CO2 avoided for reaching the Kyoto targets for the EU. International Center for Climate Change that regularly reviewed the economic models for long-term carbon price evaluation provides the average of carbon price at about €43 (s.d. €29) in 2020 for 450 ppm, or €23 (s.d. €20) for 550 ppm stabilisation target, respectively.

2.2 Linking the hybrid CGE model to the ExternE's IPA approach

By means of the hybrid computable general equilibrium model developed within DEFINE project, the effects on economy and electricity generation are quantified. The ExternE's IPA then allows deriving monetised benefits of the environmental impacts associated with air quality and GHG pollutants.
In order to quantify the environmental and health benefits associated with the effects of electro-mobility on economy and energy system, the two modelling approaches - the hybrid CGE model and the ExternE's IPA – needs to be linked. The two models are linked through emission factors linked to variables endogenously determined by the hybrid CGE model.

Specifically, we consider the environmental and health effects attributable to

(i) direct emissions stemming from domestic economic production and derive the emission-output factors,

[2] Within the ExternE project series (e.g. Externe-pol, 2004), the damage of climate change was based on the abatement costs to reach the Kyoto target by the EU-15 countries. Specifically, the central value of 19 € per tonne of CO_2 is based on the estimate by Fahl et al. (1999) which is the costs to meet a 25% emission reduction from 1990 to 2010 for Germany.

(ii) indirect emissions attributable to all imported goods produced worldwide and derive the emission-import factors,
(iii) direct emissions released by vehicles and derive the emission-fuel use factors, and
(iv) direct external costs associated with electricity generation when the damage factors per kWh electricity generated in various technologies are utilized.

Quantification of emissions for BAU and policy scenario for (i) and (ii) implicitly assumes that the emission factors remain constant across time. Resulting emission levels will capture the effect of changing scale of the economy, the effect of changing economic structure and the effect of factor (including energy) substitution. Keeping the emission factor per sector same, however, presumes a] no improvement in efficacy of the end-of-pipe abatement technologies, including introducing carbon capture and storage abatement options, and b] same structure of emission-generating technology in given sector over time.

In order to consider the effect of possible changes in technology, we quantify emissions attributable to car usage and electricity generation outside of the economic production module. While the emission factors of economic production and imports are based on CREEA multi-regional environmentally-extended input-output database that describes state of the economy in year 2007, the emission factors for the two key technologies are derived elsewhere.

Specifically, the emission factors per fuel use in passenger vehicles and freight transport are based on TREMOVE model from which we generate time variant emission factors (see below).

Utilizing CASES database on external costs per wide set of technologies, we derive the damage factors per each electricity generating technology that are included in the electricity model embodied in the hybrid CGE model.

To avoid double-counting, the effects captured under (iii) and (iv) category are subtracted from the effects that are captured in the (i) category. Next sub-chapters describe our approach in detail.

2.2.1 Direct emissions stemming from domestic economic production,

Damage factors per pollutant are linked to economic output endogenously determined by the hybrid CGE model through the emission-output coefficients. The emission factor for each economic sector in the CGE model is derived from Exiobase 2.2. database – as developed most recently within CREEA project - where 200 product categories and 163 industry sectors were merged into 22 sectors used in CGE model (see Table A1 in Appendix). Economic values in both CREEA database and SAM are recorded in basic prices, what makes our link consistent.

Exiobase database records emission for both economic production of each industry and final demand of households. After merging CREEA categories into 22 sectors, we derive an average emission factor per sector *i* (EF_i) considering the emissions attributable to both domestic economic production by sector *i* (Q_i) as well as the emissions attributable to household final demand on product *i* (FD_i) as follows:

$$EF_i = \frac{\left(P_i^q + P_i^h \cdot {FD_i^h}\Big/{\sum_i FD_i^h}\right)}{(Q_i + FD_i)}$$

where EF is emission factor P denotes pollutant and subscripts i, q and h describes sector as used in SAM and CGE model, economic production, and final use of households, respectively.[3] The term Q described sector economic output. We subtract taxes on trade (INTTAX) equal to 6,087 million € form output (these taxes are subtracted from output in proportion to sector output on total output).

Exiobase database records data for wide range of environmental pressures and impact categories. In our assessment, we account for emission for air quality pollutants (SOx, NOx, NH3, CO, NMVOC, PM10, PM2.5, and TSP) and GHGs (CO_2, CH_4, N_2O). These emissions are recorded for combustion and non-combustion processes separately.

2.2.2 Indirect emissions attributable to all imported goods produced worldwide

Emissions embodied in imports are calculated using MRIO data for total imported products and include total embodied emissions. Total imports are derived from information for individual countries since the MRIO imports are in exporter values (more important for the correct allocation of their footprints). Some imports are directly exported, therefore those are reported separately. Footprints are calculated using product-by-product MRIO model under industry technology assumption (similarly as Weinzettel et al. 2012; 2014). The 200 product categories listed in Exiobase are then merged into 22 sectors used in the CGE model. Same emissions as accounted in the assessment of direct emissions are also accounted to derive the factors for indirect emissions, i.e. embodied in imports.

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.

[3] We implicitly assume same share of final demand of household on total economic production. Incorporating simplified assumption on foreign trade in the hybrid CGE model (i.e. Armington trade elasticities equal to zero) allows us to relying on the average emission factor.

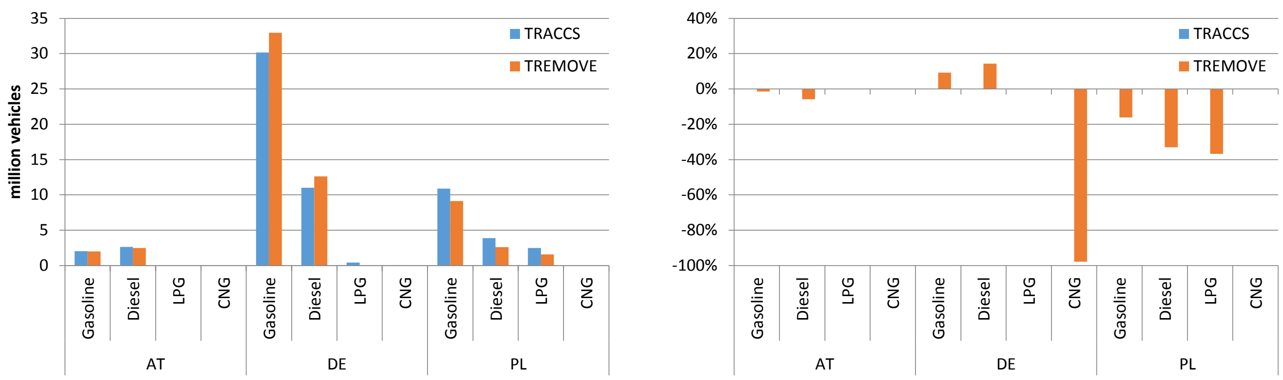
2.2.3 Emissions factors from passenger car and freight fleet

This section details how fleet-wide emission factors for passenger car fleet for Austria, Germany and Poland were derived. In order to keep a common methodology the transport emission model TREMOVE[4] were used as a point of departure mainly because it contains all the relevant data for this task for all the three countries.[5] The base-case scenario was taken as a baseline for deriving emission factors in business-as-usual situation. The emission coefficients are expressed in grams per MJ based on weighting of fuel type and region (but no distinction is made with respect to vehicle ownership).

In order to check the accuracy of TREMOVE estimates we checked the predictions for 2010 with data in TRACCS database.[6] Comparison of TRACCS statistical data and TREMOVE prediction (base-case run) of vehicle stock and fuel consumption shows relatively significant differences in all three countries.

The most profound differences in per-cent terms are an underestimation of CNG cars and fuel use in Germany, and LPG cars and fuel use in Poland. In terms of absolute numbers and volumes, the most profound differences are overestimated car stock and diesel and gasoline consumption in Germany, substantial underestimation of gasoline and to lesser extent also diesel consumption in Austria and underestimation of both car stock and fuel consumption in Poland.

Figure 1 – Absolute and relative differences in predicted and real vehicle stock (2010)



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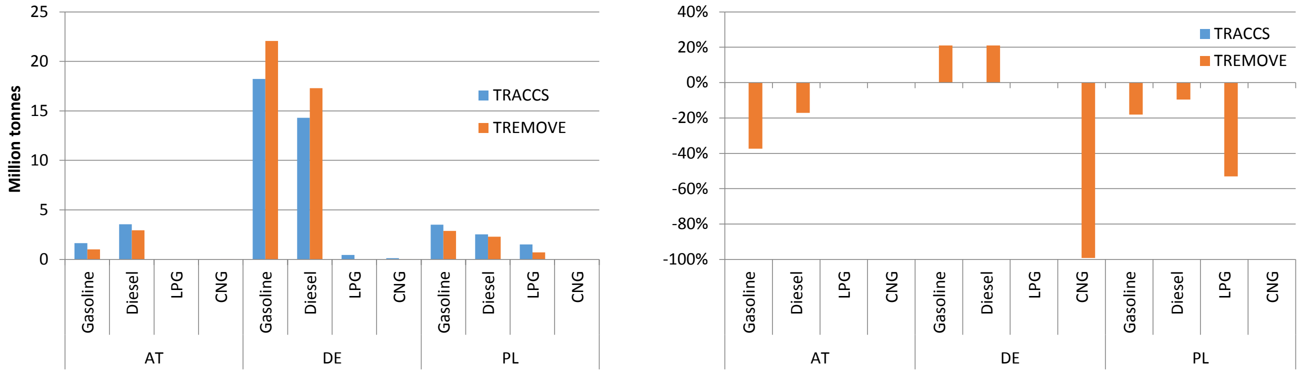
[4] The latest public version is 3.3.2 dated July 2011. See http://www.tmleuven.be/methode/tremove/home.htm for model's code and details. Updated TREMOVE model v 2.7 was *inter alia* used in a World Bank study *Transition to a low-emissions economy in Poland*.

[5] German transport emission model TREMOD would be an alternative for Germany, but it is neither publicly available nor provides data for other two countries.

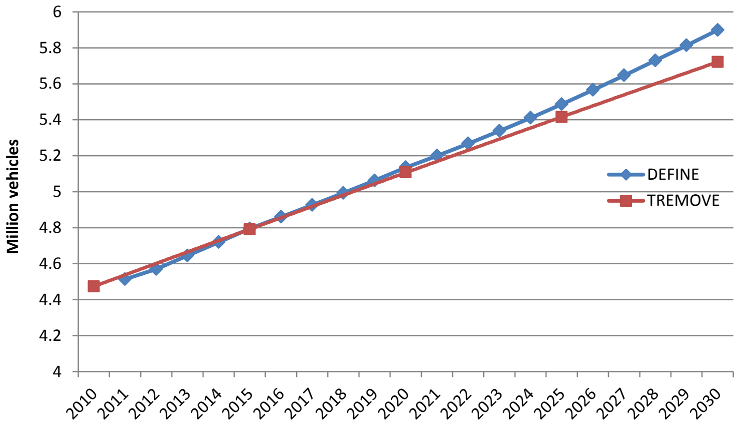
[6] An outcome of DG CLIMA project on collection of transport data to support the quantitative analysis of measures relating to transport and climate change; see http://traccs.emisia.com/

Figure 2 – Absolute and relative differences in fuel consumption (2010)



Next we compared the predicted passenger vehicle stock from TREMOVE model with predictions in BAU scenario in DEFINE project. For Austria these predictions are very close – the difference in 2030 is mere 3% as can be seen in the following figure.

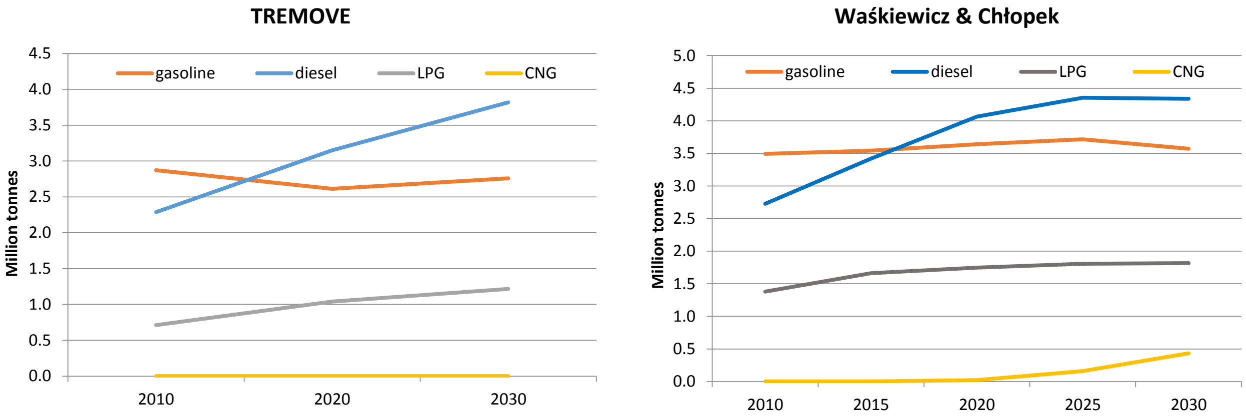
Figure 3 – Comparison of predicted passenger car stock in Austria



Since no prediction was made for Poland in DEFINE yet, we turn our attention to official Polish prognosis developed as part of national Transport development strategy (Strategia rozwoju transport). The original prognosis by prof. J. Burnewicz (Burnewicz, 2012) was further elaborated by Waśkiewicz and Chłopek in their projections of demand for passenger cars and related energy consumption by 2030 (Waśkiewicz & Chłopek, 2013).

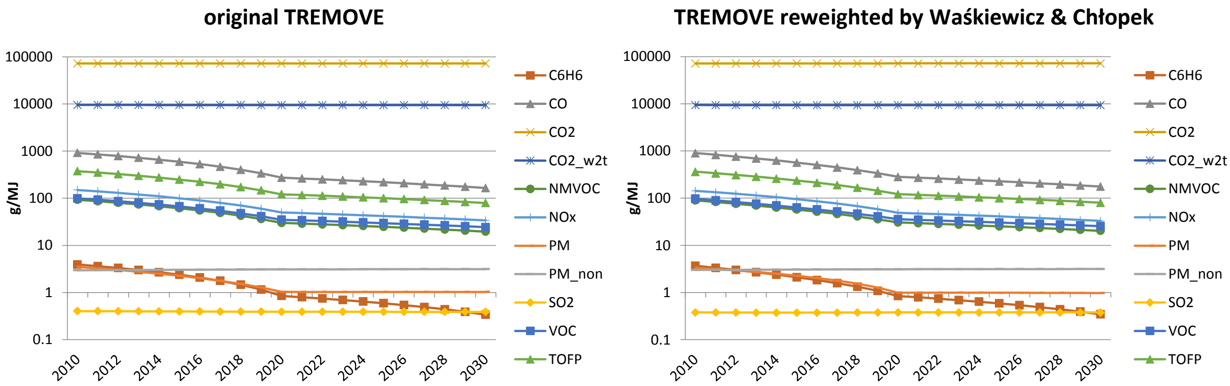
The comparison of energy consumption from both predictions is show in the following figure. Apparently, the two predictions differ in several aspects but more in respective fuel consumption trajectories than the final share in 2030; the main difference is in the overall consumption (lower in TREMOVE prediction) and in CNG consumption – close to zero over the entire 2010-2030 compared to steep rise after 2020 in Waśkiewicz & Chłopek prediction.

Figure 4 – Comparison of predicted energy consumption



In order to assess the magnitude of effects of different vehicle stock and energy consumption developments on averaged passenger vehicle emission factors we recalculated emission factors derived from TREMOVE base-case run to prediction of Waśkiewicz & Chłopek by reweighting the shares of respective fuels. This effectively accounts for change in vehicle stock but does not account for (possible) relative changes in vehicle emission profiles by these fuels.[7] The differences are however only marginal, not exceeding 7% in any of the pollutants. The following figure shows this comparison graphically.

Figure 5 – Comparison of averaged emission factors



Note: The y axes have logarithmic scales.

The resulting emission factors are displayed in tables A2 and A3 in Appendix. These factors are expressed per physical unit of fuel consumption. In order to link them to fuel use that is determined by the hybrid CGE model, we recalculate them in monetary units by using average pre-tax price of diesel and petrol taken from IEA/OECD statistics on Prices and Taxes for the year 2008. We assume

[7] In principle, TREMOVE model allows for adjustments that would effectively backcast a development similar to that predicted by Waśkiewicz & Chłopek. This would however necessitate effort beyond the scope of this project.

33.60 MJ/l (density of diesel 0.84 kg/l and of petrol 0.75 kg/l), and 25% share of diesel on propellant use in passenger cars, 100% share used in freight.

The emission factors for GHGs (CO_2, CO_2 w2t, CH_4, N_2O) and air quality pollutants (SO_2, NOx, NH3, NMVOC, PM2.5 and PMcoarse) as expressed in tones of emission per EUR of pre-tax expenditures on fuel are multiplied by fuel use in passenger cars and other vehicles (freight). Fuel use is endogenously determined for each scenario and over the period until 2030 by the hybrid CGE model and it is expressed in basic, pre-tax, prices.

External costs associated with fuel use in vehicles can be quantified by utilising two different approaches.

At first, the emission factors as derived from the Exiobase CREEA database for direct emissions can be linked to FUEL output as determined from the hybrid CGE model. For example, FUEL use in Austria in the base 2008 year is 4,610 million € (after adjustment by taxes on trade, INTTAX). Multiplying this output by the factor on direct emissions from combustion, we get the external costs of 125 million € for the base year 2008.

Second approach may utilize the emission factors as we derive them from TREMOVE database. Resulting external costs for using fuels in passenger cars and freight transport are 1,636 million € (excluding indirect impacts due to CO_2 w2t), that is a value one order of magnitude larger than the value we get in the former approach.

To validate the approach we follow in our study, we examine the emission factors for FUEL use from both Exiobase database and TREMOVE data. We report here our comparison of the factors for CO2 emission that is easy to relate to realistic value. Following stoichiometry (and when no carbon capture and storage technology in transport sector is used) we expect the emission factor of about 3.6 kg of CO2 per kg of fuel, considering the average pre-tax price of fuel in Austria in 2008 of 0.572 € per litre or 0.741 € per kg of fuel, we get the factor of 4.9 kg CO2 per € (pre-tax price). Deriving the emission factors by the former approach (based on Exiobase data) we got 0.36 kg per € that is one order of magnitude smaller factor that one would expect. On the other hand, we get the factor of 4.3 kg per € spent on fuel used in passenger cars or 5.0 kg per € spent on fuel used in freight transport if we rely on our factors derived from TREMOVE data. We therefore follow the latter approach (based on TREMOVE database) to quantify the externalities for car use. To avoid double-counting, we subtract the emissions and hence externalities attributable to FUEL use that were quantified by using economic output and the emission factors based on Exiobase data.

2.2.4 Direct emissions associated with electricity generation

Similarly, as in the case of deriving the external costs associated with fuel use in vehicles, there are two approaches at hand to derive the external costs associated with electricity generation.

First approach is based on the emission factors as derived from Exiobase database that are linked to electricity production determined from the CGE model. For instance, electricity production in Austria in the base year 2008 is 4,990 million € (after adjustment by taxes on trade, INTTAX). Multiplying this output by the emission factor derived from Exiobase, we get total externalities attributable to direct emissions of 452 million € (BAU 2008).

Second approach utilizes CASES database on the external costs of electricity generating technologies. External costs per kWh of electricity generated in Austria for the period of 2005-2010 are described in Table 2, more detailed information is provided in Table A4 in Appendix. Externalities of hydro power run on river are weighted by externalities as derived in CASES for three different capacities, taking their share for the year 2008. Utilizing this damage factors, we get total external costs attributable to electricity generation in Austria in the base year of the baseline scenario at 502 million €. The result from both of these approaches yield close estimates one to the other. In order to account for differences in technology and fuel mix in power sector over time under the policy scenario, we follow the latter approach based on CASES database, whereas the amount of externalities associated to electricity production as derived by the former approach are subtracted from aggregated values to avoid double-counting.

Table 2. External costs of electricity generation due to operation and fuel use in Austria, €c/kWh.

Technology	electric model (hybrid CGE)	2005-2010			
		Envi	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**	0.1530	1.8103	0.5879	**2.5511**
wind	**wind**	0.0030	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	**0.2400**
natural gas, gas turbine	**gas_natural**	0.1079	0.6303	1.3416	**2.0798**

Note: Externalities associated with up-stream impacts (construction) are not considered.
Source: CASES project

To quantify external costs associated with electricity generation we derive electricity production in kWh from electricity production in basic EUR price from the CGE model. Electricity production per each technology expressed in physical units (kWh) is derived as a ratio of electricity production in expressed in EUR (basic prices) and implicit price of kWh generated by given technology. The implicit price is computed from electricity production expressed in EUR in SAM and TWh generated per technology in Austria in 2008, and as a result, it is expressed in EUR basic prices.

3 Results – Quantification of external costs of EM+ for Austria

3.1 External costs attributable to fuel use in vehicles

Fuel use for BAU and EM+ for Austria is displayed in Table 3. Over the period 2008-2030, fuel use is increased by 19% in the baseline scenario, mainly in other transportation than in passenger cars. EM+ results in lower use of fuels in cars, but overall consumption increases over time.

Table 3. Fuel use in million EUR, 2008-2030, Austria

	FUEL-BAU total	FUEL-EM+ total	FUEL-passeng BAU	FUEL-passeng EM+	FUEL-freight BAU	FUEL-freight EM+	d% passeng	d% freight
2008	4 610	4 608	2 794	2 794	1 816	1 814	0.01%	-0.14%
2009	4 658	4 647	2 822	2 813	1 836	1 834	-0.30%	-0.11%
2010	4 705	4 686	2 850	2 833	1 855	1 853	-0.59%	-0.09%
2011	4 650	4 625	2 825	2 800	1 825	1 824	-0.86%	-0.07%
2012	4 698	4 666	2 855	2 823	1 844	1 843	-1.10%	-0.05%
2013	4 747	4 708	2 885	2 846	1 862	1 862	-1.34%	-0.03%
2014	4 795	4 747	2 914	2 867	1 881	1 881	-1.64%	0.00%
2015	4 844	4 675	2 944	2 826	1 899	1 849	-4.01%	-2.64%
2016	4 891	4 711	2 973	2 843	1 918	1 868	-4.38%	-2.61%
2017	4 939	4 747	3 001	2 859	1 938	1 888	-4.72%	-2.57%
2018	4 985	4 783	3 027	2 874	1 958	1 909	-5.04%	-2.50%
2019	5 030	4 710	3 051	2 827	1 979	1 883	-7.32%	-4.86%
2020	5 071	4 743	3 070	2 838	2 001	1 906	-7.58%	-4.77%
2021	5 112	4 774	3 087	2 844	2 024	1 930	-7.90%	-4.66%
2022	5 151	4 804	3 103	2 849	2 048	1 955	-8.19%	-4.55%
2023	5 191	4 835	3 118	2 855	2 072	1 981	-8.44%	-4.43%
2024	5 230	4 869	3 132	2 862	2 098	2 007	-8.62%	-4.33%
2025	5 271	4 906	3 147	2 872	2 124	2 034	-8.73%	-4.23%
2026	5 313	4 947	3 163	2 886	2 150	2 061	-8.76%	-4.15%
2027	5 357	4 990	3 180	2 902	2 177	2 088	-8.72%	-4.09%
2028	5 402	5 037	3 198	2 922	2 204	2 115	-8.63%	-4.04%
2029	5 449	5 086	3 217	2 943	2 232	2 143	-8.52%	-4.00%
2030	5 493	5 129	3 232	2 958	2 261	2 171	-8.49%	-3.94%
d(2030-2008)	19%	11%	16%	6%	24%	20%		

Source: Hybrid CGE model (Miess and Schmelzer 2015)

External costs attributable to emissions released from fuel use in cars are estimated at about 1,636 million euros in 2008. Despite the fact that fuel use is increasing over time (by +16% in passenger cars, or +24% in freight transport, respectively), total damage in the baseline scenario is declining over time as a result of increasing share of AFVs and declining emission intensities (see the emission factors in table A2 in Appendix) and it reaches a value of 1,233 million euros in 2030 (by -25%). EM+ slows down the increase in fuel use (by +6% and +20% only) and simultaneously enhances more the uptake of AFVs. As a consequence, total external costs of EM+ declines at 1,168 million euros in 2030, that is 29% less than in the reference 2008 year.

Table 4. External costs attributable to fuel use in vehicles, 2008-2030, Austria.

	BAU			**EM+**		
	passenger	**freight**	**FUEL total**	**passenger**	**freight**	**FUEL total**
2008	629	1 008	**1 636**	629	1 006	**1 635**
2009	635	1 018	**1 653**	633	1 017	**1 650**
2010	641	1 047	**1 688**	638	1 046	**1 683**
2011	611	950	**1 561**	606	950	**1 555**
2012	594	888	**1 481**	587	887	**1 475**
2013	577	833	**1 410**	570	833	**1 402**
2014	548	786	**1 334**	539	786	**1 326**
2015	521	749	**1 270**	500	730	**1 229**
2016	495	723	**1 218**	474	704	**1 178**
2017	473	707	**1 180**	450	689	**1 139**
2018	453	701	**1 154**	430	684	**1 113**
2019	436	703	**1 138**	404	668	**1 072**
2020	422	710	**1 131**	390	676	**1 065**
2021	410	720	**1 130**	378	686	**1 064**
2022	401	732	**1 134**	369	699	**1 067**
2023	394	746	**1 140**	361	713	**1 074**
2024	388	760	**1 148**	355	727	**1 082**
2025	384	775	**1 158**	350	742	**1 092**
2026	380	790	**1 170**	347	757	**1 104**
2027	378	806	**1 184**	345	773	**1 118**
2028	378	822	**1 199**	345	788	**1 133**
2029	378	838	**1 216**	346	804	**1 150**
2030	379	855	**1 233**	347	821	**1 168**

At the end of the period, EM+ results in the external costs attributable to passenger cars that are almost 9% smaller than in the business-as-usual case. Externalities attributable to remaining fuel use are by almost 6% smaller in the EM+ than in the BAU (see Table A3). In absolute terms, external costs are reduced by about 40 million euros in the second 2020's decade and by 65 million euros smaller in next decade (see Table 5).

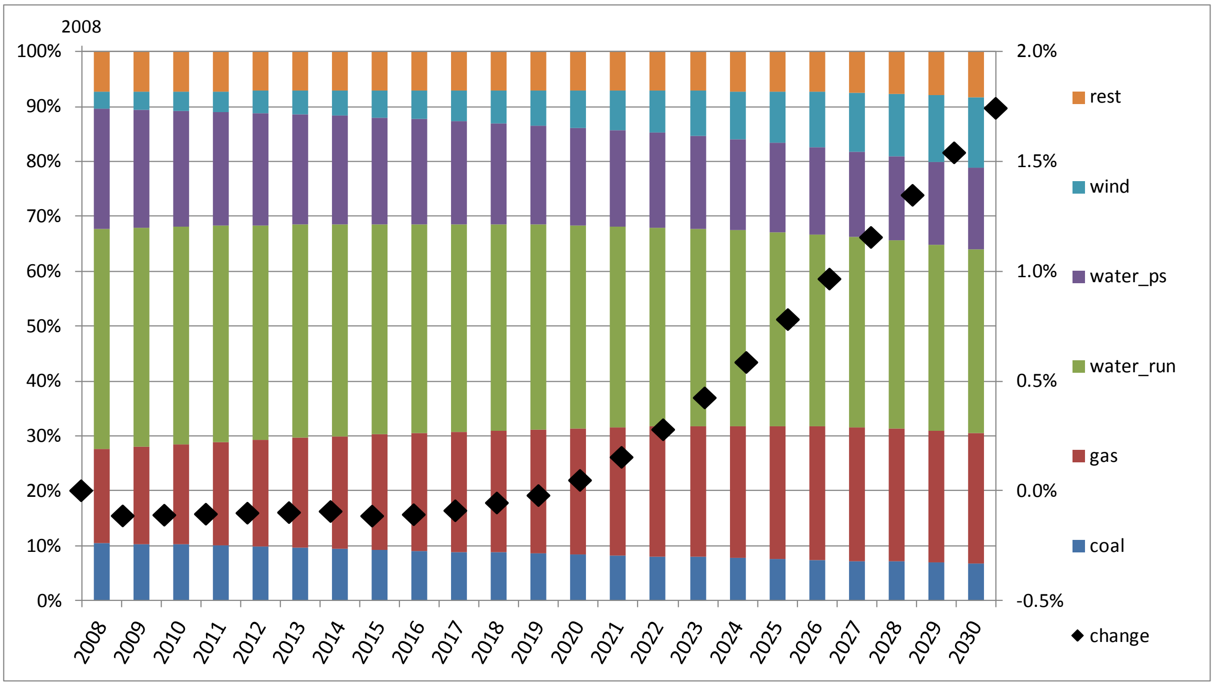
Table 5. Effect of EM+ on the external costs, 2008-2030, Austria.

	EM+ - BAU (m€)			**in % (EM+/BAU)**		
	passenger	**freight**	**FUEL total**	**passenger**	**freight**	**FUEL total**
2008	0.1	-1.4	**-1.3**	0.01%	-0.14%	**-0.08%**
2009	-1.9	-1.2	**-3.1**	-0.30%	-0.11%	**-0.19%**
2010	-3.8	-1.0	**-4.8**	-0.59%	-0.09%	**-0.28%**
2011	-5.2	-0.7	**-5.9**	-0.86%	-0.07%	**-0.38%**
2012	-6.5	-0.5	**-7.0**	-1.10%	-0.05%	**-0.47%**
2013	-7.7	-0.2	**-8.0**	-1.34%	-0.03%	**-0.56%**
2014	-9.0	0.0	**-9.0**	-1.64%	0.00%	**-0.67%**
2015	-20.9	-19.7	**-40.6**	-4.01%	-2.64%	**-3.20%**
2016	-21.7	-18.9	**-40.6**	-4.38%	-2.61%	**-3.33%**
2017	-22.3	-18.2	**-40.5**	-4.72%	-2.57%	**-3.43%**
2018	-22.8	-17.5	**-40.4**	-5.04%	-2.50%	**-3.50%**
2019	-31.9	-34.1	**-66.0**	-7.32%	-4.86%	**-5.80%**
2020	-31.9	-33.9	**-65.8**	-7.58%	-4.77%	**-5.82%**
2021	-32.4	-33.5	**-65.9**	-7.90%	-4.66%	**-5.83%**
2022	-32.9	-33.3	**-66.2**	-8.19%	-4.55%	**-5.84%**
2023	-33.3	-33.1	**-66.3**	-8.44%	-4.43%	**-5.82%**
2024	-33.5	-32.9	**-66.4**	-8.62%	-4.33%	**-5.78%**
2025	-33.5	-32.8	**-66.3**	-8.73%	-4.23%	**-5.72%**
2026	-33.3	-32.8	**-66.1**	-8.76%	-4.15%	**-5.65%**
2027	-33.0	-32.9	**-65.9**	-8.72%	-4.09%	**-5.57%**
2028	-32.6	-33.2	**-65.7**	-8.63%	-4.04%	**-5.48%**
2029	-32.2	-33.5	**-65.7**	-8.52%	-4.00%	**-5.40%**
2030	-32.1	-33.7	**-65.8**	-8.49%	-3.94%	**-5.34%**

3.2 External costs attributable to electricity production

During 2008-2030, production has increased by 27%, thus EM+ will demand more electricity than BAU since 2020, and it will be higher by about 1.74% in 2030 than in BAU. Share of coal and hydro is decreasing, whereas demand for natural gas, wind and PV is increasing in both BAU and EM+. EM+ involves slightly more usage of natural gas in electricity generation.

Figure 6. Electricity generation and technology shares under EM+ scenario, Austria.



Source: CGE model results (Miess and Schmeltzer 2015).

External costs in the reference year amount 502 million euros; climate change impacts contribute the largest share, about 56% (283 million euros). Health impacts are as high as 191 million euros (about 40%) and impacts on biodiversity, crop yield and materials amount 27 million euros (5%). Higher generation of electricity also involves larger externalities. Damage in 2030 is 689 million euros in BAU and 722 million euros in EM+ (see Table 6). EM+ leads to the external costs that are more than 30 million euros larger in 2030 than in BAU; in relative terms damage is almost 5% larger (see Table 7). Higher externality attributable to electricity generation in EM+ is a result of slightly larger electricity production, higher share of natural gas and smaller shares of water run in river and wind. The effect on technology mix in EM+ is however very small.

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Table 6. External costs attributable to electricity generation, 2008-2030, Austria.

	External costs, m€ - BAU				External costs, m€ - EM+			
	Envi BAU	**Health BAU**	**Climate change BAU**	**TOTAL BAU**	**Envi EM+**	**Health EM+**	**Climate change EM+**	**TOTAL EM+**
2008	27	191	283	**502**	27	191	283	**502**
2009	28	194	290	**511**	28	193	289	**510**
2010	45	314	503	**863**	45	314	503	**863**
2011	56	461	494	**1 012**	56	461	494	**1 012**
2012	26	195	181	**402**	26	195	181	**402**
2013	57	505	487	**1 048**	57	504	486	**1 046**
2014	26	170	207	**403**	26	170	207	**403**
2015	70	710	473	**1 253**	70	709	472	**1 251**
2016	49	304	406	**759**	49	303	406	**758**
2017	69	555	694	**1 318**	69	555	693	**1 317**
2018	50	345	512	**907**	50	344	512	**906**
2019	33	220	348	**601**	33	220	348	**601**
2020	39	287	338	**663**	39	287	338	**664**
2021	39	289	342	**670**	39	290	343	**673**
2022	39	292	346	**677**	40	293	349	**682**
2023	40	294	349	**683**	40	297	353	**690**
2024	40	296	352	**688**	41	300	358	**698**
2025	40	297	354	**692**	41	303	362	**706**
2026	40	299	355	**694**	41	305	366	**712**
2027	40	299	356	**696**	42	307	368	**717**
2028	40	299	356	**695**	42	308	370	**720**
2029	40	299	354	**693**	42	309	371	**722**
2030	40	297	351	**689**	42	309	370	**722**

Table 7. Effect of EM+ on the external costs attributable to electricity generation, 2008-2030, Austria.

	External costs, m€ (EM+ - BAU)				External costs, in % EM+/BAU			
	Envi BAU	Health BAU	Climate change BAU	TOTAL BAU	Envi BAU	Health BAU	Climate change BAU	TOTAL BAU
2008	0.00	0.00	0.00	**-0.01**	0.00%	0.00%	0.00%	**0.00%**
2009	-0.08	-0.49	-1.02	**-1.59**	-0.30%	-0.25%	-0.35%	**-0.31%**
2010	-0.01	-0.15	-0.09	**-0.25**	-0.03%	-0.05%	-0.02%	**-0.03%**
2011	0.00	-0.05	-0.02	**-0.07**	-0.01%	-0.01%	0.00%	**-0.01%**
2012	-0.01	-0.09	-0.13	**-0.23**	-0.05%	-0.05%	-0.07%	**-0.06%**
2013	-0.10	-1.09	-0.57	**-1.77**	-0.18%	-0.22%	-0.12%	**-0.17%**
2014	-0.04	-0.27	-0.17	**-0.49**	-0.16%	-0.16%	-0.08%	**-0.12%**
2015	-0.09	-0.69	-1.01	**-1.79**	-0.13%	-0.10%	-0.21%	**-0.14%**
2016	-0.04	-0.25	-0.55	**-0.84**	-0.09%	-0.08%	-0.13%	**-0.11%**
2017	-0.03	-0.33	-0.12	**-0.48**	-0.04%	-0.06%	-0.02%	**-0.04%**
2018	-0.03	-0.28	-0.15	**-0.46**	-0.07%	-0.08%	-0.03%	**-0.05%**
2019	-0.02	-0.23	-0.16	**-0.42**	-0.07%	-0.10%	-0.05%	**-0.07%**
2020	0.04	0.16	0.54	**0.73**	0.09%	0.05%	0.16%	**0.11%**
2021	0.14	0.82	1.58	**2.54**	0.35%	0.28%	0.46%	**0.38%**
2022	0.26	1.63	2.86	**4.75**	0.65%	0.56%	0.83%	**0.70%**
2023	0.40	2.59	4.35	**7.35**	1.01%	0.88%	1.25%	**1.08%**
2024	0.57	3.68	6.05	**10.29**	1.41%	1.24%	1.72%	**1.50%**
2025	0.77	5.02	8.13	**13.91**	1.90%	1.69%	2.30%	**2.01%**
2026	0.96	6.31	10.15	**17.42**	2.38%	2.11%	2.85%	**2.51%**
2027	1.16	7.67	12.26	**21.10**	2.88%	2.56%	3.44%	**3.03%**
2028	1.38	9.08	14.44	**24.90**	3.40%	3.03%	4.06%	**3.58%**
2029	1.59	10.53	16.70	**28.82**	3.95%	3.52%	4.71%	**4.16%**
2030	1.82	12.07	19.09	**32.99**	4.55%	4.06%	5.44%	**4.79%**

3.3 External costs attributable to production of economic sectors and imports

Total externalities attributable to all economic sectors in Austria, excluding the externalities attributable to FUEL and ELE sectors, amount about 25 billion euros in the reference year. Major part of this damage is due to indirect emissions, i.e. the emissions released outside in Austria embedded in net imports of goods and services. Externality associated with indirect emissions released from combustion amount 14.3 billion euros, while externality due to indirect emissions from non-combustion processes amount about 2.3 billion euros (see Table 8). About one third of the total value of these externalities is attributable to direct emissions, i.e. those emissions that are released by sources in Austria. Direct emissions stemming from combustion contributes by 6.8 billion euros of externalities (27%) and non-combustion processes deliver another 1.9 billion euros (8%).

Externalities attributable to domestic economic production and imports are increasing over time, reaching in total about 31.43 billion euros in 2030 in BAU and more-less same amount in EM+, 31.36 billion euros. As shown in table X7, EM+ generates about 68 million euros of externalities in 2030 less than BAU scenario does. This difference is however very small in relative terms, about 0.2% in 2030 (see Table 9). Overall, EM+ will not result in significantly larger externalities attributable to domestic economic production, excluding fuel use and electricity generation which impacts are quantified separately.

Table 8. Externality attributable to economic production in sectors, direct and indirect emissions, 2008-2030, Austria, in million EUR

	BAU					**EM+**				
	direct comb	direct noncomb	indirect comb	indirect noncomb	**Grand Total**	direct comb	direct noncomb	indirect comb	indirect noncomb	**Grand Total**
2008	6 764	1 900	14 311	2 322	**25 297**	6 762	1 899	14 304	2 320	**25 285**
2009	6 834	1 920	14 458	2 346	**25 558**	6 831	1 919	14 451	2 345	**25 546**
2010	6 903	1 940	14 606	2 370	**25 820**	6 901	1 939	14 600	2 369	**25 809**
2011	6 967	1 957	14 735	2 390	**26 049**	6 966	1 956	14 731	2 389	**26 041**
2012	7 037	1 977	14 882	2 414	**26 309**	7 035	1 976	14 879	2 413	**26 303**
2013	7 106	1 997	15 029	2 439	**26 571**	7 106	1 996	15 028	2 438	**26 568**
2014	7 176	2 017	15 178	2 463	**26 834**	7 176	2 016	15 179	2 463	**26 835**
2015	7 246	2 037	15 328	2 488	**27 098**	7 240	2 034	15 310	2 482	**27 066**
2016	7 317	2 057	15 480	2 513	**27 368**	7 311	2 054	15 464	2 508	**27 337**
2017	7 389	2 078	15 634	2 538	**27 640**	7 383	2 075	15 621	2 533	**27 613**
2018	7 462	2 099	15 791	2 564	**27 917**	7 457	2 097	15 782	2 560	**27 895**
2019	7 536	2 121	15 951	2 590	**28 198**	7 524	2 116	15 926	2 581	**28 147**
2020	7 611	2 142	16 113	2 617	**28 482**	7 599	2 137	16 090	2 608	**28 434**
2021	7 686	2 164	16 274	2 643	**28 767**	7 674	2 159	16 254	2 634	**28 721**
2022	7 762	2 186	16 438	2 669	**29 056**	7 749	2 181	16 419	2 661	**29 011**
2023	7 839	2 208	16 603	2 696	**29 346**	7 826	2 204	16 585	2 688	**29 302**
2024	7 916	2 230	16 769	2 723	**29 638**	7 903	2 226	16 752	2 715	**29 595**
2025	7 994	2 253	16 936	2 750	**29 933**	7 982	2 248	16 921	2 742	**29 893**
2026	8 073	2 275	17 104	2 777	**30 229**	8 059	2 270	17 087	2 769	**30 186**
2027	8 152	2 298	17 273	2 805	**30 526**	8 136	2 293	17 254	2 796	**30 479**
2028	8 231	2 320	17 442	2 832	**30 825**	8 214	2 315	17 420	2 823	**30 771**
2029	8 311	2 343	17 613	2 860	**31 127**	8 291	2 337	17 586	2 850	**31 063**
2030	8 391	2 366	17 786	2 887	**31 431**	8 367	2 360	17 758	2 877	**31 363**

Table 9. External costs associated with direct and indirect emissions released by economic sectors, 2008-2030, Austria

	difference bw EM+ and BAU, in million EUR					Percentage change in EM+ (wrt BAU)				
	direct comb	direct noncomb	indirect comb	indirect noncomb	**Total**	direct comb	direct noncomb	indirect comb	indirect noncomb	**Total**
2008	-2.8	-1.0	-7.0	-1.3	**-12.1**	-0.04%	-0.05%	-0.05%	-0.06%	**-0.05%**
2009	-2.8	-1.0	-6.9	-1.3	**-12.0**	-0.04%	-0.05%	-0.05%	-0.06%	**-0.05%**
2010	-2.4	-0.9	-5.7	-1.2	**-10.2**	-0.04%	-0.05%	-0.04%	-0.05%	**-0.04%**
2011	-1.9	-0.8	-4.2	-1.0	**-7.8**	-0.03%	-0.04%	-0.03%	-0.04%	**-0.03%**
2012	-1.3	-0.6	-3.0	-0.9	**-5.8**	-0.02%	-0.03%	-0.02%	-0.04%	**-0.02%**
2013	-0.6	-0.5	-1.4	-0.7	**-3.1**	-0.01%	-0.02%	-0.01%	-0.03%	**-0.01%**
2014	0.4	-0.2	1.0	-0.4	**0.8**	0.01%	-0.01%	0.01%	-0.01%	**0.00%**
2015	-5.9	-3.4	-17.8	-5.5	**-32.6**	-0.08%	-0.17%	-0.12%	-0.22%	**-0.12%**
2016	-6.4	-3.2	-16.1	-5.3	**-31.1**	-0.09%	-0.16%	-0.10%	-0.21%	**-0.11%**
2017	-6.3	-3.0	-13.5	-5.0	**-27.8**	-0.09%	-0.14%	-0.09%	-0.20%	**-0.10%**
2018	-5.6	-2.6	-9.4	-4.4	**-21.9**	-0.08%	-0.12%	-0.06%	-0.17%	**-0.08%**
2019	-11.6	-5.4	-25.1	-9.1	**-51.2**	-0.15%	-0.25%	-0.16%	-0.35%	**-0.18%**
2020	-12.0	-5.0	-22.4	-8.7	**-48.2**	-0.16%	-0.23%	-0.14%	-0.33%	**-0.17%**
2021	-12.4	-4.8	-20.6	-8.5	**-46.3**	-0.16%	-0.22%	-0.13%	-0.32%	**-0.16%**
2022	-12.7	-4.7	-19.1	-8.3	**-44.8**	-0.16%	-0.22%	-0.12%	-0.31%	**-0.15%**
2023	-12.9	-4.6	-17.9	-8.2	**-43.6**	-0.16%	-0.21%	-0.11%	-0.30%	**-0.15%**
2024	-13.2	-4.6	-17.1	-8.1	**-43.0**	-0.17%	-0.21%	-0.10%	-0.30%	**-0.14%**
2025	-12.6	-4.4	-15.1	-7.8	**-39.9**	-0.16%	-0.20%	-0.09%	-0.28%	**-0.13%**
2026	-13.7	-4.6	-16.3	-8.0	**-42.6**	-0.17%	-0.20%	-0.10%	-0.29%	**-0.14%**
2027	-15.3	-4.9	-18.7	-8.4	**-47.3**	-0.19%	-0.21%	-0.11%	-0.30%	**-0.15%**
2028	-17.5	-5.4	-22.6	-8.9	**-54.4**	-0.21%	-0.23%	-0.13%	-0.32%	**-0.18%**
2029	-20.5	-5.9	-27.7	-9.7	**-63.8**	-0.25%	-0.25%	-0.16%	-0.34%	**-0.21%**
2030	-24.0	-5.8	-28.2	-9.8	**-67.8**	-0.29%	-0.25%	-0.16%	-0.34%	**-0.22%**

3.4 Total external costs due to EM+

Summing the external costs across all three categories (domestic production in sectors, fuel use, electricity production), we get total value of external costs that amount about 27.4 billion euros in the reference year and 33.4 billion euros in 2030 (Table 10). Total value of externality corresponds to about 4% of total economic value of Austrian economy in 2008.

EM+ generates lower externalities but year-by-year differences are overall very small in absolute magnitude, about 100 million euros than in BAU in 2030, which is 0.3% less in relative terms (Table 11).

We get qualitatively similar results for the externalities attributable to direct emissions. EM+ results in about 0.55% lower externalities from direct emissions in 2030, that is in absolute terms about 57 million euros lower value than in BAU in 2030 (Table 12). In 2008, direct emission externality comprises about 1.3% of total economic value of Austrian economy.

Different sectors contribute to the total outcome differently. Interestingly enough, we find that EM+ will generate small benefits (i.e. reduce environmental damage) due to changes in the structure of domestic economic sectors (see Table 13). This effect is about 24 million euros or 0.29% compared to BAU in 2030. However, changes in vehicle fleet and hence fuel use will result in benefits that are much larger than the benefits due to changes in the structure of entire economy. Electromobility would hence bring annual additional benefits of about 66 million euros in 2030. In total, EM+ would generate about 80 to 90 million euros of benefits annually after 2025.

However, electromobility (EM+ scenario) would also lead to changes in electricity market and these changes would result in damage of value about 10 to 33 million euros since 2024. This damage is not sufficiently large to counterbalance the benefits generated by changes in economic structure and fuel use in vehicles.

Overall, we conclude that EM+ scenario in Austria would bring small net environmental benefits rather than it would increase environmental damage. We note, however, that our conclusion for Austria cannot be generally supported, since the overall result on the effect of electromobility on external costs will strongly depend on the technology mix to generate electricity. Positive finding for Austria is partly determined by environmentally-friendly technology mix to generate electricity, whereas more polluting electricity generating technology mix might switch environmental benefits of electromobility towards environmental damage.

Table 10. Total external costs in million EUR - direct and indirect emissions, 2008-2030, Austria

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

Table 11. Effect of EM+ on total external costs, 2008-2030, Austria

	Difference bw EM+ and BAU, in million EUR					Percentage change bw EM+ and BAU				
	direct comb	direct noncomb	indirect comb	indirect noncomb	**Grand Total**	direct comb	direct noncomb	indirect comb	indirect noncomb	**Grand Total**
2008	-4.1	-1.0	-7.0	-1.3	**-13.4**	-0.05%	-0.05%	-0.05%	-0.06%	**-0.05%**
2009	-7.5	-1.0	-6.9	-1.3	**-16.6**	-0.08%	-0.05%	-0.05%	-0.06%	**-0.06%**
2010	-7.5	-0.9	-5.7	-1.2	**-15.2**	-0.08%	-0.05%	-0.04%	-0.05%	**-0.05%**
2011	-7.9	-0.8	-4.2	-1.0	**-13.8**	-0.08%	-0.04%	-0.03%	-0.04%	**-0.05%**
2012	-8.4	-0.6	-3.0	-0.9	**-13.0**	-0.09%	-0.03%	-0.02%	-0.04%	**-0.05%**
2013	-10.3	-0.5	-1.4	-0.7	**-12.8**	-0.11%	-0.02%	-0.01%	-0.03%	**-0.04%**
2014	-9.1	-0.2	1.0	-0.4	**-8.7**	-0.10%	-0.01%	0.01%	-0.01%	**-0.03%**
2015	-48.4	-3.4	-17.8	-5.5	**-75.0**	-0.50%	-0.17%	-0.12%	-0.22%	**-0.25%**
2016	-47.8	-3.2	-16.1	-5.3	**-72.5**	-0.51%	-0.16%	-0.10%	-0.21%	**-0.25%**
2017	-47.3	-3.0	-13.5	-5.0	**-68.8**	-0.48%	-0.14%	-0.09%	-0.20%	**-0.23%**
2018	-46.5	-2.6	-9.4	-4.4	**-62.8**	-0.49%	-0.12%	-0.06%	-0.17%	**-0.21%**
2019	-78.1	-5.4	-25.1	-9.1	**-117.6**	-0.84%	-0.25%	-0.16%	-0.35%	**-0.39%**
2020	-77.1	-5.0	-22.4	-8.7	**-113.3**	-0.82%	-0.23%	-0.14%	-0.33%	**-0.37%**
2021	-75.8	-4.8	-20.6	-8.5	**-109.7**	-0.80%	-0.22%	-0.13%	-0.32%	**-0.36%**
2022	-74.1	-4.7	-19.1	-8.3	**-106.2**	-0.77%	-0.22%	-0.12%	-0.31%	**-0.34%**
2023	-71.9	-4.6	-17.9	-8.2	**-102.6**	-0.74%	-0.21%	-0.11%	-0.30%	**-0.33%**
2024	-69.3	-4.6	-17.1	-8.1	**-99.0**	-0.71%	-0.21%	-0.10%	-0.30%	**-0.31%**
2025	-65.0	-4.4	-15.1	-7.8	**-92.3**	-0.66%	-0.20%	-0.09%	-0.28%	**-0.29%**
2026	-62.4	-4.6	-16.3	-8.0	**-91.3**	-0.63%	-0.20%	-0.10%	-0.29%	**-0.28%**
2027	-60.1	-4.9	-18.7	-8.4	**-92.1**	-0.60%	-0.21%	-0.11%	-0.30%	**-0.28%**
2028	-58.4	-5.4	-22.6	-8.9	**-95.3**	-0.58%	-0.23%	-0.13%	-0.32%	**-0.29%**
2029	-57.4	-5.9	-27.7	-9.7	**-100.7**	-0.56%	-0.25%	-0.16%	-0.34%	**-0.30%**
2030	-56.9	-5.8	-28.2	-9.8	**-100.7**	-0.55%	-0.25%	-0.16%	-0.34%	**-0.30%**

Table 12. Total external costs attributable to direct emissions, in million EUR, 2008-2030, Austria

	BAU, in million EUR				EM+, in million EUR			
	sectors	FUEL	ELE	TOTAL	sectors	FUEL	ELE	TOTAL
2008	6 764	1 636	502	**8 902**	6 762	1 635	502	**8 898**
2009	6 834	1 653	511	**8 998**	6 831	1 650	510	**8 991**
2010	6 903	1 688	863	**9 455**	6 901	1 683	863	**9 447**
2011	6 967	1 561	1 012	**9 540**	6 966	1 555	1 012	**9 533**
2012	7 037	1 481	402	**8 920**	7 035	1 475	402	**8 912**
2013	7 106	1 410	1 048	**9 564**	7 106	1 402	1 046	**9 554**
2014	7 176	1 334	403	**8 914**	7 176	1 326	403	**8 904**
2015	7 246	1 270	1 253	**9 769**	7 240	1 229	1 251	**9 721**
2016	7 317	1 218	759	**9 295**	7 311	1 178	758	**9 247**
2017	7 389	1 180	1 318	**9 887**	7 383	1 139	1 317	**9 840**
2018	7 462	1 154	907	**9 522**	7 457	1 113	906	**9 476**
2019	7 536	1 138	601	**9 276**	7 524	1 072	601	**9 197**
2020	7 611	1 131	663	**9 405**	7 599	1 065	664	**9 328**
2021	7 686	1 130	670	**9 487**	7 674	1 064	673	**9 411**
2022	7 762	1 134	677	**9 573**	7 749	1 067	682	**9 499**
2023	7 839	1 140	683	**9 661**	7 826	1 074	690	**9 590**
2024	7 916	1 148	688	**9 752**	7 903	1 082	698	**9 683**
2025	7 994	1 158	692	**9 844**	7 982	1 092	706	**9 779**
2026	8 073	1 170	694	**9 937**	8 059	1 104	712	**9 875**
2027	8 152	1 184	696	**10 031**	8 136	1 118	717	**9 971**
2028	8 231	1 199	695	**10 126**	8 214	1 133	720	**10 067**
2029	8 311	1 216	693	**10 220**	8 291	1 150	722	**10 163**
2030	8 391	1 233	689	**10 313**	8 367	1 168	722	**10 256**

Table 13. Effect of EM+ on total external costs attributable to direct emissions, 2008-2030, Austria

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

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Appendix

Table A14. Attribution of Exiobase (CREAA) product groups and industry categories into CGE sectors

SAM	CREEA rows (product groups)	CREEA columns (sector groups)
AGR	1-15, 18-19	1-15, 18-19
FERR	104-115	72-83
CHEM	16-17, 42, 77-78, 85-96	16-17, 34,-57*4.4%, 58-64
ENG	116-122	84-90
CPT	123	91
OVEPRO	124	92
OTHER	32-41, 43-63, 97-101, 125-126	24-33, 35-55, 65-69, 93-94
BUI1	150	113
BUI2	151	114
PUBTRANS	**157***42.4%, **158***21.3%	**120***42.4%, **121***21.3%
PPT	**160***20%, **161***20%, **162*99.8%**	**123***20%, 124*20%, **125***99.8%
FreightTrans	**157***57.6%, **158***78.7%, 159, **160***80%, **161***80%, **162***0.2%	**120***57.6%, **121***78.7%, 122, **123***80%, **124***80%, **125***0.2%
R&D	171	134
SERV	102-103, 127, 149, 153-156, 163-170, 172-200	70-71, 95, 112, 116-119, 126-133, 135-163
CARSERV	152kfdl	115
ELRPO	128-139	96-107
ELTD	140-141	108-109
DH	148	111
GASTD	142-147	110
COAL	20-25, 27	20*94.7%
OILGASCOKE	26, 28-31, 64-66, 68-70, 73-76, 79-84	20*5.3%, 21-23, 56, 57*40.5%
FUEL	67, 71-72	57*55.1%

Table A15. Emission factors for passenger cars, in g of emissions per GJ of fuel consumption

Austria (g/GJ)

year	CO2	CO2_w2t	NOx	SO2	PM	PM_non_ exhaust	NMVOC	VOC	C6H6	CO	TOFP
2010	73 691	9 729	191.42	0.47	9.27	2.78	30.07	32.42	1.30	304.23	297.10
2011	73 705	9 727	179.48	0.47	8.21	2.79	26.66	28.81	1.12	264.83	274.79
2012	73 717	9 725	168.19	0.47	7.24	2.80	23.74	25.74	0.97	230.58	254.33
2013	73 728	9 724	157.43	0.47	6.34	2.81	21.26	23.12	0.84	201.00	235.46
2014	73 736	9 723	140.69	0.47	5.50	2.82	19.17	20.91	0.72	175.66	210.16
2015	73 743	9 722	125.09	0.47	4.74	2.82	17.42	19.05	0.63	154.08	187.00
2016	73 750	9 721	110.78	0.47	4.06	2.82	15.98	17.52	0.55	135.98	166.11
2017	73 755	9 720	97.96	0.47	3.47	2.83	14.79	16.27	0.49	120.84	147.61
2018	73 760	9 720	86.81	0.47	2.96	2.83	13.83	15.24	0.43	108.23	131.66
2019	73 764	9 719	77.40	0.47	2.55	2.83	13.04	14.40	0.39	97.70	118.23
2020	73 769	9 719	69.76	0.47	2.22	2.83	12.41	13.73	0.35	89.03	107.32
2021	73 773	9 718	63.64	0.47	1.99	2.83	11.90	13.18	0.33	82.02	98.58
2022	73 777	9 718	58.66	0.47	1.82	2.84	11.49	12.74	0.30	76.25	91.45
2023	73 781	9 717	54.51	0.47	1.70	2.84	11.16	12.39	0.29	71.53	85.54
2024	73 784	9 717	51.03	0.47	1.63	2.84	10.91	12.12	0.27	67.73	80.63
2025	73 786	9 716	48.13	0.47	1.59	2.84	10.71	11.90	0.26	64.65	76.56
2026	73 789	9 716	45.81	0.47	1.56	2.84	10.55	11.74	0.25	62.19	73.30
2027	73 791	9 716	44.04	0.47	1.54	2.85	10.43	11.60	0.24	60.14	70.79
2028	73 794	9 715	42.79	0.47	1.53	2.85	10.33	11.50	0.24	58.49	68.99
2029	73 796	9 715	42.00	0.47	1.53	2.85	10.26	11.42	0.23	57.17	67.80
2030	73 798	9 715	41.52	0.47	1.52	2.85	10.20	11.36	0.23	56.10	67.05

Germany (g/GJ)

year	CO2	N2O	NOx	SO2	PM	PM_non-exhaust	NMVOC	VOC	C6H6	CO	TOFP
2010	73 126	2.76	141.37	0.46	5.01	2.44	47.87	52.22	2.23	430.85	267.80
2011	73 155	2.69	131.07	0.46	4.52	2.45	41.43	45.50	1.89	376.44	242.79
2012	73 185	2.63	121.44	0.46	4.04	2.46	35.74	39.56	1.59	327.03	219.92
2013	73 213	2.56	112.56	0.46	3.59	2.48	30.83	34.40	1.33	282.91	199.33
2014	73 240	2.51	100.09	0.46	3.17	2.49	26.67	30.03	1.10	244.17	175.68
2015	73 265	2.46	88.69	0.46	2.78	2.49	23.19	26.35	0.91	210.46	154.59
2016	73 288	2.42	78.53	0.46	2.43	2.50	20.35	23.35	0.76	181.75	136.19
2017	73 307	2.39	69.62	0.46	2.13	2.50	18.09	20.94	0.64	157.64	120.40
2018	73 324	2.36	61.97	0.46	1.88	2.51	16.30	19.04	0.54	137.71	107.10
2019	73 339	2.34	55.49	0.46	1.67	2.51	14.91	17.54	0.46	121.38	96.00
2020	73 351	2.33	50.14	0.46	1.51	2.51	13.85	16.40	0.40	108.32	86.97
2021	73 361	2.32	45.78	0.46	1.39	2.51	13.05	15.53	0.36	98.13	79.72
2022	73 370	2.31	42.25	0.46	1.30	2.52	12.45	14.89	0.32	90.16	73.95
2023	73 377	2.31	39.44	0.46	1.24	2.52	12.02	14.41	0.30	84.01	69.41
2024	73 383	2.31	37.24	0.46	1.20	2.52	11.71	14.07	0.28	79.33	65.90
2025	73 387	2.31	35.51	0.46	1.18	2.52	11.49	13.83	0.27	75.80	63.19
2026	73 390	2.31	34.22	0.46	1.16	2.52	11.21	13.62	0.26	73.70	61.09
2027	73 393	2.31	33.24	0.47	1.15	2.52	11.12	13.51	0.25	71.66	59.59
2028	73 396	2.31	32.55	0.47	1.15	2.52	11.06	13.44	0.25	70.17	58.52
2029	73 398	2.31	32.09	0.47	1.15	2.52	11.03	13.40	0.25	69.09	57.81
2030	73 402	2.32	31.85	0.47	1.15	2.52	11.01	13.38	0.24	68.22	57.41

Poland (g/GJ)

year	CO2	CO2_w2t	NOx	SO2	PM	PM_non_ exhaust	NMVOC	VOC	C6H6	CO	TOFP
2010	71 731	9 403	142.31	0.38	3.31	3.00	89.75	96.68	3.67	903.62	362.91
2011	71 729	9 396	127.19	0.38	2.67	3.02	79.34	85.98	3.18	797.26	322.35
2012	71 727	9 388	114.47	0.38	2.16	3.04	70.22	76.59	2.74	702.77	287.31
2013	71 725	9 381	104.60	0.38	1.79	3.05	62.35	68.50	2.37	620.20	258.33
2014	71 724	9 374	92.66	0.37	1.55	3.07	55.58	61.54	2.04	548.37	229.08
2015	71 722	9 368	82.72	0.37	1.37	3.08	49.65	55.44	1.76	485.47	204.11
2016	71 747	9 370	74.19	0.38	1.23	3.08	44.60	50.24	1.52	431.52	182.72
2017	71 771	9 372	66.55	0.38	1.12	3.09	40.20	45.71	1.31	384.85	163.86
2018	71 794	9 374	59.78	0.38	1.05	3.10	36.43	41.81	1.13	344.99	147.45
2019	71 816	9 376	53.89	0.38	1.01	3.10	33.22	38.49	0.97	311.21	133.33
2020	71 837	9 378	48.92	0.38	0.99	3.11	30.53	35.73	0.84	282.88	121.47
2021	71 845	9 378	44.74	0.38	0.98	3.11	28.41	33.56	0.74	261.02	111.85
2022	71 852	9 378	41.40	0.38	0.98	3.12	26.64	31.76	0.65	242.61	103.97
2023	71 858	9 379	38.88	0.38	0.98	3.12	25.17	30.26	0.58	227.25	97.74
2024	71 865	9 379	37.09	0.38	0.98	3.12	23.96	29.03	0.52	214.55	92.95
2025	71 872	9 380	35.84	0.38	0.98	3.13	22.96	28.01	0.48	203.98	89.26
2026	71 868	9 378	34.90	0.38	0.98	3.13	22.18	27.24	0.44	195.84	86.45
2027	71 865	9 376	34.18	0.38	0.97	3.13	21.54	26.60	0.41	189.17	84.19
2028	71 861	9 374	33.60	0.38	0.97	3.14	21.03	26.08	0.38	183.78	82.38
2029	71 858	9 371	33.16	0.38	0.97	3.14	20.62	25.68	0.36	179.51	80.95
2030	71 854	9 369	32.81	0.38	0.97	3.15	20.29	25.36	0.34	176.12	79.84

Table A16. Emission factors for <u>freight transport</u>, in kg of emissions per ton of fuel consumption

<u>Austria (kg/t)</u>

Year	*Fuel Cons (t)*	CO2	CO2 w2t	CH4	N2O	NOx	SO2	PM	VOC	NMVOC	C6H6	CO	TOFP
2010	846 615	3 138	409	0.1757	0.1518	23.34	0.0200	0.3256	0.6001	0.4244	0.0007	3.4136	29.27
2011	854 530	3 138	409	0.1416	0.1538	21.16	0.0200	0.2755	0.4781	0.3364	0.0006	2.7700	26.46
2012	862 450	3 138	409	0.1112	0.1558	19.22	0.0200	0.2325	0.3715	0.2603	0.0005	2.1989	23.95
2013	870 403	3 138	409	0.0850	0.1578	17.51	0.0200	0.1966	0.2810	0.1961	0.0004	1.7104	21.74
2014	878 488	3 138	409	0.0635	0.1597	16.05	0.0200	0.1679	0.2080	0.1445	0.0003	1.3148	19.87
2015	886 834	3 138	409	0.0474	0.1614	14.87	0.0200	0.1466	0.1532	0.1059	0.0003	1.0183	18.36
2016	895 539	3 138	409	0.0364	0.1632	13.98	0.0200	0.1325	0.1162	0.0797	0.0002	0.8188	17.22
2017	904 595	3 138	409	0.0300	0.1648	13.38	0.0200	0.1246	0.0943	0.0643	0.0002	0.7022	16.46
2018	913 860	3 138	409	0.0269	0.1663	13.03	0.0200	0.1210	0.0836	0.0567	0.0002	0.6456	16.02
2019	923 113	3 138	409	0.0258	0.1678	12.87	0.0200	0.1200	0.0794	0.0536	0.0002	0.6239	15.82
2020	932 163	3 138	409	0.0255	0.1693	12.84	0.0200	0.1203	0.0782	0.0527	0.0002	0.6186	15.79
2021	941 483	3 138	409	0.0256	0.1708	12.89	0.0200	0.1210	0.0782	0.0526	0.0002	0.6201	15.85
2022	950 461	3 138	409	0.0258	0.1724	12.99	0.0200	0.1219	0.0786	0.0528	0.0002	0.6239	15.97
2023	959 135	3 138	409	0.0260	0.1739	13.11	0.0200	0.1229	0.0791	0.0531	0.0002	0.6286	16.11
2024	967 540	3 138	409	0.0263	0.1755	13.23	0.0200	0.1240	0.0797	0.0535	0.0002	0.6339	16.27
2025	975 706	3 138	409	0.0265	0.1771	13.36	0.0200	0.1251	0.0804	0.0539	0.0002	0.6394	16.43
2026	983 651	3 138	409	0.0267	0.1787	13.49	0.0200	0.1263	0.0811	0.0544	0.0002	0.6450	16.59
2027	991 383	3 138	409	0.0270	0.1804	13.63	0.0200	0.1275	0.0818	0.0548	0.0002	0.6508	16.75
2028	998 898	3 138	409	0.0272	0.1820	13.76	0.0200	0.1287	0.0826	0.0553	0.0002	0.6568	16.92
2029	1 006 189	3 138	409	0.0275	0.1837	13.90	0.0200	0.1299	0.0833	0.0559	0.0002	0.6628	17.08
2030	1 013 252	3 138	409	0.0277	0.1854	14.03	0.0200	0.1312	0.0841	0.0564	0.0002	0.6689	17.25

<u>Germany (kg/t)</u>

Year	*Fuel Cons (t)*	CO2	CO2_w2t	CH4	N2O	NOx	SO2	PM	VOC	NMVOC	C6H6	CO	TOFP
2010	8 910 277	3 138	409	0.1519	0.1366	21.73	0.0200	0.3567	0.7235	0.5717	0.0019	3.7154	27.49
2011	8 841 476	3 138	409	0.1210	0.1383	19.59	0.0200	0.3027	0.5818	0.4608	0.0017	3.0688	24.70
2012	8 779 505	3 138	409	0.0954	0.1399	17.77	0.0200	0.2583	0.4648	0.3695	0.0016	2.5340	22.32
2013	8 723 820	3 138	409	0.0749	0.1415	16.24	0.0200	0.2228	0.3710	0.2961	0.0014	2.1079	20.34
2014	8 673 384	3 138	409	0.0592	0.1430	14.99	0.0200	0.1954	0.2984	0.2391	0.0013	1.7854	18.73
2015	8 627 316	3 138	409	0.0479	0.1445	14.02	0.0200	0.1752	0.2447	0.1968	0.0013	1.5574	17.47
2016	8 584 822	3 138	409	0.0402	0.1459	13.31	0.0200	0.1612	0.2070	0.1668	0.0012	1.4093	16.56
2017	8 545 118	3 138	409	0.0352	0.1473	12.82	0.0200	0.1520	0.1815	0.1463	0.0012	1.3221	15.94
2018	8 507 394	3 138	409	0.0322	0.1487	12.52	0.0200	0.1463	0.1648	0.1327	0.0012	1.2756	15.55
2019	8 470 905	3 138	409	0.0303	0.1502	12.36	0.0200	0.1428	0.1538	0.1235	0.0012	1.2532	15.35
2020	8 435 077	3 138	409	0.0291	0.1516	12.30	0.0200	0.1408	0.1463	0.1172	0.0012	1.2430	15.26
2021	8 384 840	3 138	409	0.0283	0.1528	12.29	0.0200	0.1396	0.1414	0.1131	0.0012	1.2469	15.24
2022	8 333 957	3 138	409	0.0278	0.1540	12.31	0.0200	0.1391	0.1380	0.1102	0.0012	1.2530	15.27
2023	8 283 138	3 138	409	0.0274	0.1553	12.36	0.0200	0.1391	0.1354	0.1081	0.0012	1.2602	15.33
2024	8 232 378	3 138	409	0.0270	0.1566	12.42	0.0200	0.1393	0.1336	0.1065	0.0012	1.2680	15.40
2025	8 181 775	3 138	409	0.0268	0.1579	12.49	0.0200	0.1397	0.1322	0.1054	0.0013	1.2765	15.49
2026	8 131 465	3 138	409	0.0267	0.1592	12.57	0.0200	0.1403	0.1324	0.1057	0.0013	1.2923	15.59
2027	8 081 580	3 138	409	0.0266	0.1605	12.66	0.0200	0.1410	0.1319	0.1053	0.0014	1.3025	15.69
2028	8 032 211	3 138	409	0.0265	0.1618	12.75	0.0200	0.1418	0.1316	0.1051	0.0014	1.3136	15.80
2029	7 983 395	3 138	409	0.0265	0.1631	12.84	0.0200	0.1426	0.1317	0.1051	0.0014	1.3256	15.92
2030	7 935 114	3 138	409	0.0265	0.1644	12.94	0.0200	0.1436	0.1319	0.1054	0.0014	1.3383	16.04

Poland (kg/t)

Year	*Fuel Cons (t)*	CO2	CO2_w2t	CH4	N2O	NOx	SO2	PM	VOC	NMVOC	C6H6	CO	TOFP
2010	3 406 911	3 139	409	0.2261	0.1389	26.24	0.0200	0.5216	1.0768	0.8507	0.0040	5.7554	33.50
2011	3 502 180	3 139	409	0.2085	0.1398	24.86	0.0200	0.4750	0.9801	0.7716	0.0037	5.3344	31.69
2012	3 597 047	3 139	409	0.1924	0.1408	23.63	0.0200	0.4344	0.8936	0.7012	0.0034	4.9544	30.08
2013	3 691 567	3 139	409	0.1774	0.1417	22.52	0.0200	0.3992	0.8162	0.6387	0.0032	4.6111	28.63
2014	3 785 687	3 139	410	0.1637	0.1426	21.52	0.0200	0.3689	0.7471	0.5834	0.0030	4.3011	27.31
2015	3 879 130	3 139	410	0.1509	0.1435	20.61	0.0200	0.3429	0.6853	0.5344	0.0029	4.0199	26.12
2016	3 971 031	3 139	410	0.1388	0.1444	19.78	0.0200	0.3198	0.6289	0.4901	0.0027	3.7606	25.04
2017	4 060 669	3 139	410	0.1273	0.1453	19.00	0.0200	0.2986	0.5764	0.4491	0.0026	3.5174	24.02
2018	4 147 818	3 139	410	0.1162	0.1463	18.26	0.0200	0.2790	0.5271	0.4109	0.0025	3.2866	23.06
2019	4 232 267	3 139	410	0.1054	0.1473	17.57	0.0200	0.2606	0.4804	0.3750	0.0024	3.0652	22.15
2020	4 314 030	3 139	410	0.0949	0.1484	16.91	0.0200	0.2433	0.4361	0.3412	0.0024	2.8521	21.29
2021	4 377 913	3 139	410	0.0850	0.1497	16.33	0.0200	0.2279	0.3954	0.3104	0.0023	2.6611	20.53
2022	4 438 724	3 139	410	0.0753	0.1511	15.77	0.0200	0.2127	0.3556	0.2804	0.0023	2.4579	19.79
2023	4 497 011	3 139	410	0.0660	0.1525	15.24	0.0200	0.1984	0.3183	0.2523	0.0023	2.2643	19.10
2024	4 553 057	3 139	410	0.0574	0.1540	14.76	0.0200	0.1854	0.2839	0.2265	0.0022	2.0844	18.46
2025	4 607 697	3 139	410	0.0497	0.1554	14.33	0.0200	0.1740	0.2535	0.2038	0.0022	1.9259	17.90
2026	4 662 023	3 139	410	0.0434	0.1569	13.97	0.0200	0.1648	0.2286	0.1852	0.0022	1.7976	17.43
2027	4 716 115	3 139	410	0.0385	0.1583	13.70	0.0200	0.1579	0.2092	0.1707	0.0022	1.6997	17.07
2028	4 771 466	3 139	410	0.0355	0.1597	13.52	0.0200	0.1537	0.1969	0.1613	0.0022	1.6405	16.84
2029	4 828 117	3 139	410	0.0342	0.1610	13.45	0.0200	0.1520	0.1908	0.1566	0.0022	1.6156	16.74
2030	4 884 254	3 139	410	0.0336	0.1623	13.44	0.0200	0.1516	0.1878	0.1542	0.0022	1.6076	16.73

Table A17. External costs for electricity generating technologies – CASES database, in €c per kWh.

Technology	electric model (hybrid CGE)	2005-2010				2020				2030			
		Envi	Health	Climate change	Total	Envi	Health	Climate change	Total	Envi	Health	Climate change	Total
hydro run of river *	**water_run**	0.0015	0.0164	0.0077	**0.0256**	0.0016	0.0204	0.0077	**0.0297**	0.0018	0.0241	0.0111	**0.0370**
natural gas combined cycle without CO2 capture	**gas_sewage**	0.0715	0.4204	0.8967	**1.3886**	0.0796	0.5382	0.8316	**1.4494**	0.0885	0.6268	1.1741	**1.8895**
hard coal condensing power plant	**coal_black**	0.1593	1.2457	1.7176	**3.1226**	0.1906	1.5123	1.5802	**3.2832**	0.2073	1.7363	2.1790	**4.1226**
biomass (woodchips) CHP with an extraction condensing turbine	**biomass**	0.0665	0.4266	0.1157	**0.6089**	0.0773	0.5710	0.1157	**0.7640**	0.0873	0.6758	0.1653	**0.9283**
MCFC (biogas)	**biogas**	0.1530	1.8103	0.5879	**2.5511**	0.1748	2.3344	0.5911	**3.1004**	0.1715	2.4284	0.7350	**3.3349**
wind	**wind**	0.0030	0.0377	0.0117	**0.0524**	0.0017	0.0226	0.0058	**0.0300**	0.0016	0.0224	0.0072	**0.0312**
hydropower, pump storage	**water_ps**	0.0004	0.0045	0.0018	**0.0067**	0.0005	0.0056	0.0018	**0.0078**	0.0005	0.0066	0.0025	**0.0097**
solar PV open space	**pv**	0.0129	0.1749	0.0522	**0.2400**	0.0133	0.2028	0.0457	**0.2618**	0.0145	0.2344	0.0632	**0.3121**
natural gas, gas turbine	**gas_natural**	0.1079	0.6303	1.3416	**2.0798**	0.1270	0.8499	1.3072	**2.2840**	0.1399	0.9797	1.8283	**2.9479**
hydropower, run of river 10MW		0.0021	0.0225	0.0106	**0.0352**	0.0023	0.0280	0.0106	**0.0409**	0.0025	0.0332	0.0152	**0.0509**
hydropower, run of river <100MW		0.0015	0.0161	0.0076	**0.0251**	0.0016	0.0200	0.0076	**0.0292**	0.0018	0.0237	0.0109	**0.0363**
hydropower, run of river >100MW		0.0013	0.0145	0.0068	**0.0226**	0.0015	0.0180	0.0068	**0.0263**	0.0016	0.0213	0.0098	**0.0327**

Note: * Externalities for hydro power run on river is weighted externality as derived for hydropower below 10 MW, below 100 MW and above 100 MW, taking the shares of these technologies operand in 2008 in Austria (15.6%, 41.1%, and 43.3%). Up/stream impacts attributed to plant construction are not considered.