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The socio-economic impact of the deployment of electromobility on greenhouse gas and local emissions on EU-level

Abstract

To reduce carbon emissions, electric vehicles are widely seen as one of the promising options. However, the effect of regulation and technological development on the possible deployment paths of electric vehicles, emission reduction and on economic factors has not been examined in detail yet.

This article presents a two-step analysis of regulation accelerating the deployment of electric vehicles in terms of technological development and a stronger CO_2 emission regulation. In a first step, three scenarios for different regulatory frameworks are created. For each scenario, the deployment path of electric vehicles is simulated by a detailed agent-based vehicle technology choice model (VECTOR21). The model's results allow the analysis of technology diffusion into the passenger car fleet and, thus, the carbon emission reduction potential of electric vehicles. In a second step, the scenario results for the passenger car fleet are used in a socio-economic cost-benefit evaluation of the impacts of the market diffusion of electric vehicles. The benefits encompass environmental effects and savings in operating costs, which are expressed in monetary terms. Hence, the economic analysis is able to show the effectiveness of a stronger emission regulation and of a faster battery system development supporting the introduction of electric vehicles.

The market penetration of electric vehicles on EU-level can be enhanced by both technical and policy measures (regulation). The stronger CO_2 regulation in the Politically Driven scenario (PoD) is not efficient, whereas the Technology Driven scenario (TeD) has a positive socio-economic impact (Benefit-Cost-Ratio > 1). If technologies develop further and costs for EV components decrease significantly, tightened CO_2 limits could be met without other regulative measures.

Keywords

Market assessment, EV policies, scenario analysis, CBA

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1. Introduction

In order to meet road transport's major challenges of the environmental burden imposed by global warming emissions and local pollutants and decrease the EU's dependence on oil, the broad market penetration of electric vehicles coupled with energy from renewable resources can be an important part of the solution. To reduce carbon emissions, electric vehicles are widely seen as one of the promising options. However, the effect of regulation on the possible deployment paths of electric vehicles, emission reduction and on economic factors has not been examined in detail yet.

In 2011, the European Commission sets an ambitious goal to reduce greenhouse gas emissions in the transport sector until 2050 of at least 60% with respect to 1990. As one potential measure to achieve this goal without sacrificing the transport systems efficiency and compromising mobility, the European Commission proclaimed the goal of halving the use of conventionally-fuelled cars in urban transport by 2030 (EC 2011).

To identify the adjusting screws and to overcome the barriers and challenges for a further deployment of electric cars, the funding initiative Electromobility+ has been launched in 2010 as part of the EU Green Car Initiative. As one of the funded programs, the project eMAP (electromobility – scenario based Market potential, Assessment and Policy options) focuses on the analysis and assessment of the market penetration of electric vehicles and its socio-economic impacts.

The project eMAP concentrates on the analysis and assessment of the market penetration of electric vehicles and its socio-economic impacts. In this process feasible deployment paths of electric vehicles are investigated for the time horizon until 2030. This is done by a scenario based market model which specifies the demand potential and market supply of electromobility. The socio-economic impact of the deployment of electromobility in terms of savings in costs of greenhouse gas, local emissions and noise, transport costs, production costs and infrastructure costs is evaluated using different scenarios. Policy support measures and strategies for electric vehicles are identified and their impact on the deployment path is analysed and evaluated in the eMAP-project. In this paper, the results of the VECTOR21 market model regarding different scenarios are presented. Based on this, a cost-benefit analysis for the development of electric vehicles on EU-level is carried out for two different scenarios.

2. Scenario calculation using the VECTOR21-model

Within eMAP, deployment paths of electric vehicles, i.e. Battery electric vehicles (BEV), fuel cell hydrogen vehicles (FCHV), Plug-in hybrid vehicles (PHEV) and Range extended electric vehicles (REEV), are analysed up to 2030. For the analysis, the vehicle market model VECTOR21 is used specifying consumer demand and market supply of electric mobility in Finland, Germany, Poland and the EU. Therefore, an extended version of VECTOR21 is developed to cover European markets (EU28). The EU-calculations are based on the markets in Finland, France, Germany, Italy, Poland and the United Kingdom. Thus, a total of about 73 percent of the European market is mapped to project on EU-level.

This chapter encompasses

- a brief overview of the VECTOR21 model
- a description of the technologic and economic framework of each scenario including e.g. battery cost development as well as the accompanying regulatory framework including e.g. CO_2 targets
- Results for each scenario, e.g. vehicle stock data of electric and conventional powertrains and CO_2 emissions

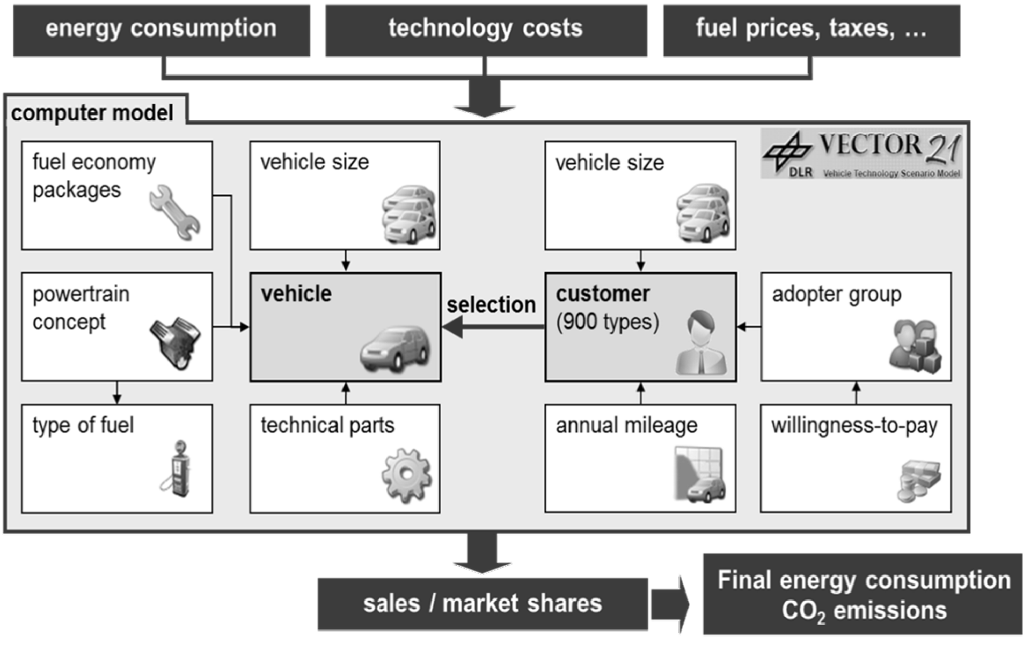

Figure 1: VECTOR21 model approach (Mock 2009)

Figure 1 illustrates the most important components of the VECTOR21 model. In this model, 900 different customers, differing by vehicle size, annual mileage and adopter type, are taken into account, who can choose among 120 different types of vehicles - distinguished by powertrain, size and implemented level of fuel saving technologies. The purchase decision is executed in several steps which are depicted in Figure 2.

In the first step vehicles that do not match the customer's demanded size are excluded. In a second step, the vehicle with lowest relevant costs of ownership (RCO) is identified – taking the annual mileage, the purchase price and the operating costs into account. Those vehicles that exceed this minimum RCO value by more than the customer's willingness-to-pay are not considered for purchase. Finally, the vehicle with the lowest well-to-wheel CO2 emissions is chosen for purchase.

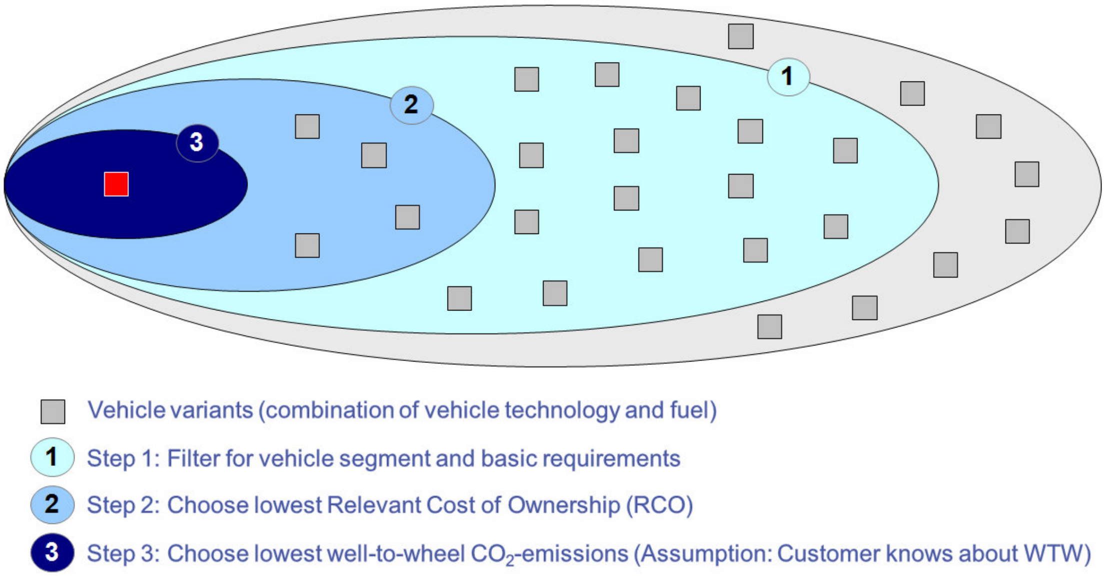

Figure 2: Purchase decision process for each year and customer group (Mock 2010)

Three deployment paths (scenarios) are modelled: Business as Usual (BaU), Technology Driven (TeD) and Politically Driven (PoD) (Kugler et al. 2015).

Scenario	Experience Curve of the battery system	Vehicles	CO_2 limits [g/km]	Taxation scheme/ subsidies
BaU	Function is fixed, but the curve depends on the sales of the last years	120 different types of vehicles - distinguished by powertrain, size and implemented level of fuel saving technologies	2015: 130, 2021: 95, 2030: 75, phase-in and super credits taken into account	As current legislation
TeD	Decrease faster than in BaU	Higher efficiency of electrified vehicles	Same as BaU	Same as BaU
PoD	Same as BaU	Same as BaU	2030: 60	Same as BaU

Table 1: Scenario overview

TeD:

The assumption is, that the technological development (in terms of the battery system) proceeds more quickly compared to the BaU scenario. As a result, the battery-prices decrease faster than in the BaU-Scenario (see Figure 3). Higher invests into battery research and development are assumed and thereby a higher degression rate can be realized. Thus, the battery costs are reduced, which in turn leads to a higher number of sales of electrified vehicles. This again causes a positive feedback on the cost development of the battery system and the floor costs are reached in 2020/21.

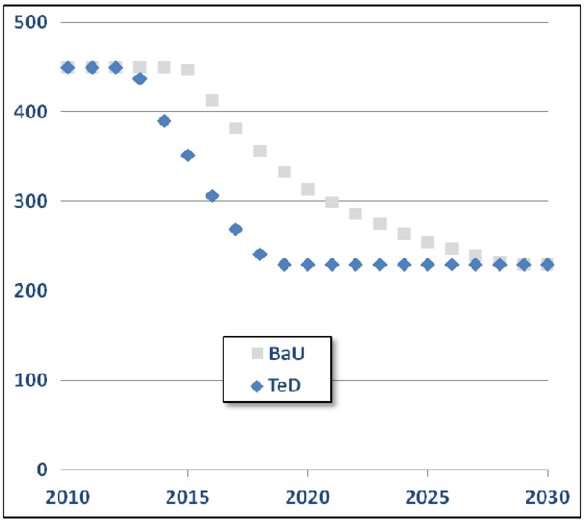

Figure 3: Price of battery system [€/kWh]

Additionally, the development of the efficiency of the electric drivetrains of EV (BEV, REEV and PHEV) is assumed to be enhanced by 10% in comparison to the vehicles in the BaU scenario. This can be realized by more efficient electrified components and, for PHEV and REEV, by a higher share of pure electric driven mileage.

PoD:

The only difference between the PoD and the BaU scenario is the CO_2 emission target in 2030. The EU CO_2 emission target is not yet set for 2030, so an assumption has to be made. In PoD the target is set to 60 g/km CO_2 in contrast to 75 g/km CO_2 in the BaU scenario. That means that there is a reduction of 35 g/km (BaU scenario: 20 g/km) between 2021 and 2030. So the CO_2 emission reduction for new car sales in 2030 is 75% higher compared to the BaU scenario. In the BaU scenario the average reduction per year in the period 2021 and 2030 (2.2 g CO_2 per year) is much lower than between 2015 and 2021 (5.8 g CO_2). In the PoD scenario the average reduction per year with 3.9 g CO_2 (2021 – 2030) doesn't decrease so much after 2021 as in the BaU scenario. In both scenarios the average CO_2 target reduction per year in the period 2021 to 2030 (BaU: 2.2 g CO_2 and PoD: 3.9 g CO_2) decreases in contrast to the period 2015 to 2021 (BaU and PoD: 5.8 g CO_2).

Scenario results:

The results show, that the electrification of the European market takes place in all scenarios (see Figure 4).

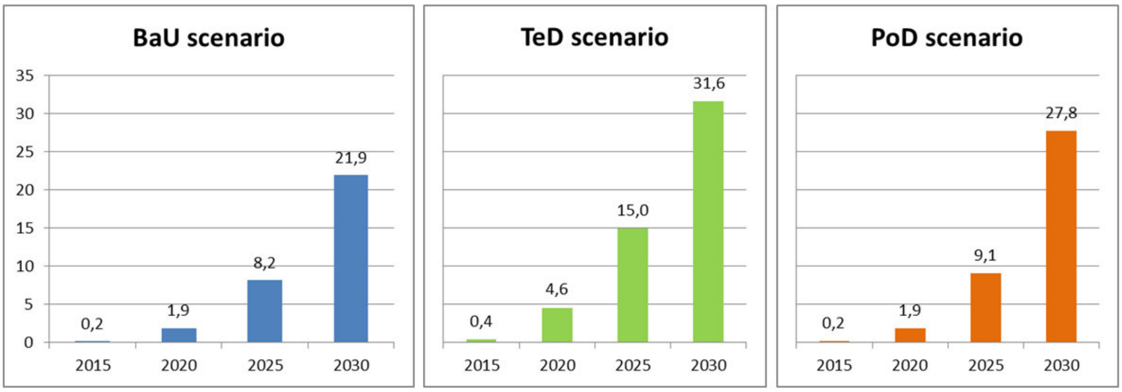

Figure 4: Number of EVs in stock (EU28, in million)

In the BaU scenario approx. 1.9 Mio. EV are in the passenger car stock in 2020. Until 2030 the number of vehicles with charging device increases up to approx. 22 Mio vehicles. In 2030, almost 50% of the new vehicles (sales) have an electric or electrified drivetrain, of which 50% are equipped with a plug-in device.

In the TeD scenario 31.6 million EV are in the European stock in 2030. Compared to the BaU scenario this means an increase of about 44%. In 2030, the TeD scenario has the highest share of vehicles with charging device of all scenarios. The total CO_2 emissions of the entire car stock can be lowered by 30% (2030 to 2010).

Untill 2021, the same amount of EV can be found in the passenger car stock in the PoD scenario as in the BaU scenario, because all input parameter are the same until 2021. Only after 2021 the tightened CO_2 emission target for 2030 leads to an increasing electrification. After 2021 the share of EV in the stock is notably higher than in the BaU scenario. In 2030, the PoD scenario has the highest reduction of total CO_2 emissions of the car stock compared to the BaU und TeD scenario. The total CO_2 emissions of the entire passenger car stock can be lowered by 31% (2030 to 2010).

3. Cost-benefit-analysis

Cost-benefit analysis (CBA) is the most known and most used methodology for determining the worth, value and feasibility of a policy measure. CBA is based on welfare economics using the Kaldor-Hicks criterion: a policy measure is efficient when it makes some people better off without making other people worse off. Thus CBA shows whether it is profitable to the society to use productive resources (labour, capital) to provide e-vehicles and infrastructure to achieve savings of resource consumption (in this case energy and environmental pollution). Both sides – the resource use (= costs of e-mobility) and the resource savings (= benefits of e-mobility) – are expressed in monetary terms in order to build the ratio out of them. When the benefits exceed the costs (benefit-cost ratio > 1), it is profitable from the society point of view. The ratio does not only show profitability but also allows to rank alternatives resp. scenarios of e-mobility (Kurte et al. 2015). The scenario results are used to calculate costs and benefits and to make a decision support for the policymakers (see Figure 5).

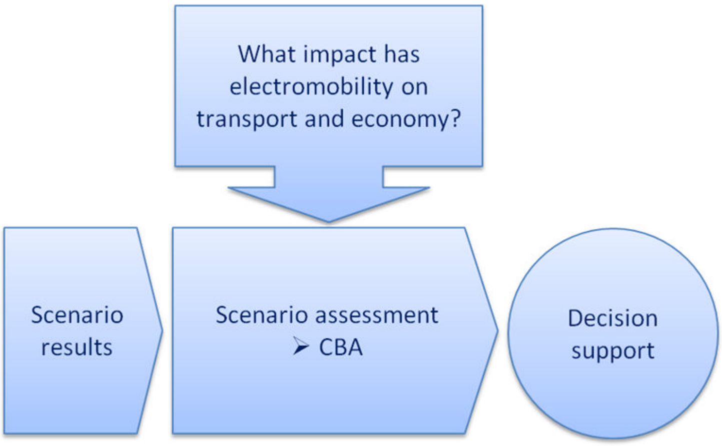

Figure 5: CBA as an option to rank scenarios

Unfortunately cost-benefit analysis is limited. The CBA does not take into account macro-economic impacts (e.g. fiscal effects, productivity gains, growth and employment effects of e-mobility), so that a detailed view on stakeholders is not possible. Furthermore there are aspects which cannot be expressed in monetary terms (e.g. political enforceability, implementation/ application complexity, etc.), but can have an influence on the ranking order of measures. Nevertheless the CBA is a commonly used and appropriate method to evaluate projects or measures in international transport and provides a first ranking order of alternatives.

In order to perform a socio-economic evaluation, the simulation results are used directly for a comparison of costs and benefits, which are caused by a technical progress or a policy measure. There the influences on the actors concerned are monetized.

A policy measure is accordingly recommended from a societal point of view, if the monetized benefits of a measure (better welfare for consumers, less environmental damages, etc.) exceed the additional costs (costs of car production, infrastructure development).

The cost-benefit-analysis is based on the following principles:

- The evaluation of a policy measure is always compared to the reference scenario (BaU). For example the model takes the costs or benefits for vehicle owners into account by calculating changes in fuel costs, which would have been incurred in the "Without political measure" case.
- Future costs and benefits are discounted. Thus, it is considered that a payment, which lies in the future, is worth less than the same payment today. In accordance with the current interest level, a discount rate of 1 percent per year is used.
- The evaluation period is 2010-2030. All cash flows during this period are calculated, discounted and cumulated.

Cost-benefit analysis (CBA) to evaluate e-mobility

The cost-benefit analysis examines the economic efficiency of policy measures, investments and projects. It shows if a measure is efficient at all and what degree of efficiency it reaches. The efficiency can be measured by:

- the internal rate of return
- the net present value of the measure
- the cost-benefit-ratio.

Internal rate of return (IRR)

The internal rate of return is defined as the discount rate at which the present costs of a measure equals the present benefits of the measure. The internal rate of return helps enterprises to identify the investment which is the best. To decide the internal rate of return is usually compared to some other critical rates, e.g. long term market interest rate.

Net present value (NPV)

The difference between the monetary value of all benefits of a measure and the specific costs of a measure is called net present value:

$$NPV = present\ value\ of\ all\ benefits - present\ value\ of\ implementation\ costs$$

NPV shows the efficiency of a measure (NPV > 0) but it does not show the degree of efficiency.

Benefit-cost-ratio (BCR)

The benefit-cost-ratio is defined as the ratio between benefits and costs of a measure:

$$BCR = \frac{present\ value\ of\ all\ benefits}{present\ value\ of\ implementation\ costs}$$

The BCR shows the efficiency at all (BCR > 1) but it also shows the degree of efficiency: the higher the BCR the more efficient is the measure. Preferably all costs and all benefits which could be expressed in a monetary dimension will be included. Those are for example:

COSTS

Regarded cost-positions:

- Costs for charging infrastructure (public and private)
- Costs of car production (net costs without taxes and subsidies)

BENEFITS

Benefits result out of decrease of the following cost positions:

- Savings in operating costs
- Savings in noise costs
- Savings in costs of local air pollution (e.g. particles)
- Savings in CO_2-Costs

Regarding that list there are some typical cost positions missing. Normally CBA deals beyond that with costs of time and costs of induced travel. Those cost position are irrelevant in the eMAP-project because there is no relevant difference between electric and conventional cars with regard to these cost positions.

CALCULATING COST-BENEFIT-RATIO

In order to calculate the cost-benefit-ratio it is necessary to have comparable costs and benefits. This means on one hand that we have to express costs and benefits in monetary terms. On the other hand we need to harmonize the regarded time horizon.

We propose to consider all costs and all benefits during the whole period of consideration (2010 to 2030) and to use the net present value of costs and benefits. The differences in the results between the scenarios TeD (PoD) and BaU are used to calculate the costs and the cost-savings of the TeD and the PoD scenario.

Costs of charging infrastructure:

Investment costs and yearly running costs for public infrastructure depend on the number of charging points and on the kind of charging point. The number of charging points is derived from the availability rates out of VECTOR21 calculations. Investment costs of private infrastructure depend on the number of EVs and on the kind of charging point. Investments for private infrastructure are only necessary for those consumers which buy an EV first time. Thus the differences in stock are used to assess the costs.

Costs of car production:

Every car is composed of various components with their respective costs. One part for example is the battery system. If a measure leads to higher number of sales of electrified vehicles, it has a positive influence on the cost development of the battery system. So the costs of car production depend on the sales of the last year. Hence, the costs of car production can differ from scenario to scenario.

Savings in operating costs:

Costs of operating are insurance costs, maintenance costs, repair costs and energy costs. The energy costs for example depend on the energy source and the efficiency of the powertrain.

Savings in noise costs:

In an urban environment e-vehicles are very silent compared to conventional combustion cars. So there are differences in noise emissions between scenarios and the savings in noise costs have to be evaluated. These costs are calculated on the base of the Update of the Handbook on External Costs of Transport (Korzhenevych et al. 2014).

Savings in costs of air pollution:

The savings in air pollution costs are calculated with the help of information about the distribution of the EURO emission standards in the passenger car stock (scenario results) and air pollution cost factors (in € ct/vkm) per EURO standard and fuel type (diesel and petrol car). The air pollution cost factors are multiplied with the mileage of the respective cars depending on the area, where the air pollutants are emitted.

In the Update of the Handbook on External Costs of Transport, for each EURO emission standard (EURO 0 to EURO 6) an emission factor is assigned. This emission factor is multiplied with the appropriate damage cost factor. Marginal external cost values for passenger cars per kilometre are used, which were calculated using damage costs and emission factors. These unit values are representative for the EU and are calculated for the vehicle types actually present on European roads. The air pollution costs in € ct/vkm for passenger cars are differentiated by area and road type, for which respective damage costs are applied.

Savings in CO_2-Costs:

The tonnes of CO_2 emissions, with regard to the different powertrain technologies, are an output of the VECTOR21 calculations. The emissions depend on the fuel consumption, the fuel type and the European energy mix (in case of EV).

Results for the TeD scenario:

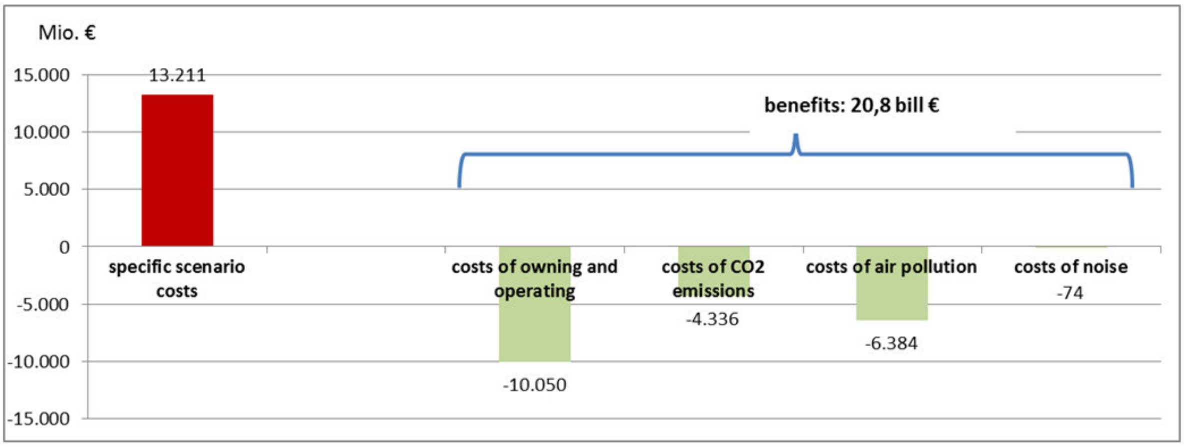

Figure 6: Cost-Benefit-Analysis results for the EU; 2010-2030, net present values, without taxes, without subsidies

In 2030, 31.6 million EV are in the European stock (+44% compared to BaU scenario). There are increasing costs of about 13.2 bill. € and increasing benefits of 20.8 bill. €. The result is a benefit-cost-difference (over 20 years) of about 7.6 bill. €. This corresponds to an average benefit surplus of 380 Mio. € per year and the Benefit-Cost-Ratio amounts to 1.6.

Results for the PoD scenario:

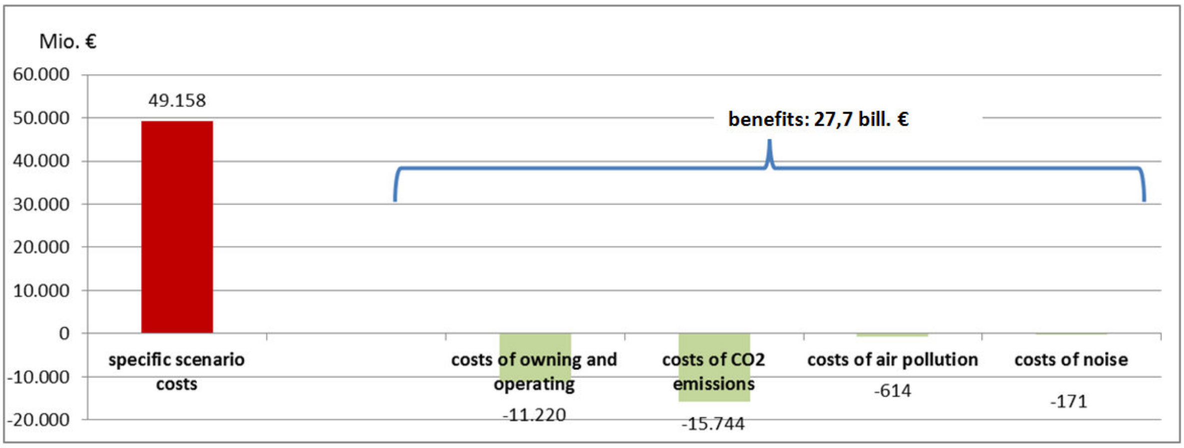

Figure 7: Cost-Benefit-Analysis results for the EU; 2010-2030, net present values, without taxes, without subsidies

In 2030, the PoD scenario has the highest share of vehicles (sales) with charging device of all scenarios. There are increasing costs of about 49.1 bill. € and increasing benefits of 27.7 bill. €. The result is a benefit-cost-difference (over 20 years) of about -21.4 bill. €. So the Benefit-Cost-Ratio amounts to 0.6.

4. Conclusion

The presented article explains a two-step analysis of regulation fostering the deployment of electric vehicles in terms of technological development and a stronger CO_2 emission regulation. In a first step, three scenarios for different regulatory frameworks are created. For each scenario, the deployment path of electric vehicles is simulated by a detailed agent-based vehicle technology choice model (VECTOR21). The model's results allow the analysis of technology diffusion into the passenger car fleet and, thus, the carbon emission reduction potential of electric vehicles. In a second step, the scenario results for the passenger car stock are used in a socio-economic cost-benefit evaluation of the impacts of the market diffusion of electric vehicles. The benefits encompass environmental effects and savings in operating costs, which are expressed in monetary terms. Also the costs for charging infrastructure as well as the costs of car production are taken into account. Hence, the economic analysis is able to show the effectiveness of a stronger emission regulation and of a faster battery system development supporting the introduction of electric vehicles.

The results show, that even in the Business-as-Usual scenario the share of EV will increase mainly due to the assumed CO_2-target in 2030 (75 g/km). The market penetration of electric vehicles on EU-level can be enhanced by both technical and policy measures (regulation). The stronger CO_2 regulation in the PoD scenario is not efficient, because it has a Benefit-Cost-Ratio of 0.6, which is smaller than 1. In the TeD scenario the technological development (in terms of the battery system) leads to a Benefit-Cost-Ratio of 1.6 and thus the scenario is efficient. If technologies develop further and costs for EV components decrease significantly, tightened CO_2 limits could be met without other regulative measures. Also the CO_2 limits in 2021 can be met with a slight electrification and an efficiency improvement of conventional vehicles.

References

EC – European Commission (2011), White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, COM(2011) 144 final, European Commission. Brüssel, 28.3.2011.

Korzhenevych, A.; Dehnen, N.; Bröcker, J.; Holtkamp, M.; Meier, H.; Gibson, G.; Varma, A.; Cox, V. (2014). Update of the Handbook on External Costs of Transport. Final report. RICARDO-AEA, London.

Kugler, Ulrike; Schimeczek, Christoph; Klötzke, Matthias; Schmid, Stephan; Gis, Wojciech, Järvi, Tuuli (2015). D6.2 Scenario report. The eMAP project (electromobility – scenario based Market potential, Assessment and Policy options).

Kurte, Judith; Esser, Klaus; Schimeczek, Christoph; Klötzke, Matthias; Heinl, Felix; Bühne, Jan-André; Balke, Iwona; Gis, Wojciech; Auvinen, Heidi; Järvi, Tuuli; Baum, Herbert (2015). D7.1 Evaluation of scenarios for electromobility. The eMAP project (electromobility – scenario based Market potential, Assessment and Policy options).

Mock, Peter (2009). Market Prospects of Electric Passenger Vehicles and Their Effect on CO2 Emissions up to 2030 (VECTOR21). Presentation on the PHEV’09 – Plug-In Hybrid and Electric Vehicles, Montreal, Sept. 29, 2009

Mock, Peter (2010). Entwicklung eines Szenariomodells zur Simulation der zukünftigen Marktanteile und CO2-Emissionen von Kraftfahrzeugen (VECTOR21). Forschungsbericht 2010-26. Deutsches Zentrum für Luft- und Raumfahrt. Institut für Fahrzeugkonzepte. Stuttgart, Germany.