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Abstract

The primary purpose of this study is to assist a research team of Austrian Institute of Technology (AIT) in development of a decision-making application for fleet managers. This piece of software is designed to solve a kind of combinatorial problem that is a sub-problem of a fleet size and mix vehicle routing problem. Based on the existing literature, decision process of a fleet professional was investigated in order to identify crucial cost parameters related to vehicles. The role and applicability of fully electric and hybrid electric vehicles in commercial fleets were investigated in order to justify introduction of such vehicles in the AIT's computer program. Then, mid-term scenarios for cost parameters of the software package using data available in the literature were created. A moderate number of combinations of costs' scenarios, serving as a tool to model the stochasticity of costs, was generated. Solutions of the application corresponding to each combination were examined. In particular, influence of parameters on the total costs, total emissions and fleet structure was analysed; vehicle routing was not addressed. Additionally, fleet structures of four distinct scenarios were investigated. Finally, recommendations for government structures and fleet managers based on the findings were made. The key outcomes include validation of utilisation of fully electric and hybrid electric vehicles in commercial fleets based on the studied literature. It was supported by high share of alternative fuel vehicles in the analysed fleets. Government authorities are recommended to make more efforts to expand charging infrastructure and financial incentives for buyers of fully electric and hybrid vehicles. It was observed that the support of research and development of zero and low emission vehicles would decrease air pollution. Lastly, transportation companies were recommended to place emphasis on fuel the efficiency of conventional vehicles.

Zusammenfassung

Mit der vorliegenden Arbeit soll ein Forschungsteam am Austrian Institute of Technology (AIT) bei der Entwicklung einer Softwareanwendung zur Entscheidungsfindung bzw. Entscheidungsunterstützung für Fuhrparkmanager unterstützt werden. Eine Funktion dieser Anwendung ist unter anderem das Lösen eines Problems, das auf dem Fleet Size und Mix Vehicle Routing Problem basiert ist. Für dieses sollen im Zuge dieser Arbeit relevante Kostenparameter und Daten evaluiert werden und außerdem die Lösungen, die das Programm liefert, untersucht werden. Insbesondere soll dadurch herausgefunden werden, ob es Sinn macht Elektro- sowie Hybridfahrzeuge in das Computersystem des AIT einzubinden.

Auf Basis von in der Literatur vorhandenen, themenrelevanten Arbeiten wurde der Entscheidungsprozess von Fuhrparkmanagern analysiert, um ausschlaggebende Kostenparameter im Zusammenhang mit Entscheidungen bezüglich der Fuhrparkstruktur zu ermitteln. Eine Vielzahl von Parametern zeigte dabei einen signifikanten Einfluss. Die Parameter wurden in vier Blöcke gruppiert und verschiedene Kombinationen daraus gebildet. Jede dieser Kombinationen wurde dann mit der entwickelten Softwareanwendung getestet und die Lösungen analysiert, insbesondere der Einfluss der Parameter auf Gesamtkosten, Emissionen und die Zusammensetzung des Fuhrparks. Die Lösungen enthalten auch Informationen hinsichtlich des Vehicle Routing Problems - dieser Teil spielte jedoch in unseren Untersuchungen keine Rolle.

Unsere Resultate bestätigen unter anderem die bereits in anderen Arbeiten gezogene Schlussfolgerung, dass Elektro- und Hybridfahrzeuge in einen Fuhrpark integriert werden sollen. Demzufolge sollten Regierungsbehörden in die Infrastruktur für alternativ betriebene Fahrzeuge investieren und finanzielle Unterstützung für deren Kauf gewähren. Die Ergebnisse zeigen des Weiteren, dass durch die Verwendung von solch umweltschonenden Fahrzeugen die durch den Güterverkehr verursachten Abgasemissionen beträchtlich reduziert werden können. Außerdem sollen Transportunternehmen im Falle von herkömmlich betriebenen Fahrzeugen besonderen Wert auf deren effizienten Einsatz legen.

Contents

Acronyms

EV – Electric Vehicle, a vehicle moved by an electric motor

PHEV – Plug-in Hybrid Electric Vehicle, a vehicle that utilizes a combination of internal combustion engine and electric motor

ICEV – Internal Combustion Engine Vehicle, a conventional vehicle with internal combustion engine only

BEV – Battery Electric Vehicle, here is a synonym to EV

AFV – Alternative Fuel Vehicle, it is applied mainly to both EVs and PHEVs

1 Introduction

The present paper studies the problem of fleet management. A fleet manager is a professional whose role is to make decisions regarding the size and composition of a vehicle fleet. He plans when to sell an old vehicle and when a new one (if necessary) should be purchased. The manager is also responsible for making a choice between vehicle models available for acquisition. These tasks are interconnected, which makes them complex. A piece of software can be used to assist analysing influential aspects and produce a good advice for a fleet manager.

Austrian Institute of Technology (AIT) has recently developed such a planning application. This thesis was written in collaboration with the research institute that takes part in the VECEPT project. The project was started in July 2012 and it is supported by Climate and Energy Funds of Austrian government. The goal of the VECEPT is to promote and assist market development of PHEVs and EVs.

In the core of the software package is an algorithm that solves a combinatorial problem. Fleet size and mix vehicle routing problem (FSMVRP) was modified and serves as a basis for the application. A transportation network with a set of customers distributed across it are considered. The goal is to provide the fleet composition and routing plan for vehicles across the network to satisfy customers' demand.

According to a recent literature review by Koç Ç. et al, the existing literature follows a simplified approach to model costs. Two types of costs for each vehicle are considered: fixed and variable. Furthermore, all models are deterministic in terms of costs. Only a study by Teodorović D. et al addressed stochasticity, in the form of uncertainty of customers' demand. Some papers such as (Jabali O. et al, 2012) include a sensitivity analysis of influence of costs on solutions. Juan A. et al consider EVs as alternative vehicles and address their range limit. The authors introduced a new type of FSMVRP where vehicles are supposed to have various driving ranges. They showed that the inclusion of AFVs results in only a slightly larger total distance travelled as compared to completely conventional fleets.

Present state of research lacks considering costs in a more detailed way. It makes sense to consider disintegrated costs (fuel costs, maintenance, etc.) and parameters directly associated with them (fuel consumption, energy efficiency). However, the list of these costs and parameters is absent. Another gap is the assumption that costs are deterministic. Finally, it is still unknown how cost parameters effect total costs and total emissions, and the decision of a fleet manager regarding the fleet composition.

Researchers of AIT modified formulation of FSMVRP. They introduced EVs and PHEVs and implemented a wide range of costs related to fleet vehicles instead of the simplified approach of fixed and variable costs. The authors also modelled the stochasticity of costs by considering different scenarios of future cost changes. Another feature of the model is that it takes into account alternative means of transportation (outsourcing, public transport). However, some simplifications to FSMVRP were done for computational reasons.

Among the goals of this thesis is to assist AIT in developing a list of cost parameters based on available literature. The study generates master scenarios of cost parameters evolution until 2019. Numerous solutions each corresponding to a master scenario were analysed in order to reveal the effect of parameters on total costs and emissions of the solutions. An emphasis was put on the analysis of fleet' structure and the role of EVs and PHEVs. Details of development of the decision-making software are not addressed.

2 Fleet manager's decision process and role of electric vehicles

2.1 Introduction: Chapter 2

When a fleet professional makes his decisions regarding vehicle fleet under supervision, he considers a set of quantitative and qualitative factors. Austrian Institute of Technology developed a decision support application that is supposed to consider the same parameters in order to simulate fleet manager's way of thinking. In the given chapter, these factors are identified, and the process of decision making of a fleet manager is investigated. Special emphasis is placed on the role of electrical vehicles.

Beginning of this part is devoted to comparison of contrast approaches to choosing a new vehicle. The methods are discussed in the light of features of EVs and PHEVs. Procedure of a new vehicle selection can be triggered by a fleet renewal strategy. Three possible renewal policies present in the literature are compared and criticised. Vehicles powered by electrical motor are still new and largely unknown for fleet professionals. It is important to address the reasons EVs and PHEVs experience difficulties with entering the market. These vehicles have a set of disadvantages that lead to certain market barriers discussed further. However, commercial companies already purchase electric vehicles nowadays, and their incentives are analysed. Current critical disadvantages of EVs and PHEVs are supposed to be removed as seen in the further discussion. Studies show that the new technology will occupy a larger market share if the revealed barriers are removed. Conclusions are drawn in the end of the part.

2.2 Key factors of fleet acquisition

One of the crucial decisions a fleet manager has to take is to choose the right vehicles to extend or renew fleet. Two main approaches to compare candidate vehicles to be purchased are considered in this paragraph. One of them is more complex and the other is a basic rule of several elements. Both approaches are used by fleet managers simultaneously and suit for different stages of comparison. The first one is based on the concept of total cost of ownership (TCO) which combines all the costs associated with a vehicle during its utilization. Typically, these costs can be grouped as follows (Dolce, 1992): Operating expenses, Investment cost, Salvage price, Depreciation, Insurance, Administrative expenses, Licences and taxes, Parking and tolls.

Operating expenses are associated with purchasing fuel, oil and tires; providing required maintenance and occasional repairs. Investment costs include the price paid for a vehicle, or total leasing payments and the interest to be paid in case of a credit. Salvage price is the possible income from selling the vehicle at the end of its usage period. Vehicle depreciation has an indirect impact on the company's cashflow as it effects financial reports and decreases income before tax. A vehicle has to be insured at least by a compulsory insurance program. According to Currie R. and Currie M., administrative expenses are related to purchasing, human resources, management information system, accounting and processing, tracking expenses and reporting. Transport companies usually have to purchase special licenses to be able to operate in the desired field of business.

The enlisted costs can be sufficiently different for comparable models of electric vehicles (EV) and internal combustion engine vehicles (ICEV). Operating costs are considerably lower for EVs as they require fewer regular tune-ups and no oil changes. Faria R. et al and Gass V. et al argue that EVs do not have such components as water pumps, timing belts, radiators, tailpipes and fuel injectors.

According to the catalogue prices of vehicle producers, AFVs are significantly more expensive than ICEVs. For instance, a good model to compare would be "VW Up!" which is produced both with electric and internal combustion engines. In Austria the price for the electric one is as high as EUR 25,630 (Volkswagen, e-up!) whereas for the most expensive model with petrol engine "sky up! BMT" it is EUR 14,030 (Volkswagen, up!). Selling a used EV is generally seen today as a problem and will be discussed further.

Basic bookkeeping rules state that depreciating of a more expensive asset brings a bigger reduction of profit before tax ceteris paribus (Needles B.E., Powers M., 2011). The last two groups of costs might be lower for EVs as Austrian and other European governments make efforts to introduce additional financial incentives to encourage acquisition of AFVs. These measures include registration and purchase taxes depending on CO_2 emission level, circulation or motor tax depending on the engine power, cylinder capacity or fuel consumption and fuel tax (Gass V. et al., 2014).

An alternative approach to choose a new vehicle is applicable at the early stage of decision process. Nesbitt and Sperling showed that a candidate vehicle is assessed according to these criteria: suitability (whether the vehicle can perform adequately in its intended application), experience with vehicle (and/or manufacturer), purchase price. Hoff A. et al categorised vehicle's suitability in more details as follows:

- Product types to be carried
- Where the vehicle can travel
- Special equipment installed (load/unload)
- Special certificates to operate in the area (noise, gas and particles emission)
- Special vehicles to transport special goods (dangerous, oversized)

A possible combination of the mentioned approaches could be using the second one to shorten the list of candidates and the first method to make a final decision. The whole process of comparing candidate vehicles can also be triggered by a vehicle replacement strategy approved in a company. Basic approaches to replacement policy are discussed in the succeeding paragraph.

2.3 Basics of replacement strategies

According to common sense, a vehicle can stay effectively operational in a fleet only a limited amount of time. Another key job of the fleet manager is to develop and carry out a replacement strategy suitable to a particular business. In literature, there are at least three basic approaches to vehicle replacement.

The one presented by Dolce is based on comparison of relative total costs (per hour/year or mile), that will occur if a company keeps the old vehicle, to the costs referred to a new vehicle. An annual review of the whole fleet is usually performed to make a decision, which vehicle to replace taking into account the following key factors:

- Strategy of the company
- Amount of money borrowed and interest for old and new vehicle
- Old and new vehicle maintenance cost
- Old vehicle salvage price
- Old and new vehicle operating costs
- New vehicle manufacturer's incentives

A company may plan to grow what might require increasing its fleet, so it could be reasonable to keep vehicles longer at least during the growth phase. There are also strategies requiring a decrease in fleet size. Usually, the credit to be returned and the interest to be paid for the old vehicle decrease while maintenance and operating costs grow. A manufacturer may offer financial incentives for purchasing a new vehicle (quantity discounts) which may be significant enough and influence the decision.

Though this method utilizes the concept of total cost of ownership, it contains only flexible recommendations and does not offer a clear procedure to implement it. Another drawback is that the approach does not take into account the specific nature of AFVs. As the reader will see further, there are qualitative incentives for a company to purchase an AFV which are absent in the factors above. Besides, as mentioned above such costs as insurance, licenses, taxes, tolls and parking fee can be significantly lower for AFVs but not present in the method under discussion.

An alternative approach presented by Schiller is based on vehicle's age and mileage. It involves three strategies depending on priorities of a company. Strategy 1 aims at optimizing salvage value while minimizing downtime and maintenance costs. The recommended policy would be to replace a vehicle after four years of service or less, or after 60,000 miles travelled or less. This strategy is suitable for companies which main goal is minimizing downtime and keeping good image. Strategy 2 optimizes salvage value and minimizes capital and maintenance costs. Replacement policy here: 4-8 years, 60,000-100,000 miles. The strategy is balanced and provides effective vehicle utilization until it becomes too old and brings significant costs and downtime. Minimizing capital costs is the goal of the strategy 3. Replacement policy: eight years or more, 100,000 miles or more. Downtime and company's image do not play an important role.

This approach is not flexible enough. It will fail to provide a timely recommendation to replace a vehicle when a new significantly more cost-effective vehicle becomes available for purchase or an owned vehicle started to cause too much costs.

Another straightforward method to identify a vehicle to be replaced is to consider downtime and maintenance costs of a vehicles (Currie R., Currie M., 2006). For each vehicle, one could compute the share of its downtime in the whole working time for similar vehicles. The vehicle with the downtime share significantly higher than for the others would be a good candidate. Another indicator of a required replacement is maintenance costs, i.e. their steep rise or difficulties in their prediction.

Criticism of the first approach regarding AFVs is also appropriate here. The third method depends on the choice of a threshold for downtime share and maintenance cots growth, and there are no recommendations how to set them. As it concentrates on downtime and particular type of costs, the method neglects all the other costs. It might be more suitable for a firm targeting low downtime with minimal maintenance costs; however, a company may prefer another strategy.

2.4 Current AFVs' market barriers and opportunities

Alternative fuel vehicles such as EVs and PHEVs are still uncommon on the modern vehicle market. However, Sierzchula W. et al argue that during 1991 - 2011 development of AFVs showed considerable progress, as number of models, companies and technologies involved increased significantly. Development of the new technology innevilably draws attention of fleet managers. The following is devoted to current problems EVs have to face on the vehicle market and incentives a company may have to extend its fleet with an EV.

Authors of the final report of PROCURA project managed by the Euro Commission (Mönter M., Escriba L., 2009) and an article by Koetse and Hoen point out negative factors related to AFVs nowadays:

- Final investment
- Status
- Reliability on new technology
- Limited driving range
- Risk of a low second hand value
- Necessary supporting schemes
- AFVs on the whole are more expensive than ICEVs
- Long recharge time
- Limited availability of refuelling opportunities

The first term is price for a new AFV that is higher than for an ICEV due to high production costs of battery pack (Faria R. et al., 2012). Users may consider some AFV models as being not adequate to their social or official status. Electrical or hybrid power train, as a new technology in the early phase of its development, may seem to be not reliable or efficient enough. According to Tushman and Anderson, such a drastic innovation as EV increases uncertainty for the involved parties and results in another market barrier. Moreover, Turrentine argues that many potential adopters of EVs are not informed about their fuel-efficiency good enough, i.e. their rational choice is bounded.

Although the limited driving range is one of the disadvantages, the modern models can travel 150-210 km (topprodukte.at, 2014). It does not contradict with the annual mileage required to keep an EV economically feasible. According to a research by Feng and Figliozzi, a commercial EV has to travel about 25,749.5 km per year. It corresponds to 104.2 km per day if we consider 247 working days in Vienna, Austria in 2014 (arbeitstage.at). Thus, modern range of EVs might suffice for a commercial vehicle.

As discussed by Foxall, since there might be no established second-hand market of AFVs and every next generation of AFVs is significantly better than the previous one, EVs lose their value very fast over time. Moreover, Golson argues that in the light of current government financial incentives to buy a new EV, it might be more expensive to purchase a used one.

Government grants still pay a significant supporting role for AFV's sales; demand may decrease in case they are cancelled. Countries with developed financial incentives and local manufacturing facilities of EVs tend to have a bigger market share of EVs (Sierzchula W. et al, 2014b). TCO of an AFV may be higher than for an ICEV. Faria et al suggest that it may take up to 10 years to compensate the higher purchase price of an EV with lover operational costs.

There is still a significant difference in the recharging time of the most EV models and conventional ones. This loss of productive time leads to an increase of driver's wage as has to work longer (Nesbitt K., Sperling D., 1998). Another drawback of EVs is the shortage of recharging stations. According to Sierzchula et al (2014b), presence of a local EV manufacturing facilities contributes to development of recharging network.

In spite of these disadvantages, up to 26% of private car travellers in Germany could substitute their current vehicle with an EV (Weiss C. et al., 2014). This conclusion indirectly relates to commercial fleets, because some fleet vehicles are used for needs similar to those for a private driver, e.g. driving around a city. Moreover, commercial fleet managers already show their interest in the new technology. A survey (Sierzchula, 2014a) of 14 US and Dutch organizations that adopted EVs from 2010 to 2013 showed that companies do purchase EVs nowadays despite the discussed market barriers. The main reasons for them to do so were:

- Testing new technologies
- Lowering company's environmental impact
- Improving the organization's public image
- Government grants

Authors of the fleet manager's guide by Volkswagen mention: "All-electric: At the moment models available are small, expensive and have a limited range. However, new technology is continuing to bring them closer to the fleet market." Companies dealing with vehicles professionally are willing to get their own experience with the new technology in order to evaluate its possible further application. This meets the expectations of Nesbitt and Sperling that commercial firms will be among the first to adopt EVs. The next two incentives from the list above are considered to be connected by the authors. The third motivation is a phenomenon known as "greenwashing" (Ramus C., Montiel I., 2005) when a company introduces some green technology primarily in order to enhance its public image. Financial aid from government played a role for eight out of fourteen firms in the sense that it compensated uncertainty of using the new technology and high prices of EVs.

Sierzchula also revealed that seven companies decided afterwards to extend their EV fleet, four decided not to do it and the remaining three were still thinking. The main incentives to expand an EV fleet were:

- First-mover advantage
- Specialized operational capabilities
- Appealing business model
- Lower environmental impact
- Improve firm's public image

These reasons were firm specific, some companies were targeting a first-mover advantage from adopting the new technology. The others were using EVs as a specialization tool or managed to build a profitable business model. The author also shows reasons not to expand EV fleet (with current generation):

- Not viable
- Lack of operational capabilities
- Driving range lower than expected

Six public and nine private companies took part in the survey. Public companies came from different levels: city, state, national, and private ones represented taxi businesses, industry, car sharing and car renting. Each public company had more than 50 employees; private firms were of different size ranging from small start-ups to international corporations. The firms were utilizing such plug-in hybrid-electric and fully electric vehicles as Nissan Leaf, Chevrolet Volt, Peugeot iOn, Toyota Plug-in Prius, other low-speed EVs and larger maintenance and utility vehicles. Number of vehicles in fleet varied from three to several hundreds.

2.5 Expected AFVs' position on the market

Despite the fact that EVs face serious market problems discussed in the previous paragraph, evidences prove that EVs have potential on the market. Papers discussing improvements of EV users' experience as well as solutions to the key problems of the current generation of EVs are discussed in the given paragraph.

Wikströma et al conducted a research aimed to evaluate utilization experience of EV users. A group of respondents was giving feedback several times on their experience of using a commercial EV during 18 months in Sweden. The main results are as follows:

- Users started to charge less frequently at not-home chargers
- Users tend to take longer journeys
- Vehicles assigned to a single user increased monthly mileage by 51.4%
- More respondents want to have extra EVs in their fleet
- More respondents could consider increasing of EV fleet
- Users report a higher satisfaction with driving range
- Satisfaction by charging process increased

Over time, users' experience with an EV increases and that allows estimating daily driving range more accurately. As the result, more users decide not to charge during the day at charging stations located somewhere not at the default charging point. They also can rely on driving range and take longer journeys. Users reported having less problems with charging due to faulty power outlets and handling problems, i.e. incorrect positioning of charging plug. Table 1 represents how the respondents used their vehicles.

Entity vehicles are those used by a single user, service vehicles are used in a fixed scenario with little flexibility. Multiple users use pool vehicles, and their assignments may vary. Showroom vehicles are used to promote EVs and for test-drives.

A choice experiment on preferences of company car drivers (Koetse M., Hoen A., 2014) modelled choice decision by company car drivers to pick a conventional vehicle or an AFV. The essence of the experiment was to vary key characteristics of the AFV in order to see how it influences the choice. The results reveal that improvements in critical disadvantages of AFVs such as:

- Limited driving ranges
- Long recharge/refuelling times
- Limited availability of refuelling opportunities

would dramatically increase preference of AFVs over ICEVs. The same key factors were identified in the other papers analysing private car drivers' preferences by Hidrue et al as well as Potoglou and Kanaroglou.

Major results of the experiment show that if selling prices and monthly contributions were equal, better recharging infrastructure and models variety were available, AFVs would be even preferred to conventional ones. Another finding is that taxation favouring clean technologies has a big impact. The authors conclude that the level of AFVs adoption will increase in the medium and long run. Preference for EVs is highly influenced by annual mileage. EVs are more preferred for small annual mileage, and this contradicts with the fact that EVs are economically beneficial in case of high annual mileage.

Table 1
Vehicle usage patterns

Pattern	*Number of vehicles*	*Share of vehicles, %*
Entity vehicles	8	16
Service vehicles	17	34
Pool vehicles	21	42
Showroom vehicles	4	8

Source: (Wikströma M. et al., 2014)

Table 2
Degree of urbanization of the respondents' habitat

Urbanization Category (inhabitants/km2)	*Share, %*
Non urbanised (less than 500)	13
Little urbanised (500–1000)	18
Moderately urbanised (1000–1500)	27
Urbanised (1500–2500)	27
Very urbanised (2500 or more)	15

Source: (Koetse M., Hoen A., 2014)

In literature, there are discussions regarding the future of AFVs, and they include such topics as TCO, battery pack price, market share, optimal battery capacity, recharge time, and availability of charging stations. Gass V. et al analyse possible future cost competitiveness of EVs. An EV would have been comparable in terms of TCO with ICEV in 2011, if annual mileage had been 19,500 km or battery costs had reached 480 EUR/kWh. The authors expected Nissan Leaf and Mitsubishi i-Miev to be cost competitive by the year 2012/13 in case of mass production with the corresponding economies of scale. According to Dinger et al, TCO of an EV will be the same as of an ICEV after 9 years of exploitation without financial incentives by 2020 in Western Europe.

Dinger et al support the expected decrease of battery pack price and predict battery costs to drop to \$360 - \$440 by 2020. It was assumed that the share of EVs and hybrids sales will reach 26%, and all the EVs and 70% of hybrids will be equipped with lithium-ion batteries. Although, a forecast of the German Federal Government assumes that battery prices will remain high until 2020 and fall only thereafter. According to the prevailing opinion in literature, the batteries will cost less in the future, but there is ambiguity regarding when and how much will it go down in price. Reduction of battery price will dramatically lower final price of an EV.

Kihm and Trommer estimate share of EVs and plugged-in hybrids in new cars sales as high as 7.6% by 2020 in Germany. Zubaryeva et al argue that EVs will reach 10-20% of new cars sales by 2020 in Europe. Another estimation forecasts AFVs to reach 33-38% share of new car sales by 2020 in Germany (Propfe B. et al, 2013). These forecasts do not converge, and even the most modest estimate of 7.6 % indicates that AFVs will play an important role in the future car market and might become much more beneficial for business.

Redelbach et al claim that the optimal battery capacity to minimize TCO from a consumer's point of view is 6 kWh for 15,000 km travelled per year and 13 kWh for 30,000 km under German market conditions. These estimations are provided for the latest generation of so-called extended range electric vehicles (EREVs). These cars contain an internal combustion power generator aimed solely to produce electric power when battery is depleted to a certain level. As mentioned in the previous section, we assume that commercial vehicle hast to travel 25,749.5 km per year, so the optimal battery size should be within 6-13 kWh. Batteries being installed on the modern EREVs even exceed those values. Opel Ampera and Chevrolet Volt have battery capacity of 16 kWh (topprodukte.at, 2014), BMW i3 - 18.8 kWh (BMW, 2013). This leads to a conclusion that the required optimal driving range might have already been reached for a considerable share of business applications of EVs.

Grünig addresses the problem of long recharging time. He claims that available technologies are already able to reduce battery recharging time to the levels comparable with refuelling an ICEV. However, such fast charging is more hazardous and may reduce life cycle of battery.

It is likely that the problem of availability of charging stations will remain in the near future. There is no economically feasible business model to run such a station due to high capital costs, low returns and relatively long charging duration (Grünig, 2011).

2.6 Conclusion: Chapter 2

The crucial findings are:

- From the costs point of view EVs have advantages and disadvantages
- Today total cost of ownership of an AFV can be bigger than of a conventional one, however TCO of EV will decrease in the future
- Currently application range of AFVs for fleets is limited though present
- Current AFVs models can be used when they suit a business model
- Improvements of critical market barriers for AFVs will take place and will lead to increase of their adoption
- Governments (taxation, financial incentives) could help to introduce AFVs
- For a significant share of business tasks EVs are good enough or even better than ICEVs

These points allow drawing a conclusion that it makes already sense to include EVs in commercial fleets. Moreover, as the new technology improves, the key market barriers will be overcome and the sphere of EVs implementation will get wider. We argue that fleet managers should consider EVs among the other conventional vehicles during the process of fleet composition or renewal.

The traditional approach to a fleet manager's decision process has major problems. Fleet composition and vehicle replacement are seen as separate processes, whereas they are strongly integrated. As mentioned by Nesbitt and Sperling, only 24% of fleets carry out a life-cycle cost analysis, and the rest make their choice based mostly on qualitative criteria. This may lead to a solution away from the optimal one. The detailed cost analysis approach exists but at least in the available literature it is not formalized and too flexible. Its another disadvantage is that it takes a lot of fleet manager's effort and time to conduct such an analysis, and they do it usually only once per year. Emission are usually seen purely as costs in terms of emission tax, but a manager might be interested in comparing possible decisions with different pollution levels. Total emissions can be seen as another objective function, and then the decision maker has a set of solutions with different combinations of emissions and total costs to choose the preferred one. Further improvement could take into account development of key costs in time; one could also consider various possible scenarios of their alteration.

3 Mid-term forecast of parameters of the fleet-management software package

3.1 Introduction: Chapter 3

In the previous chapter, the decision process of a fleet manager was considered. The accent was made on the specific related to vehicles factors that have a crucial influence on manager's decision. These parameters are further used in an optimisation algorithm that is designed to help a fleet manager to make decisions. The application is supposed to solve a fleet composition and routing problem, i.e. provide at least a near-optimal plan of purchasing specific new vehicles and selling old particular ones from the existing fleet. The routing part of the algorithm is responsible for assigning a vehicle from the fleet to a specific trip. Further discussion of development and details of the piece of software is outside the scope of the given thesis. The second chapter concentrates on the parameters of the algorithm, and the list of them is as follows:

1. Fossil fuel price
2. Electricity price
3. Emissions by outsourcing vehicle
4. Emissions of the substitute vehicle
5. Emissions by public transport
6. Coverage by charging stations
7. Grants to support EVs
8. Demand on rental vehicles
9. Outsourcing costs
10. Costs on a substitute vehicle
11. Energy consumption by vehicles
12. Battery range
13. Fuel usage
14. Emission using fuel
15. Acquisition costs
16. Vehicle salvage price
17. Maintenance costs
18. Public transport costs

The first objective of the given chapter is to conduct a literature research and find forecasts of the parameters' values for the years 2015 – 2019. Three scenarios are supposed to be constructed for each parameter. It was not always the case that the required data could be taken from the source without any alterations. Extrapolation of historical data was applied for certain parameters, or data for the present were assumed to stay constant in the future. Other approaches included rough estimations, assuming some reasonable values, calculations based on related parameters. In addition, the future user of the application served as a valuable source of data being an expert in the field of fleet management. Each parameter is discussed in the separate paragraph of the given chapter.

The second objective is to create a moderate number of so-called "master scenarios"; each of them is a certain combination of scenarios of individual parameters. Parameters were grouped in four blocks and all the possible combinations of scenarios of these blocks were enumerated using a program written by the author for that purpose.

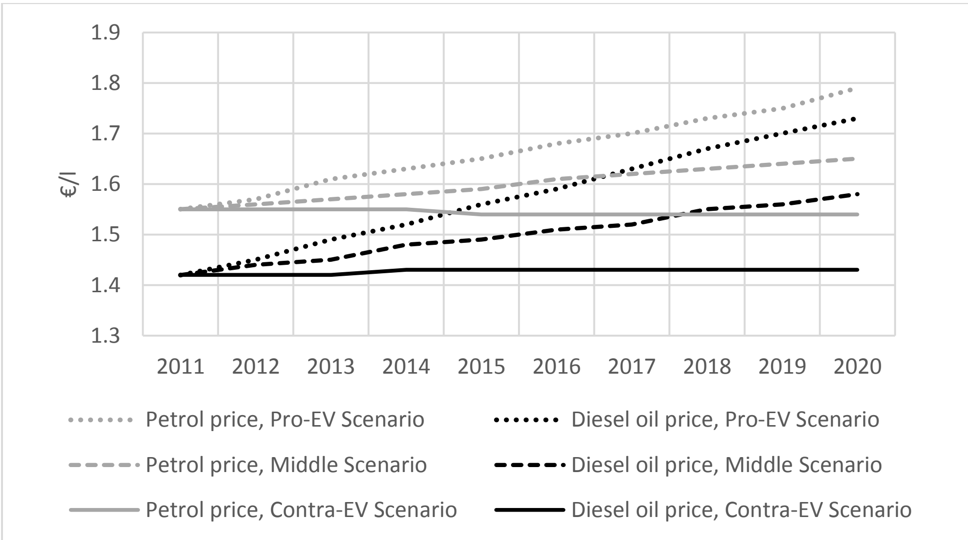
3.2 Fossil fuel prices

The majority of vehicles on the roads nowadays are running on fossil fuels such as petrol and diesel oil. Fuel costs constitute a great share of total cost of ownership of e a vehicle. Fuel prices are not stable, and historical data show significant changes over time. In this section, prices projections from two reports are compared, and one of them is chosen as a basis. Then, German fuel prices are adjusted to Austrian market, and three scenarios of prices development are created.

In the report "Markthochlaufszenarien für Elektrofahrzeuge", Plötz P. et al. derive future fuel prices in Germany from raw oil prices. They assume that fuel price consists of the following: VAT, petroleum tax, marginal return and raw oil price. Taxes for petrol and diesel are assumed to stay constant at the level of January 2013 until 2020.

Plötz P. et al base their estimations on a report World Energy Outlook (WEO) 2012. New Policy Scenario from the publication is taken as a Middle scenario. To create the Pro-EV scenario the authors increased values of the New Policy Scenario by 20%, for the Contra-EV scenario decreased by 20%. Fuel prices are forecasted in such a way for the year 2020, and linear interpolation was applied to get intermediate prices between 2011 and 2020. Fuel prices are assumed to be the same for households, commercial companies and industry. In Figure 1 and in Table 29 in Appendix 1: Data tables one can see the prices the authors forecast.

Figure 1
Fuel prices in Germany



Source: (Plötz P. et al, 2013)

Another research "Plug-in Hybrid Electric Vehicles for CO_2-Free Mobility and Active Storage Systems for the Grid (Part 1)" performed by E.ON Energy Research Center is based on historical data from "Entwicklung von Energiepreisen und Preisindizes" by Federal Ministry for Economic Affairs and

Energy, Germany. Petrol prices are forecasted to reach 2.3 €/l in 2020 using linear extrapolation, while taxes are assumed to be constant.

After comparing the forecasts performed by Plötz P. et al and E.ON Energy Research Center, a decision was made to use the former one. The petrol price predicted by E.ON Energy Research Center at the level of 2.3 €/l is to too high. Moreover, the approach of Plötz P. et al is more preferable because it has stronger methodological background. However, some additional work has to be done, i.e. the projections for Germany should be adjusted to Austrian prices. For that purpose, the following procedure was applied (with an assumption that Austrian prices will develop in the same manner as in Germany):

1. Calculate a ratio of petrol prices in Austria to prices in Germany for the previous years
2. Forecast the ratio of petrol prices in Austria to prices in Germany for 2020
3. Calculate a ratio of diesel oil and petrol prices in Austria for the previous years
4. Forecast the ratio of diesel oil and petrol prices in Austria, 2020
5. Derive petrol price in Austria, 2020 using the forecast of Plötz P. et al for Germany, 2020 and the ratio of petrol prices in Austria to prices in Germany
6. Derive diesel oil price in Austria, 2020 by adjusting petrol price in Austria, 2020 using the ratio of diesel oil and petrol prices in Austria, 2020
7. Interpolate missing prices in Austria between 2014 and 2020

To execute the first step average yearly petrol prices 2005 – 2014 in Austria and Germany were calculated based on the data available in Weekly Oil Bulletin and Oil Bulletin Price History published by European Commission. The ratio of petrol prices in Austria to prices in Germany was calculated for the years 2005 – 2014. At the second step, the forecasting tools available in Excel were applied in order to perform a linear extrapolation of historical data up to 2020.

It would be rational to carry out the same procedure for diesel oil prices, but it leads to the result that in the last years of the period 2014 – 2020 diesel oil price is higher than the price of petrol. Actually, it happened before in Austria, namely in 2008, that diesel oil was more expensive. Schüller mentioned in his article that diesel oil prices were lower than petrol prices 1985 – 2007 in Austria. In 2008, the diesel oil cost more than petrol mainly because of the dramatic increase of demand for diesel oil. According to our calculations, since 2009 up to 2014 the average yearly diesel oil prices were lower than petrol prices again. Thus, in the recent history it was common to have diesel oil cheaper than petrol, assume that this tendency will be kept. Therefore, another way will be applied to derive diesel oil prices in Austria.

To do the third step the ratio of diesel oil and petrol prices in Austria was calculated for the years 2014 – 2020. A procedure similar to the step 2 was used to extrapolate the ratio of diesel oil and petrol prices in Austria until 2020. The results for the steps 1- 4 are given in Table 64, Appendix 2: Intermediate calculations. At the step 5 the petrol price in Germany, 2020 was multiplied by the ratio of petrol prices in Austria to prices in Germany to get the petrol price in Austria in 2020. Diesel oil prices in Austria 2020 are derived from petrol prices in Austria 2020 by multiplying it by the ratio of diesel oil and petrol prices in Austria, 2020.

Finally, the prices for the years 2015-2019 for the Pro-EV and the Middle scenarios were obtained by linear interpolation. For the Contra-EV scenario the prices were assumed to be constant as in the forecast of Plötz P. et al. Table 3 and Figure 2 present the result of the calculations. Numerical data for prices are given in Appendix 1: Data tables, Table 30.

Figure 2
Scenarios for petrol and diesel oil prices in Austria 2014 – 2020

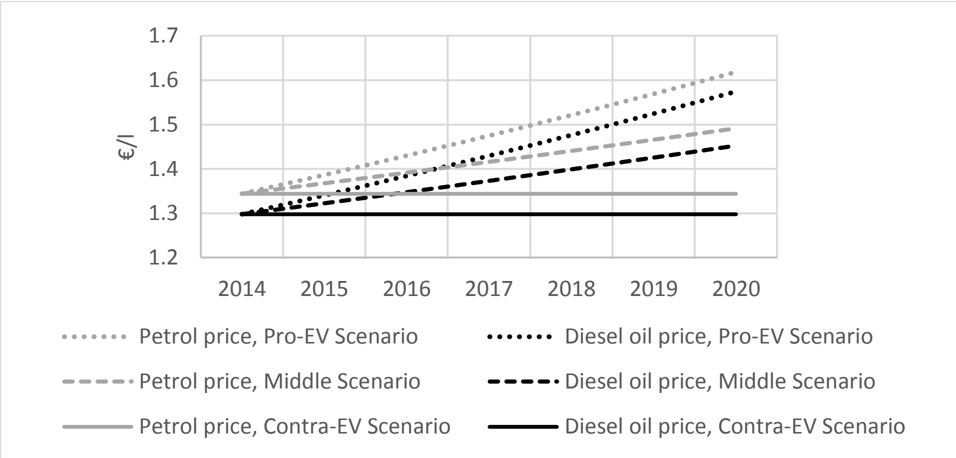


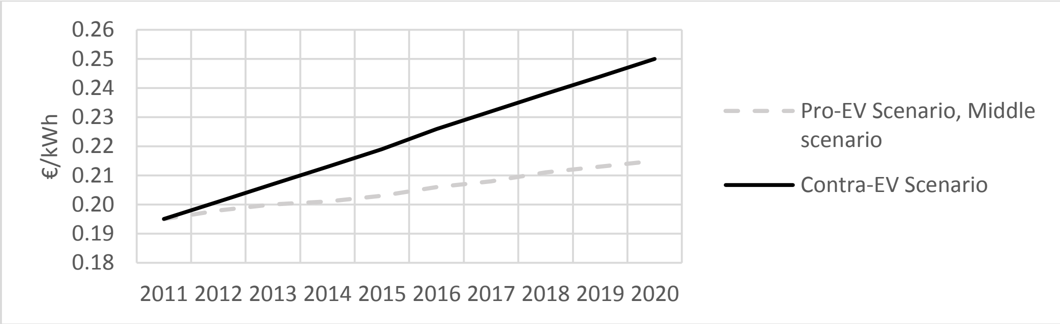
Table 3
Relative change of petrol and diesel oil prices in Austria, 2014 – 2020

Parameter\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Petrol price, (Pro-EV)	-	0.031	0.031	0.031	0.031	0.031	0.031
Diesel oil price, (Pro-EV)	-	0.033	0.033	0.033	0.033	0.033	0.033
Petrol price, (Middle)	-	0.018	0.018	0.018	0.018	0.018	0.018
Diesel oil price, (Middle)	-	0.019	0.019	0.019	0.019	0.019	0.019
Petrol price, (Contra-EV)	-	0.000	0.000	0.000	0.000	0.000	0.000
Diesel oil price, (Contra-EV)	-	0.000	0.000	0.000	0.000	0.000	0.000

3.3 Electricity prices

The second type of "fuel" in the given work is electricity, which is used to supply EVs and electric motor of PHEVs. Plötz at al considered several electricity price forecasts conducted by different agencies. The authors used the forecast by McKinsey for the Middle scenario, and projections by BSG for the Contra-EV. The Pro-EV scenario coincides with the Middle one. Using the forecasts, Plötz P. et al calculated prices for 2020 and linearly interpolated missing values from 2011. The forecast by BSC splits prices for households and commercial customers, so no additional work was required to distinguish prices for them. Electricity prices by Plötz P. et al for trade and commercial companies are given in Figure 3. For the numerical values, refer to Table 31 in Appendix 1: Data tables.

Figure 3
Electricity prices in Germany



Source: (Plötz P. et al, 2013)

Electricity prices in Austria are derived based on the forecast for Germany by Plötz P. et al. Assume that electricity prices in Austria will develop in the same way as in Germany and apply the following procedure to the projections of the authors:

1. Calculate a growth rate 2013 – 2020 of the prices by Plötz P. et al
2. Find the average industrial price for Austria 2013
3. Calculate prices for Austria in 2020 using the growth rate 2013 – 2020
4. Interpolate Austrian prices 2014 - 2019

Simple calculations showed that, according to the projections of Plötz P. et al, prices will increase 2013 – 2020 as follows: Pro-EV and Middle scenarios by 7.5%, Contra-EV scenario by 20.773%. Next, in order to estimate prices in Austria, the prices of 2013 (available from Statistik Austria at the level of 0.106 EUR/kWh) were used as a basis. Average industrial electricity prices are available for the potential user of the application under development. Increasing this price by the corresponding growth rates gives an estimation of prices in Austria in 2020. Linear interpolation allows completing Figure 4 and the corresponding Table 32, Appendix 1: Data tables. Table 4 represents relative change of prices.

Figure 4
Electricity prices for commercial companies in Austria 2013-2014

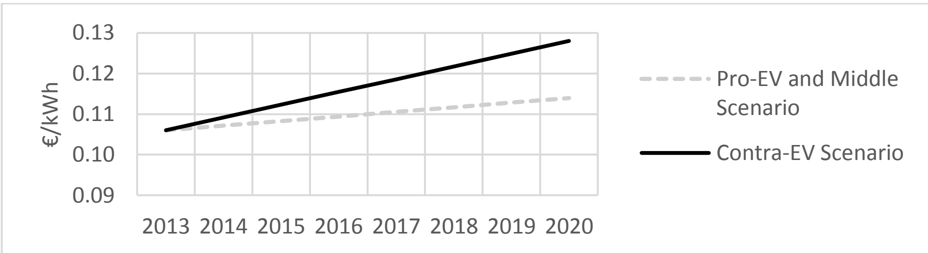


Table 4
Relative change of electricity prices for commercial companies in Austria 2013-2014

Scenario\Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Pro-EV	-	0.011	0.011	0.010	0.010	0.010	0.010	0.010
Middle	-	0.011	0.011	0.010	0.010	0.010	0.010	0.010
Contra-EV	-	0.030	0.029	0.028	0.027	0.027	0.026	0.025

3.4 Coverage by charging stations

EVs and PHEVs use electricity as a main or supplementary source of energy, and recharging is required at least once a day in case of a moderate mileage. A motorist may need to recharge vehicle's batteries at some public recharging station or a charging point. Availability of a proper recharging network is a crucial factor of EVs' and PHEVs' adoption. Further, an attempt is taken to quantify coverage by recharging stations. Information one can find related to estimations of coverage by charging stations both for Austria and Europe is very scarce. The same can be said related to a methodology to calculate the coverage. Nevertheless, some data were obtained for making rough estimations.

Starting point would be an assessment of the number of electrical vehicles in EU at the level of 1,394,000 by 2020. The figure comes from the report "Competitiveness of the EU Automotive Industry in Electric Vehicles" by Proff H. and Kilian D. In the press release of European Commission "EU launches clean fuel strategy", it is mentioned that Austrian authorities expect the number of electric vehicles in Austria to reach 250,000 by 2020. Comparing those values gives an estimation that 17.9% of all the European electric cars will be in Austria by 2020.

Computations performed in the report by Proff H. and Kilian D. estimate the number of public charging stations in EU to reach 170,000 by 2020. Assuming that Austria will have 17.9% of European public stations leads to the outcome that Austria will need 30,430 public recharging stations in 2020. The press release of European Commission also contains a target number of public recharging stations for all the member states by 2020. For Austria, it is 12,000 and can be considered as a forecasted expected amount. It corresponds to 39.4% of the required number of charging stations (30,430).

However, a good way to set the charging stations ratio would be to take into account characteristics of every-day trips, which can be obtained from the future user of the piece of software. Our customer plans to have basic recharging capabilities at every communal building in the region, i.e. the actual coverage of recharging stations for the customer will be significantly higher than the average. Assume that the coverage in 2014 was twice larger than 39.4%, i.e. take it as 78.8%. For the Middle scenario, this value is expected to grow linearly 10% by 2020, for the Pro-EV scenario by 20%, and stay constant for the Contra-EV scenario. Figure 5 and Table 37 in Appendix 1: Data tables represent the resulting values, and for the relative change values, refer to Table 5.

Figure 5
Relative coverage of recharging stations at trip stops

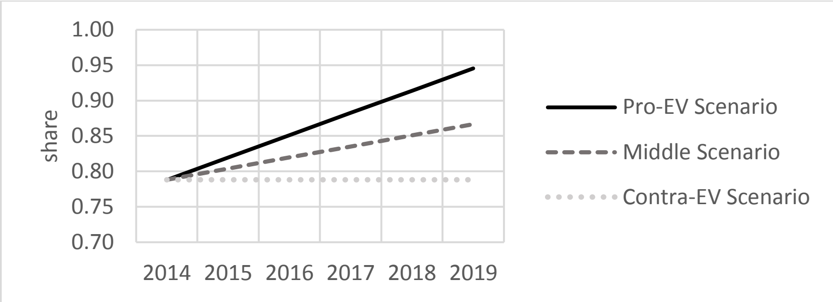


Table 5
Relative change of relative coverage of recharging stations

Scenario\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Pro-EV	-	0.040	0.038	0.037	0.036	0.034
Middle	-	0.020	0.020	0.019	0.019	0.019
Contra-EV	-	0.000	0.000	0.000	0.000	0.000

3.5 Grants to support AFVs

Numerous studies such as (Sierzchula W. et al, 2014b) show that additional financial incentives have a significant influence on adoption of EVs and PHEVs. Nowadays in Austria, grants to purchase an AFV are presented only in a form of a reduction of the fuel consumption tax NOVA. Our calculations show that the tax equals to zero not only for EVs and the most PHEVs but also for efficient ICEVs, VW Golf 1.6l 66kW, for instance. Meanwhile, many countries inside and outside Europe supply a more significant support and return a certain share of a vehicle's price to buyers of BEVs and PHEVs.

According to the article by Morris W., one can get a vehicle price reduction of 35% (maximum £5,000) in the UK. The conditions are as follows. A vehicle must be new and produce low CO_2 emissions, have some minimum electric range and be able to reach defined speed, satisfy minimum warranty duration and certain safety standards. Recently French government has introduced a bonus of up to €10,000 for purchasing a BEV and €6,500 for PHEVs for those who replace their old ICEV (Editorial Staff, 2015). Edelstein S. reports that in the Netherlands private persons and companies can benefit from one-time price reduction and exemptions from taxes that are to be paid regularly while a car is in use. Total reductions reach several thousands of Euro. Plötz P. et al showed that one-time price reductions as large as €1,000 and €2,000 during 2012 – 2020 could increase the number of EVs and PHEVs by 75% and 275% respectively in Germany by 2020 compared to a scenario without any grants. Exactly these constant values are assumed for the scenarios in the given work as shown in Table 6.

Table 6
Grants to purchase EV or PHEV, €

Scenario	*2015 - 2019*
Pro-EV	2000.000
Middle	1000.000
Contra-EV	0.000

3.6 Demand for rental vehicles

Demand for transportation services of a given company trying to optimize its fleet plays an important role because it determines the size of a fleet. A fleet manager should have expectations regarding the change of demand in time. Experts from the given branch of business possess accurate estimations regarding the development of demand for a certain service. Our partners involved in the project operate in the same market and have similar business processes as the potential user of our algorithm.

The partners assume demand to stay relatively stable and steadily increase by 5% yearly, and this will serve as the Middle Scenario. For the Pro-EV scenario, a more rapid growth of 10% annually is assumed. It can be supported by increasing interest towards EVs present on the government and customer's levels and a resulting improved position on the market. In the future government may issue a law, which would oblige government organisations to use AFVs more intensively. Moreover, currently measures are taken to build a positive image of an AFV among potential users. This could lead to an increase of demand for a particular car rental company in case of the shortage of AFVs on the market if rivals cannot supply the need for AFVs adequately. As to the Contra-EV scenario, assume saturation of the car rental market, moderate level of competition and constant demand.

Table 7
Scenarios for relative change of demand

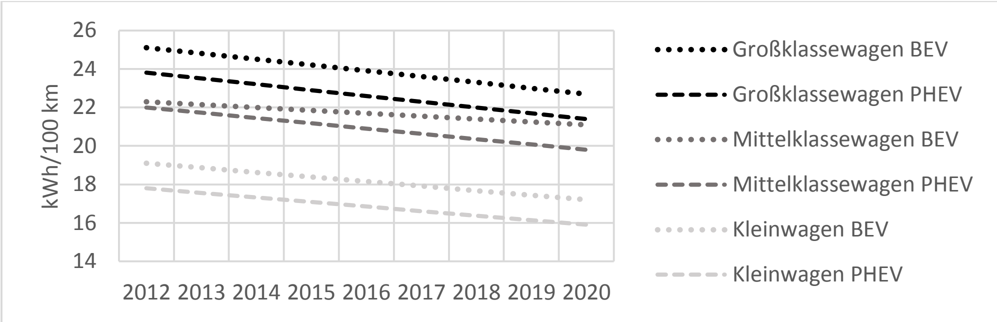
Scenario	*2015 – 2019*
Pro-EV	0.100
Middle	0.050
Contra-EV	0.000

3.7 Energy consumption

EV's range depends, among the other parameters, on energy consumption rate. A more energy-efficient vehicle can travel a longer distance on a single charge then a vehicle that has higher energy consumption rate with similar battery capacity. In the given section two research works are compared, one of them is chosen to serve as a source of data, and scenarios of energy consumption are derived.

A forecast of energy consumption in the research by Plötz P. et al is based on a report "Umweltbilanzen Elektromobilität: Grundlagenbericht" by Helms et al. The authors of the latter work built a model that calculates energy consumption based on parameters: weight, rolling resistance, air resistance, car's frontal surface area and driving pattern. Values of the parameters come from different reports for different car types for the years 2010 and 2030. The model allows estimating fuel consumption for 2012 and 2020, which is given in Figure 6; numerical values are in Table 42, Appendix 1: Data tables.

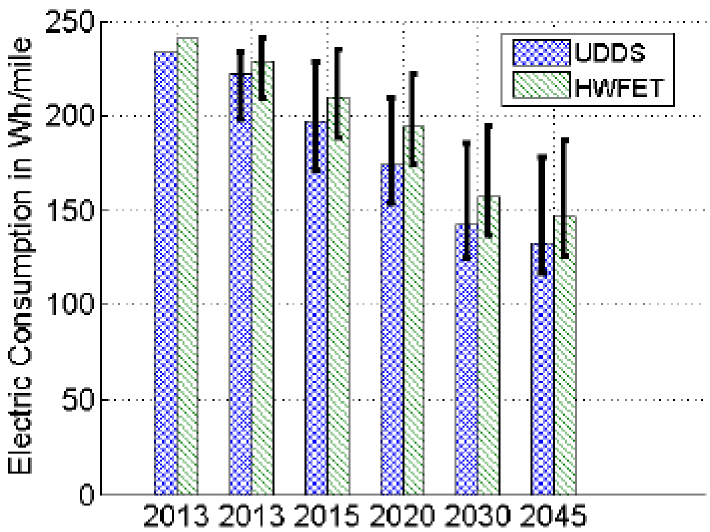
Figure 6
Energy consumption



Source: (Plötz P. et al, 2013)

Another report by Moawad A. and Rousseu A. provide an alternative point of view on the development of energy consumption. The authors built "a software environment and framework for automotive control-system design, simulation, and analysis". They applied that vehicle simulation tool to estimate future energy consumption of BEVs, and the result is shown in Figure 7.

Figure 7
Energy consumption of BEVs



Source: (Moawad A., Rousseu A., 2014)

UDDS and HWFET are test cycles established in the USA, which provide different results, and the average will be considered further. Data are in Wh/mile in Figure 7, and the first horizontal axis label might actually correspond to 2012. Unfortunately, the report does not contain similar estimations for PHEVs. Table 8 shows energy consumption values by Plötz P. et al, and Table 9 contains values from the report by Moawad A. and Rousseu A. converted from Wh/mile to kWh/100 km.

Table 8
Energy consumption, kWh/100 km

Segment\ Year	*2012*	*2020*
Bus PHEV	23.800	21.400
Bus BEV	25.100	22.700
Medium PHEV	22.000	19.800
Medium BEV	22.300	21.100
Small PHEV	17.800	15.900
Small BEV	19.100	17.200

Source: (Plötz P. et al, 2013)

Table 9
Energy consumption of BEV, kWh/100 km

Segment\ Year	*2012*	*2020*
BEV	14.789	11.495

Source: (Moawad A., Rousseu A., 2014)

Values from the report by Plötz P. et al are preferred to the ones by Moawad A. and Rousseu A. for two reasons. Firstly, Plötz P. et al based their projection on European standards of energy efficiency measurement and their data must be closer to the European vehicle market. Secondly, the data by Moawad A. and Rousseu A. are not detailed in terms of vehicle segmentation, and an attempt to derive values for the segments may cause reduction of data reliability.

Scenarios for energy consumption are constructed as follows. Middle scenario consists of the values by Plötz P. et al with no change. Energy consumption in the Contra-EV is assumed to stay constant at the level of 2012. This scenario represents a case that there will be no improvements in the future. Pro-EV scenario allows energy consumption to shrink even sharper reaching 10% less consumption than in Middle scenario by 2020. For all the scenarios, linear interpolation was applied to fill values 2013 – 2019. The scenarios are presented in Figure 8, Figure 9, Figure 10 and in Appendix 1: Data tables: Table 43, Table 44, Table 45.

Figure 8
Energy consumption, Pro-EV scenario

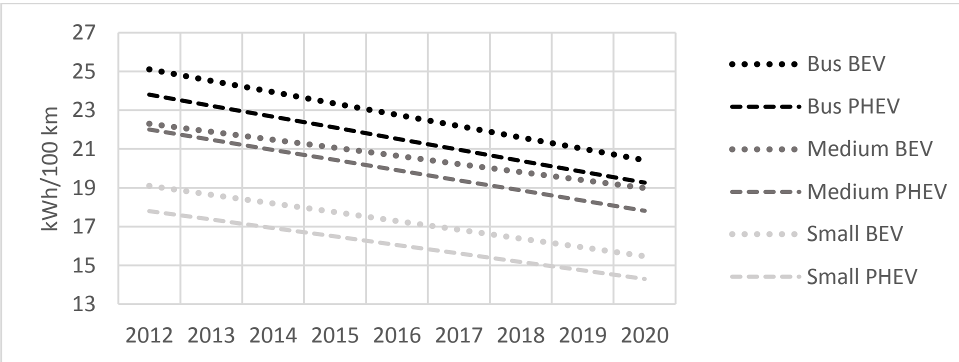


Figure 9
Energy consumption, Middle scenario

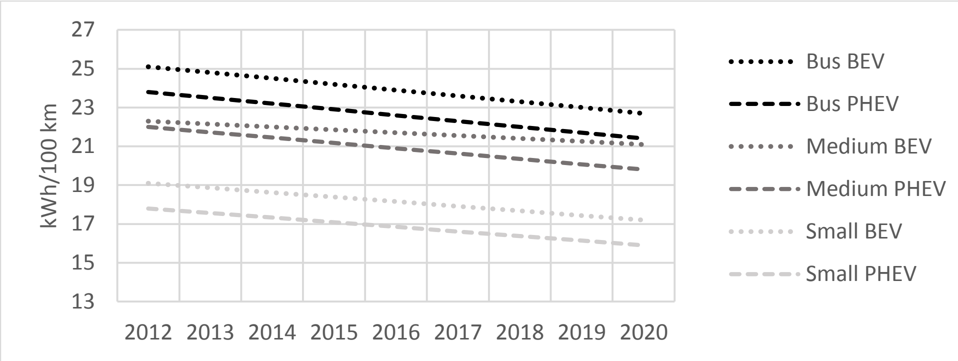
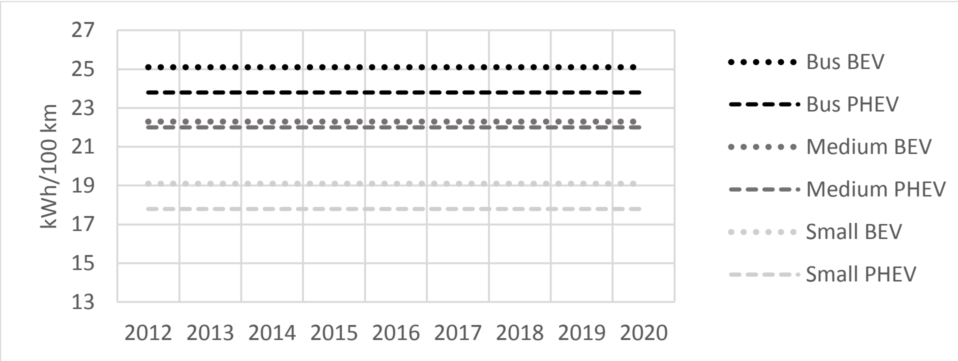


Figure 10
Energy consumption, Contra-EV scenario



3.8 Battery range

The parameter under discussion in this section is closely related to the energy consumption. Range of electric vehicle's battery is also determined by capacity of the installed battery. Further calculations are based on the research by Plötz P. et al. The authors did no direct estimations of battery range, but they forecasted battery capacity. Using them together with data from the section "3.7 Energy consumption" allows constructing scenarios for battery range.

Plötz P. et al base their results on four different reports by third parties that contain estimations of battery capacity for PHEVs and BEVs in different classes. Data are absent in those sources for some of the classes, and Plötz P. et al derived the missing data on their own. The authors assume battery capacity to stay constant during 2013 – 2020 (see Table 10). It can be explained by the fact that, according to at least one research paper (Redelbach M. et al, 2014), the optimal battery capacity has already been reached given a proper charging network.

Table 10
Battery capacity, kWh

Segment	*2013 – 2020*
Bus PHEV	13
Bus BEV	28
Medium PHEV	10
Medium BEV	24
Small PHEV	7
Small BEV	20

Source: (Plötz P. et al, 2013)

Using data in Table 10 and the energy consumption values of the Middle scenario one can calculate battery range for a Middle scenario. In order to derive battery range for Pro-EV and Contra-EV scenarios, battery capacity values were combined with energy consumption values from the corresponding scenarios. The resulting scenarios are presented in Figure 11, Figure 12, Figure 13 and in Appendix 1: Data tables: Table 46, Table 47 and Table 48.

Figure 11
Battery range Pro-EV scenario

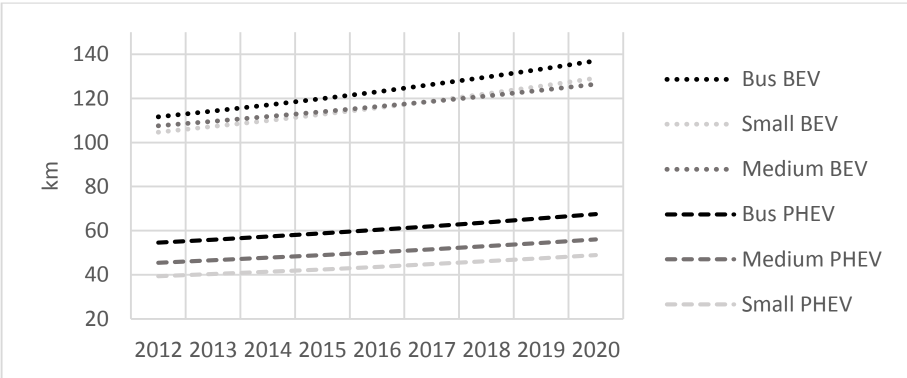


Figure 12
Battery range Middle scenario

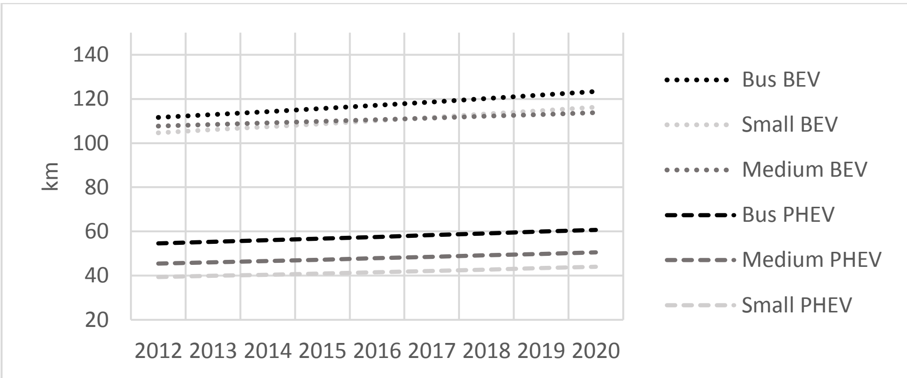
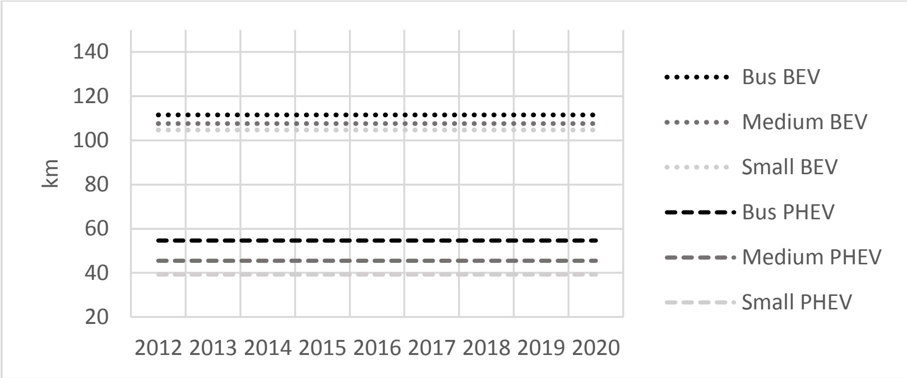


Figure 13
Battery range Contra-EV scenario

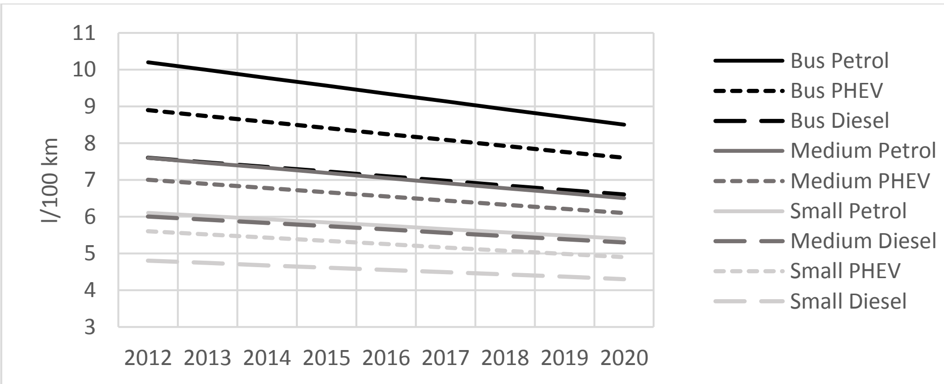


3.9 Fuel usage

Fuel usage has an impact on Total Cost of Ownership through fuel costs and on emissions. The longer distance a vehicle can travel using the same amount of fuel, the less it emits CO_2. In this section, two sources of data are compared, and one of them is chosen as a basis. Then updated fuel usage values are obtained from the manufacturers' websites, and a forecast from the chosen source is recalculated in order to build three scenarios.

Plötz P. et al base their projections of fuel usage on the same report as for 3.7 Energy consumption ("Umweltbilanzen Elektromobilität: Grundlagenbericht" by Helms et al.). The authors note that the forecast of fuel consumption of PHEV has a high level of uncertainty because there were not enough of data available. Values for some car classes were missing, and the authors calculated them based on the values for a middle class car with corrections, according to vehicle mass. Plötz P. et al provide values for the years 2012 and 2020, the values 2013 – 2019 were derived via linear interpolation as given in Figure 14 and Table 49, Appendix 1: Data tables.

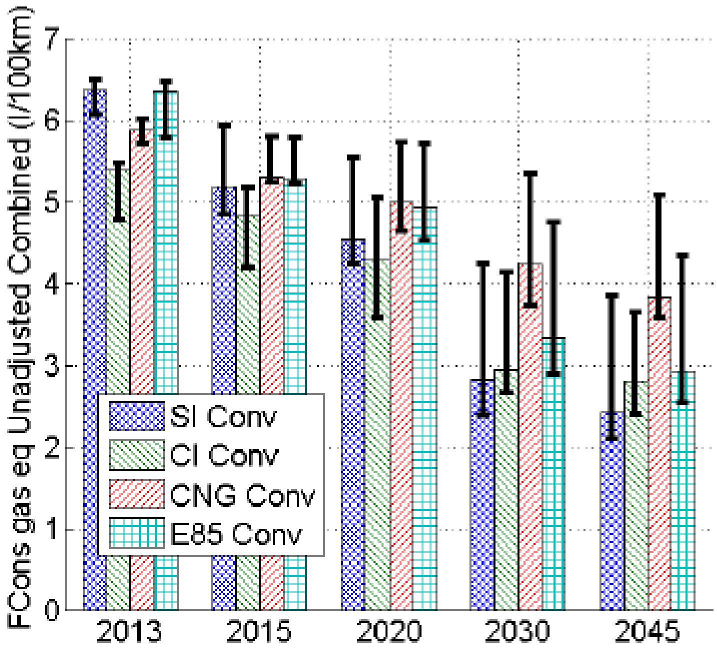
Figure 14
Fuel consumption



Source: (Plötz P. et al, 2013)

Moawad A. and Rousseu A. also predict fuel consumption to decrease for a conventional "midsize car", as shown in Figure 15. SI Conv stands for spark ignition (petrol engine), CI Conv – compression ignition (diesel engine). CNG Conv and E85 Conv are not related to our discussion.

Figure 15
Fuel consumption of "midsize car", l/100 km



Source: (Moawad A., Rousseu A., 2014)

A possible option would be combining both sources to construct the scenarios, but it has two issues. The first one is that the authors use different test procedures for vehicles. Data by Plötz P. et al are based on tests common for Europe, meanwhile, Moawad A. and Rousseu A. applied standards used in the USA. Another problem is that the reports are based on different vehicle classifications. It would be wrong to compare data for the Medium ICEV (Plötz P. et al) to data for the "midsize car" (Moawad A. and Rousseu A.). It was decided to stick to the values proposed by Plötz P. et al since they are closer to Austrian market and are more detailed in terms of vehicle segments.

Data by Plötz P. et al were produced several years ago, and it makes sense to update fuel consumption values and recalculate them for the future. Consumption values for the year 2013 can be found on the websites of car produces. In order to calculate the weighted average consumption for the whole segment, five top selling models in each sub-category are taken, according to the sales statistics (Kraftfahrt-Bundesamtes (KBA), 2013b) in Germany.

A classification of segments and sub-categories given in Figure 16 is a basis for the given work, and further calculations are grounded on it. Klein, Mittel and Groß are the segments. A single vehicle model to represent BEVs and PHEVs is taken for each segment, according to Table 11. Market of EVs is rather small, and only a few models in each segment have significant sales. Models with the highest sales in Germany 2012 were taken as a reference for 2012. Details of the calculations are available in Appendix 2: Intermediate calculations, Table 69.

Table 11
PHEV and BEV models representing segments in 2012

Segment	*Model*
Bus PHEV	Mitsubishi Outlander PHEV
Bus BEV	Tesla Model S
Medium PHEV	Toyota Auris Hybrid
Medium BEV	Nissan Leaf
Small PHEV	Toyota Yaris Hybrid
Small BEV	Renault Zoe

Figure 16
Vehicle segments and sub-categories

Source: (Plötz P. et al, 2013)

The next step is to calculate a ratio of fuel usage values in 2020 to values in 2013 from the report by Plötz P. et al. To construct the Middle scenario these ratios can be combined with the updated fuel usage values for 2013 to obtain updated consumption in 2020. According to Pro-EV scenario, fuel consumptions is assumed to stay constant. Consumption in 2020 in Contra-EV scenario is 10% less than in the Middle scenario. Values inside time intervals for all the scenarios were interpolated linearly, they are presented in Figure 17, Figure 18, Figure 19 and in Table 50, Table 51 and Table 52, Appendix 1: Data tables.

Figure 17
Fuel consumption Pro-EV scenario

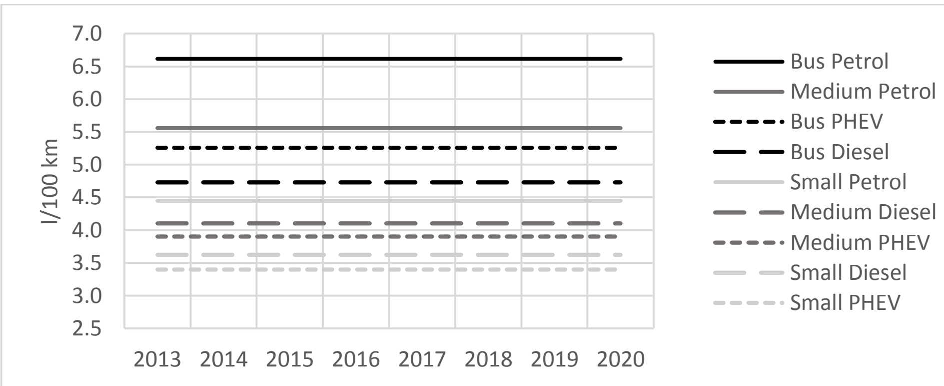


Figure 18
Fuel consumption Middle scenario

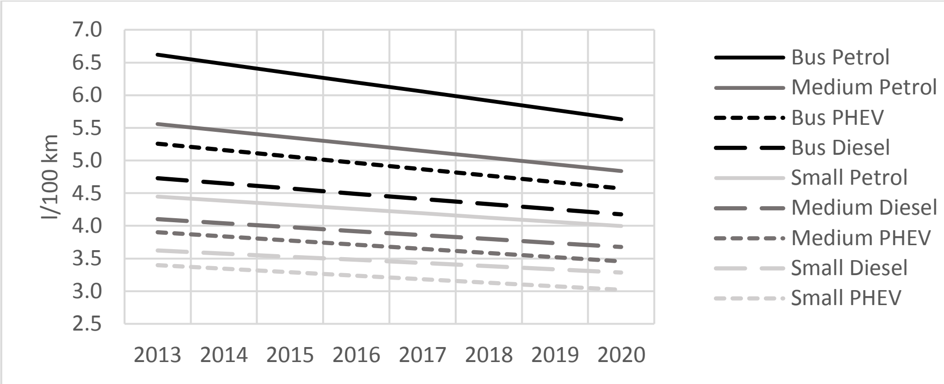
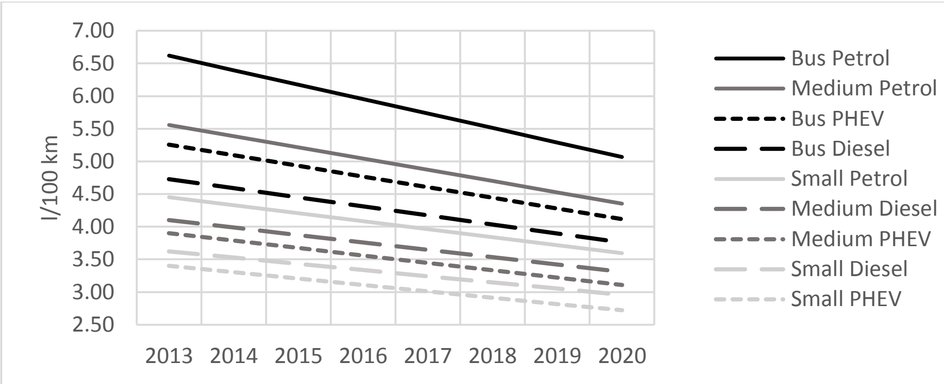


Figure 19
Fuel consumption Contra-EV scenario



3.10 Outsourcing costs

Possibility of outsourcing is included in the model, therefore one also has to consider outsourcing costs. Assume that an average car rental company can serve as an eligible outsourcing company. In this section, an attempt to derive car rental prices based on a German car rental market research fails to produce an acceptable forecast. An alternative way of using forecast of inflation in Austria is applied. Fixed rental costs in Austria are estimated by inspection of the current offers available on the market. Variable costs per km are calculated using data already discussed in the given work.

A German car market research (Fraunhofer IAO, 2014) shows how average car rental prices changed over time during the recent years. Authors developed their own methodology and cooperated with experts in the field to collect relevant data. Data from the following rental companies operating in Germany were involved in the work: Avis, Buchbinder, Budget, Caro, Enterprise, Europcar, Hertz, and Sixt. A representative sample of all the renting stations across Germany was analysed. The authors investigated two channels of ordering (the internet and the telephone) and used two classifications of cars (Eurotax-Schwacke and ACRISS). For the year 2014 the data were collected during the period 1st March 2014 – 31st July 2014, data for the previous years come from the earlier analogous research.

Data were collected for orders of 1, 3, 5 and 7 days several times during the period for each chosen station and for all the cars available there.

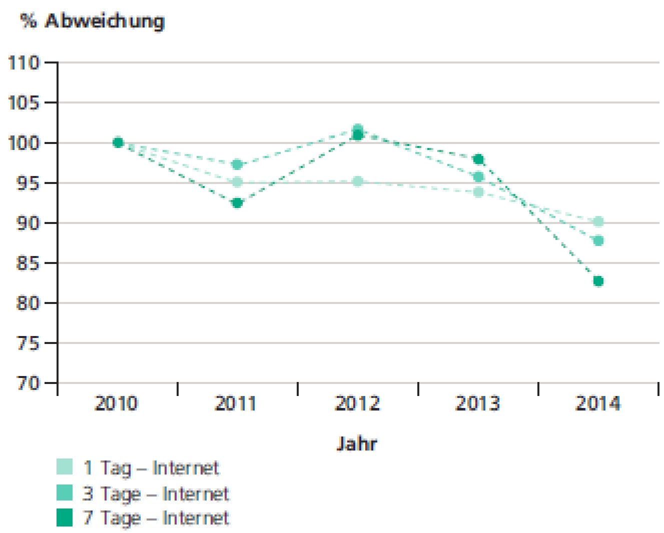
Figure 20 represents a price index to rent a car from the research by Fraunhofer. The index is presented for economy class car according to ACRISS classification, for rental duration of one, three and seven days, for orders made over the internet. If one applies extrapolation for the index of one-day rental period, the index value will be negative in the future. It contradicts with the fact that inflation in Austria is forecasted to be positive according to reports by Österreichische Nationalbank and Wirtschaftskamer Österreich (see Table 12). Furthermore, the outlook of car rental prices was conducted for Germany. Considering these facts, development of rental car prices in Austria was assumed to coincide with the forecasted inflation rate in Austria for all the vehicle segments.

Table 12
Forecasted inflation rates in Austria, %

Source\ Year	*2015*	*2016*
Österreichische Nationalbank	0.9	1.9
Wirtschaftskamer Österreich	1.1	1.7

Source: (Österreichische Nationalbank, 2015), (Wirtschaftskamer Österreich, 2015)

Figure 20
Index of rental car price



Source: (Fraunhofer IAO, 2014)

The estimations of inflation from both sources were averaged, and these average values are used further as a relative change for Middle scenario. Relative change for the Pro-EV scenario was derived from Middle scenario by increasing its values by 15%; values for the Contra-EV scenario were obtained by decreasing the indexes of Middle scenario by 15%.

Now, an estimation of costs in terms of money for some starting year is required. According to its presentation, a large car-rental internet-portal Check24.de claims that the average price to rent a car in Germany was 44.92 EUR in 2014. The estimation is the result of analysis of their own statistics. In order to adjust the value to Austrian prices, a comparison of Austrian and German car rental prices was conducted.

Prices of three rental companies were compared: Sixt, Europcar and Enterprise. For each company prices from three largest Austrian and three largest German cities for the similar cars on the official web pages were collected. The comparison revealed that prices in Austria are 9.193% higher than in Germany on average. That corresponds to the price of 49.05 EUR in Austria, 2014. The resulting estimation turns out to be too low for Austrian market. An inspection of rental car prices in Austria reveals that charges should be around 143, 105 and 95 EUR for Bus, Medium and Small vehicles correspondingly for the year 2015. The price check was performed for three different car rental companies operating in Austria: Sixt, Europcar and Enterprise. These values are taken as fixed outsourcing costs for the year 2015.

There is an additional source of significant costs related to a rental car. Usually a car rental company requires that customers pay all the consumed petrol on their own. Therefore, fuel costs also have to be taken into account. Fuel prices from the section "3.2 Fossil fuel prices" and fuel consumption rates from "3.9 Fuel usage" are used to calculate the fuel costs per km. Fuel consumption corresponds to a vehicle with diesel engine and both parameters were taken from the Middle scenario. No distinction between variable outsourcing costs for different scenarios was made, thus values are the same for Pro-EV, Middle and Contra-EV scenarios.

The fixed part of outsourcing costs for the Middle scenario, i.e. the costs per day excluding fuel expenses is given in Figure 21. The difference between scenarios would be hardly see in figures, so values for Pro-EV and Contra-EV as well as Middle scenario are presented in Appendix 1: Data tables, Table 38, Table 39 and Table 40. Variable outsourcing costs are shown in Figure 22 and in Appendix 1: Data tables, Table 41. Relative change of outsourcing costs' fixed part is presented in Table 13.

Figure 21
Fixed outsourcing costs, Middle scenario

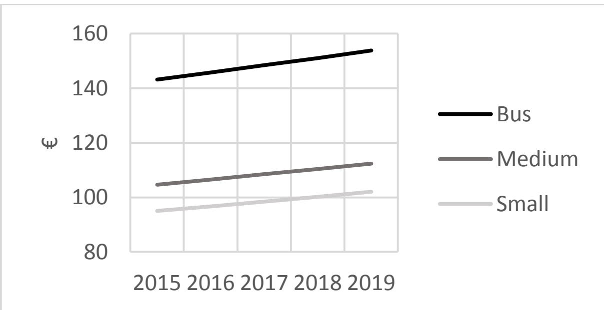


Figure 22
Variable outsourcing costs

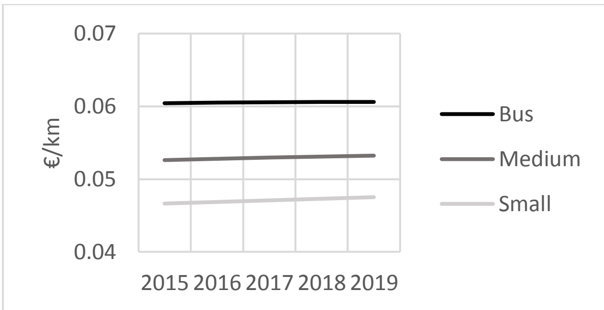


Table 13
Relative change of outsourcing costs

Scenario\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Pro-EV	-	0.012	0.021	0.021	0.021	0.021
Middle	-	0.010	0.018	0.018	0.018	0.018
Contra-EV	-	0.009	0.015	0.015	0.015	0.015

3.11 Cost of a substitute

Mainly because of lack of data regarding the cost of the substitute, assume it to coincide with the estimations made for the outsourcing costs.

3.12 Emissions using fuel

Emissions produced by fleet vehicles constitute the largest share of all the emissions analysed in the given work. This section follows the previous one because emissions using fuel for vehicle categories will be derived from fuel usage.

Relation of those parameters is described by chemical reaction of fuel burning, and converting it to carbon dioxide and water. According to the article "Informationen zur Berechnung des CO_2-Ausstoßes" posted on spritmonitor.de, burning 1 litre of petrol and diesel oil produces 2.33 kg and 2.64 kg of CO_2 correspondingly. Using fuel consumption values from the Pro-EV, Middle and Contra-EV scenarios allows computing the corresponding emissions shown in Figure 23, Figure 24, Figure 25 and in Appendix 1: Data tables, Table 53, Table 54 and Table 55.

Figure 23
Emissions using fuel Pro-EV scenario

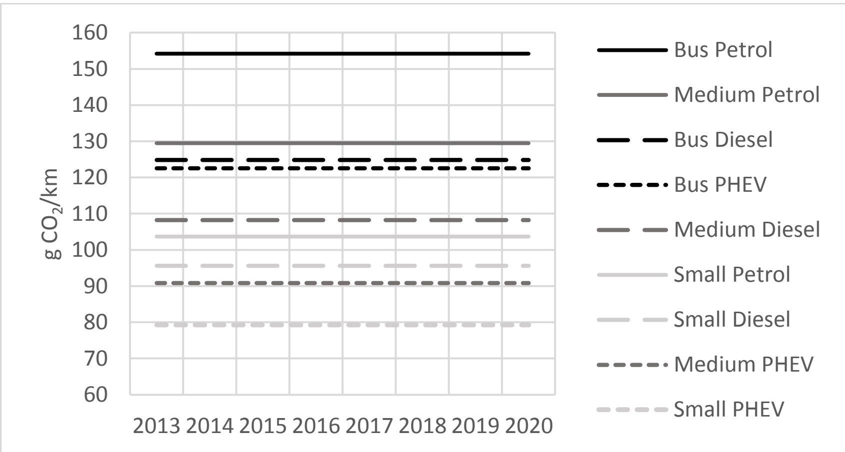


Figure 24
Emissions using fuel Middle scenario

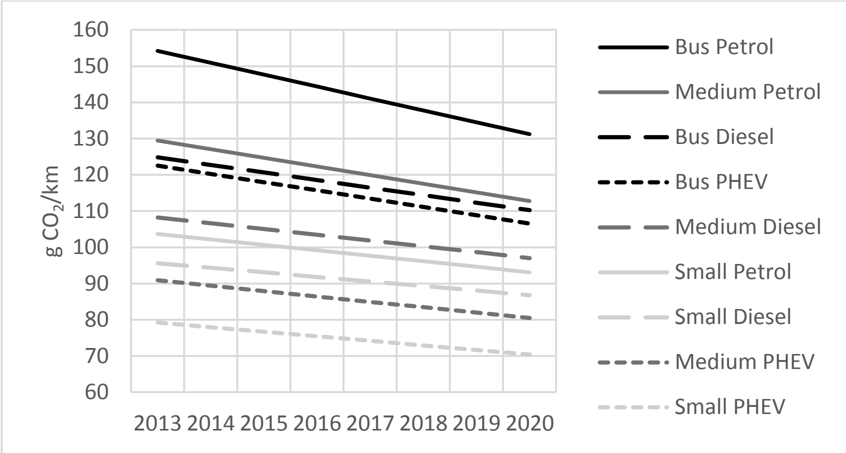
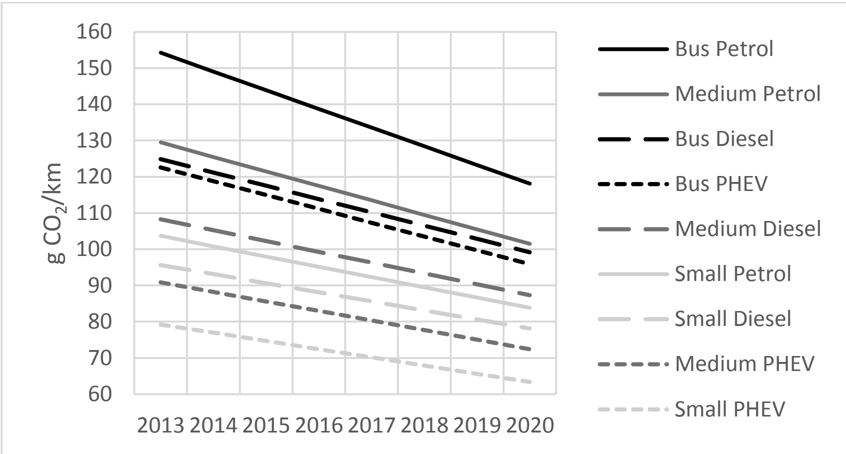


Figure 25
Emissions using fuel Contra-EV scenario



3.13 Emissions by outsourcing

In case a car rental company has no its own vehicles available to serve a client, it can turn to outsourcing and rent a vehicle from another rental company. It means that one also has to consider the CO_2 emissions of vehicles of an outsource provider. In this section, it will be argued that emissions of new passenger cars can be applied to outsourcing vehicles, and the emission scenarios will be derived.

Assume that an outsourcing company has average emissions at the level for new cars, and it can be supported by the following. Europcar, one of the biggest car rental companies in Europe claims that its fleet is 4.7 months old and emissions are 125.2 g CO_2/km on average in Austria (europcar). It means that their average rental car is less than half-year-old, and its CO_2 emissions are less that the average emissions in 2013 in Europe (126.1 g CO_2/km) according to (EEA, 2014).

Therefore, the same emission values are used for outsourcing emissions as in the section 3.12 Emissions using fuel. Outsourcing vehicles are assumed to run on diesel oil, thus corresponding values are taken. Outsourcing emissions are shown in Figure 26, Figure 27, Figure 28, and in Appendix 1: Data tables in Table 33, Table 34 and Table 35.

Figure 26
Emissions by outsourcing, Pro-EV scenario

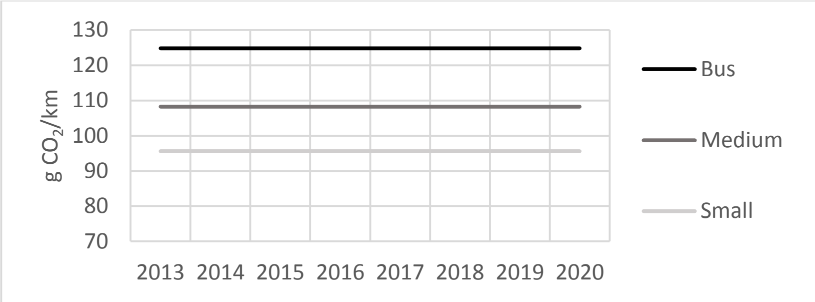


Figure 27
Emissions by outsourcing, Middle scenario

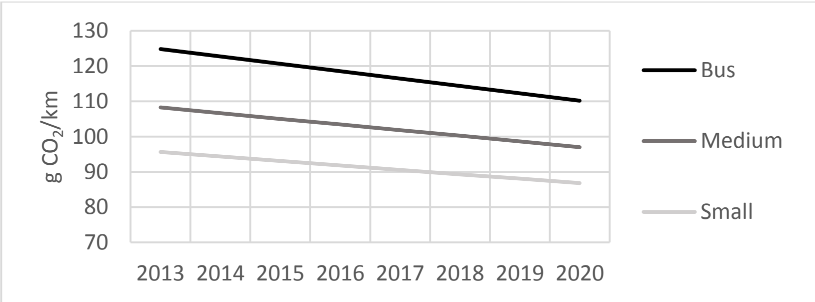
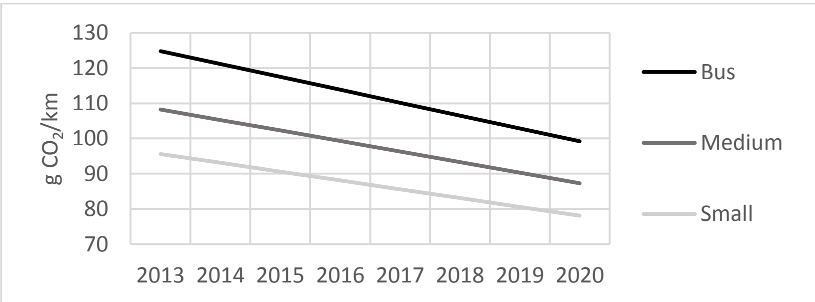


Figure 28
Emissions by outsourcing, Contra-EV scenario



3.14 Emissions of the substitute

A substitute in the model would be a taxi a client can take instead of a vehicle from the rental company. The difference between an outsourcing vehicle and a substitute is that the service provider has a long-term contract with an outsourcing company. An outsourcing vehicle is used when there is no vehicle available from the own fleet. Thus, a substitute vehicle is not related to the rental company. Assume emissions of the substitute to coincide with estimations for emissions by outsourcing.

3.15 Emissions by public transport

Several alternative means of transportation are considered in the model, and one of them is public transport. Train, bus, tram and subway are the means of public transport used in Austria. All of them except a bus emit no CO_2. This section is devoted to estimating emissions of public transport per km. Emissions of different means of transport are weighted according to passenger flow.

As stated by a factsheet by VCÖ, the average CO_2 emission of a bus is 36 CO_2 g/km calculated per one passenger. A good way to calculate the average emissions of public transport would be weighting emissions of the means of transportation by passenger flow. Steigenberger K. and Feßl T. mention statistical data regarding the flow of passengers in Austria 2010 as shown in Table 14. Using flow as a weight allows calculating the average emission for public transport, which equals to 14.409 CO_2 g/km.

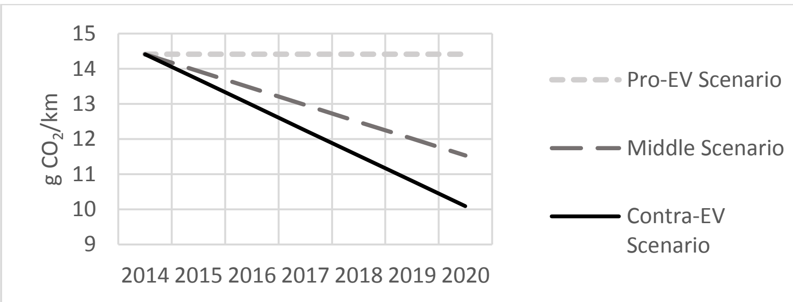
Table 14
Emissions and passengers flow by means of transportation per passenger

Means of transportation	*Emissions, CO_2 g/km*	*Flow, Person-km*
Train	0	10737
Bus	36	9874
Other public transport (ÖPNV)	0	4059

Source: (Steigenberger K. and Feßl T., 2013)

The following report can work as a basement to construct the scenarios of public transport emissions. Law K. et al did a research for The International Council on Clean Transportation to estimate a potential reduction of greenhouse gas emissions by heavy-duty vehicles. The authors claim that bus emission can by reduced up to 40% applying all technologies available in 2015 – 2020 timeframe. A more conservative approach will be taken, assume that emissions will stay constant for the Pro-EV scenario during 2014 – 2020; emissions will be reduced by 20% for the Middle scenario and by 30% for the Contra-EV scenario. Figure 29 and Table 36 in Appendix 1: Data tables show the scenarios.

Figure 29
Public transport emissions scenarios



3.16 Acquisition costs

Another parameter, a fleet manager has to consider, is price of a vehicle. Grants and other financial incentives to purchase an EV discussed in the section "3.5 Grants" are not taken into account. Here acquisition prices for ICEVs and EVs excluding battery price are considered. Then scenarios of battery prices are analysed, and vehicle prices in Austria and Germany are compared. Finally, scenarios of acquisition costs are constructed.

The report by Plötz P. et al contains data required to estimate vehicles' prices in the future: prices excluding battery costs, battery prices and battery capacities, for the segments in 2011 – 2020. Prices of vehicles without battery are based on estimations by authors' partner Nationalen Plattform Elektromobilität (NPE). Data for some classes are missing, and they are derived from values for given classes. The authors also examined surcharge of petrol and diesel cars by analyzing three most demanded models on the German market in all the car categories for 2012. Surcharge for EVs is determined from previous prices of NPE. Surcharge for diesel categories differs only slightly from petrol ones, so it is assumed that the difference for EVs is also insignificant.

Plötz P. et al assumed that prices for conventional cars are growing because UE policy is forcing producers to increase fuel efficiency. Prices of EVs without battery are assumed to stay constant over time to "meet fleet boundary values". The authors note that the resulting values are lower than the average market prices due to many models are offered with various supplementary equipment. Conventional vehicle prices as projected by Plötz P. et al are displayed in Table 15, further values for the years 2012 – 2019 are obtained by linear interpolation. Prices of EVs and PHEVs are shown in Table 16.

Table 15
Conventional vehicle prices in Germany, €

Segment\ Year	*2011*	*2020*
Bus Petrol	30555.000	31502.000
Bus Diesel	32787.000	33734.000
Medium Petrol	17165.000	17515.000
Medium Diesel	19352.000	19702.000
Small Petrol	10403.000	11176.000
Small Diesel	12592.000	13365.000

Source: (Plötz P. et al, 2013)

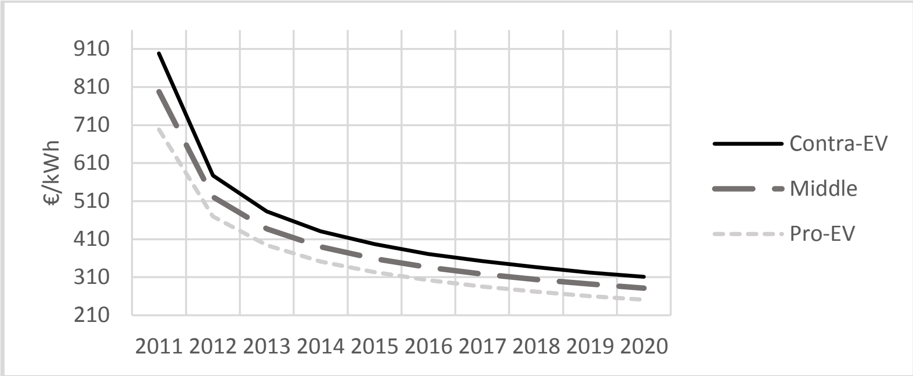
Table 16
EV and PHEV prices without battery 2011 – 2020 in Germany, €

Segment	*Price*
Bus PHEV	35551.000
Bus BEV	31432.000
Medium PHEV	22116.000
Medium BEV	18042.000
Small PHEV	15365.000
Small BEV	11280.000

Source: (Plötz P. et al, 2013)

To obtain complete price of an EV one has also to consider battery price. NPE provided Plötz P. et al with three basic scenarios of battery prices development, presented in Figure 30 and Table 56, Appendix 1: Data tables. It is assumed that prices are similar for BEV and PHEV. These projections agree with forecasts of such experts as DOE, McKinsey, Deutsche Bank, Boston Consulting Group, gathered in the report by Khan S. and Kushler M.

Figure 30
Battery prices



Source: (Plötz P. et al, 2013)

In order to convert German prices to the Austrian level, the difference of taxation and price levels in Austria and Germany is addressed. Plötz P. et al provide vehicle prices without value-added tax. It is 19% for cars in Germany since 2007 according to the legislation database "Gesetze im Internet". The average relative price difference (value-added tax included) between the countries was estimated. A comparison was performed for five top-selling models in Austria taken from (Statistik Austria, 2015). Details are available in Appendix 2: Intermediate calculations, Table 70. According to the calculations, cars in Austria are 7% more expensive on average for the chosen models. Then German value-added tax and 7% are added to data of Plötz et al to obtain Austrian price with the tax included.

For PHEVs and BEVs an extra step is done, i.e. including price of battery pack. It is computed as a multiplication of battery capacity and battery cost per capacity unit (kWh). Battery price in Figure 30 allows constructing different scenarios of acquisition costs. Figure 31, Figure 32, Figure 33 and Table 57, Table 58, Table 59 in Appendix 1: Data tables contain the scenarios for acquisition prices. Note that values for ICEVs are similar in all the scenarios.

Figure 31
Acquisition costs, Pro-EV scenario, €

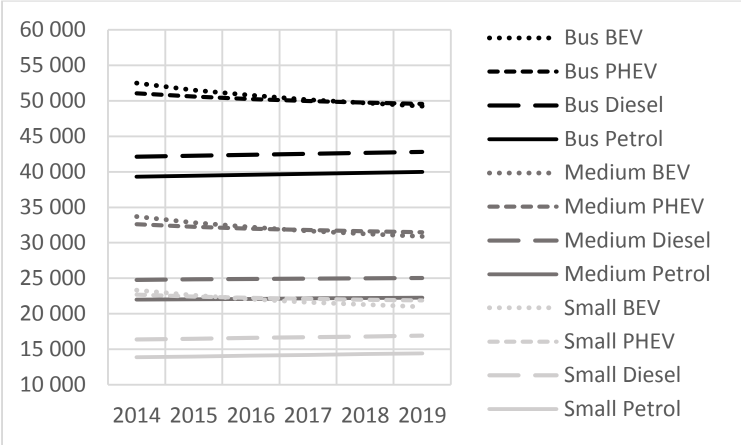


Figure 32
Acquisition costs, Middle scenario, €

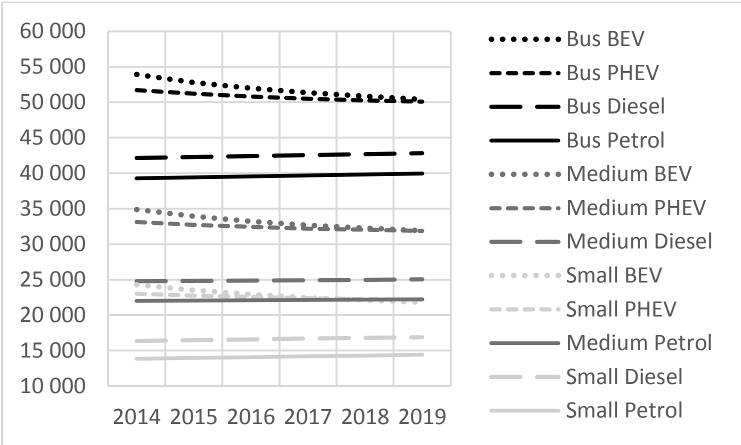
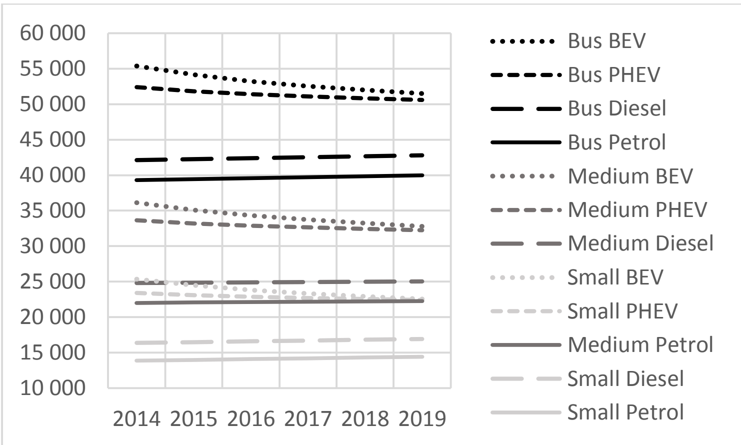


Figure 33
Acquisition costs, Contra-EV scenario, €



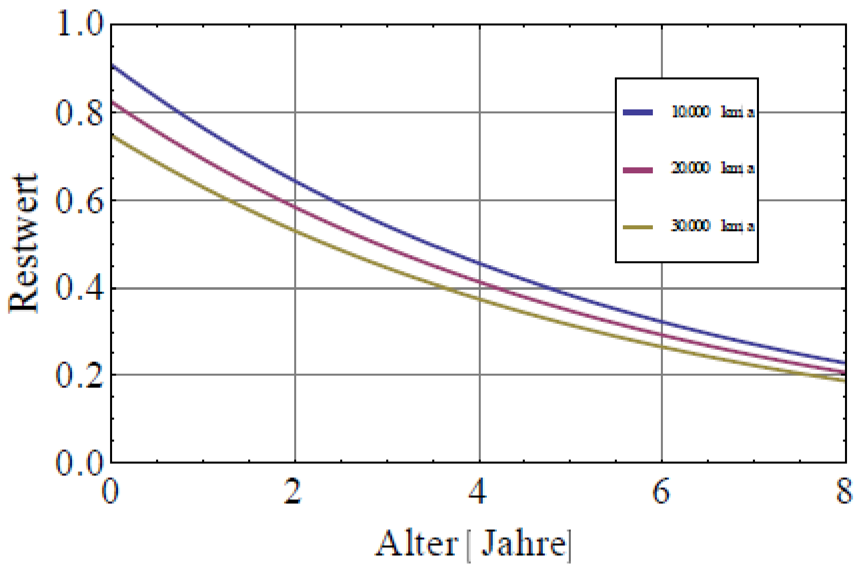
3.17 Vehicle Salvage price

A fleet vehicle is supposed to be utilised during a limited amount of time, and, eventually, the owner-company sells the vehicle. The older the vehicle, and the higher the mileage is, the lower is the salvage price excepting special cases of retro vehicles and rare models. In the given section, two sources of related data are analysed. Residual value curves for ICEVs and AFVs are constructed and reworked in a more convenient way. Three salvage price scenarios are set.

Proff H. and Kilian D. estimate that an EV loses 70% of its original price in 5 years, and an ICEV loses only 55% in 5 years. They support lower estimations for EVs with the lack of knowledge on car market concerning the future development of residual value of an electric vehicle. Propulsion battery, complete electric drivetrain and especially lifetime of these components have strong impact on residual value of such a vehicle. The authors also mention an opinion of experts from Schwacke that after 3 years residual value of an EV will be 31% of original price, gasoline model – 43%.

Data from the report by Plötz P. et al are also taken into account. The authors base their estimations on a study by Statistische Bundesamt (Germany). It contains a regression model of salvage price based on the following parameters: vehicle's age, mileage, original price. Curves in Figure 34 represent vehicle's residual value for cases with different annual mileage according to Plötz P. et al. Assume that a vehicle travels 24,800 km annually (100 km per working day), so the line corresponding to 20,000 km is the closest one, and it will be used for ICEVs.

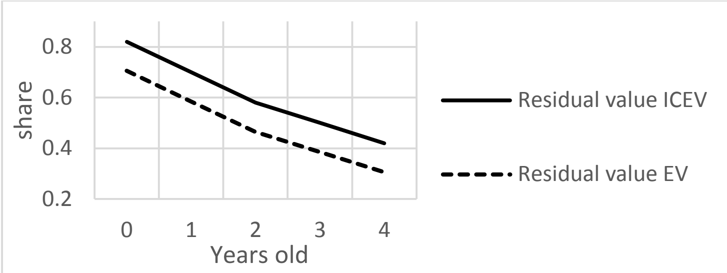
Figure 34
Residual value



Source: (Plötz P. et al, 2013)

Consider estimations of residual value for EVs in 3 years by Proff H. and Kilian D., and in 5 years by Schwacke experts. Taking the average of both figures gives residual value of 30.5% in 4 years, which is further used for EVs and PHEVs. Next, the difference between the residual values for ICEVs and EVs for the period 4 was found (0.115). Values for EVs and PHEVs (see Figure 35) for the periods 0 – 3 were obtained by decreasing the corresponding value for ICEV by 0.115. Table 60 contains values for ICEVs from the curve corresponding to 20,000 km in Figure 34, and calculated values for EVs and PHEVs.

Figure 35
Residual value, Middle scenario



The values in Table 60 have to be reworked. It would be more convenient to express change of salvage price in terms of salvage gain for the first year and constant relative change of it for the remaining years. Here a method of least squares can be applied to construct a salvage gain curve with constant relative change as closer to the curves in Table 60 as possible. Calculations are shown in Table 17 where "alternative salvage value" stands for the salvage values with constant relative change; "residual squares" – squared difference of the original values in Table 60 and alternative values. The alternative salvage values for the year 0 are set to be the same as original the ones. For the further years the alternative values are calculated, according to a simple formula: $ASV_t = (1 + \text{relative change})ASV_{t-1}$. Minimizing the sum of squares allows obtaining the required constant relative change that equals to -0.154 for ICEVs and -0.185 for EVs and PHEVs.

Table 17
Conversion to constant relative change of salvage price, Middle scenario

Parameter\ Year	*0*	*1*	*2*	*3*	*4*
ICEV alternative salvage value	0.820	0.694	0.587	0.497	0.420
ICEV residual squares	0.000E+00	3.769E-05	5.077E-05	1.018E-05	1.488E-07
EV, PHEV alternative salvage value	0.705	0.574	0.468	0.381	0.311
EV, PHEV residual squares	0.000E+00	1.109E-04	9.632E-06	1.272E-05	3.375E-05
ICEV relative change	-	-0.154	-0.154	-0.154	-0.154
EV, PHEV relative change	-	-0.185	-0.185	-0.185	-0.185

Further, the other two scenarios have to be built. Salvage gain is assumed to stay the same for all the scenarios, i.e. 0.820 for ICEVs and 0.705 for EVs. The scenarios differ in relative change values, and they were calculated by adding or subtracting 0.05 from the values of the Middle scenario correspondingly as shown in Table 18.

Table 18
Scenarios of relative change of salvage gain

Vehicle type\ Scenario	*Pro-EV*	*Middle*	*Contra-EV*
ICEV	-0.204	-0.154	-0.104
EV, PHEV	-0.135	-0.185	-0.235

3.18 Maintenance costs

During vehicle's lifetime, periodical maintenance is required. To construct maintenance costs scenarios, three sources of data will be used: the research by Plötz and two databases of maintenance costs for specific car models (an Austrian automobile magazine Auto Revue and a German automobile club ADAC). Data from the databases are used to calculate weighted costs for conventional vehicle segments. Maintenance costs for AFVs are taken based on a single vehicle model. Eventually, the scenarios of maintenance costs are built.

An estimation of maintenance costs by Plötz P. et al is based on a third-party study that includes a vehicle model and features a simulation of its components over time. It allowed predicting maintenance costs for ICEV, PHEV and BEV for a middle-class car. Two other studies helped Plötz P. et al to derive costs for small and large vehicles. It is assumed in the research of Plötz P. et al that costs remain constant until 2020, as shown in Table 19. The values are presented per km travelled for Germany, and they will be converted to costs per quarter in Austrian prices.

Table 19
Maintenance costs

	Wartungskosten [Cent/km]			
Antrieb	*Klein*	*Mittel*	*Groß*	*Transporter*
Benzin	2,6	4,8	7,4	5,9
Diesel	2,6	4,8	7,4	5,9
PHEV	2,4	4,4	6,9	5,5
REEV	1,7	3,3	5,8	4,1
BEV	2,1	4,0	6,2	4,9

Source: (Plötz P. et al, 2013)

The database of Auto Revue contains maintenance costs for particular vehicle models, not the whole categories as needed (Bus, Middle, Small). A data sample from the database was used in order to calculate the weighted average costs for the sub-categories in Figure 16. Costs of five top-selling models were considered. Their sales in Germany, 2012 from (Kraftfahrt-Bundesamtes (KBA), 2013b) were taken as a weight. Sales statistics in Austria is available for Brands and only top 20 vehicle models. This is not enough for our calculations, therefore the sales in Germany were used. The year 2012 is a basis because it was used as a reference year by Plötz P. et al, and one should stick to it in order to get comparable maintenance cost values. For conventional vehicles, costs from Auto Revue were taken. Costs for PHEVs and BEVs are absent there, so values from ADAC database have to be used. The variety of PHEV and BEV models is much lower than of conventional vehicles, thus costs of these segments are represented by costs of the models in Table 11. Each vehicle model has several modifications, and costs may vary. A model with the lowest costs was always picked from the databases for further calculations. For details of the computations, see Appendix 2: Intermediate calculations, Table 67.

The next step is to adjust maintenance costs from different sources to common quarterly mileage. Data in ADAC are given for a monthly mileage of 15,000 km, and for 12,000 km in Auto Revue. According to arbeitstage.at, there are 248 working days in Vienna in 2015, and that corresponds to 62 working days per quarter on average. Assume that the number of working days per quarter is constant during 2015 – 2020. The assumption of 100 km travelled per day corresponds to 6,200 km covered quarterly. Costs per 1 km for both databases and quarter costs corresponding to 6,200 km travelled were computed. Finally, a ratio of maintenance prices in Austria and Germany is estimated. Table 68 in Appendix 2: Intermediate calculations illustrates the calculations in a more detailed way.

In order to adjust ADAC values for PHEVs and BEVs to Austrian prices, the ratio for maintenance prices for ICEVs of Auto Revue and ADAC were applied as coefficients. The same coefficients were used to adjust costs from the work by Plötz P. et al to Austrian prices. Maintenance costs adjusted to Austrian prices and in common units from both databases and the research are shown in Table 20.

One can notice that in Table 20 for some segments values are higher from Auto Revue and ADAC, for others from Plötz P. et al. As the result, both of them together cannot be used to build scenarios for future costs. The values from Auto Revue and ADAC were chosen because they are closer to the current year and require less adjustment to Austrian prices.

Costs for Bus PHEV and Bus BEV are significantly higher than for Bus Petrol and Bus Diesel. It does not conform to the segments Medium and Small, where PHEVs and EVs have lower costs according to both sources. This contrast can be explained by the fact that PHEV and BEV for Bus (Mitsubishi Outlander PHEV and Tesla Model S) come from a more expensive car segment than those for Medium and Small (Toyota Auris, Nissan Leaf, Toyota Yaris, Renault Zoe). Costs for Bus PHEV and Bus BEV are recalculated as a share of costs for Bus Petrol (see Table 21). The share for Bus PHEV is the average between ratios of costs of Medium PHEV to Medium Petrol and of Small PEHV to Small Petrol. A share for Bus BEV is calculated in the same manner as for PHEVs.

Table 20
Maintenance costs, €/quarter

Segment/ Source	*Auto Revue, ADAC*	*Plötz P. et al*
Bus Petrol	423.789	579.057
Bus Diesel	423.789	579.057
Bus PHEV	600.967	539.931
Bus BEV	901.450	485.156
Medium Petrol	357.023	376.956
Medium Diesel	357.023	376.956
Medium PHEV	295.282	345.543
Medium BEV	276.434	314.130
Small Petrol	281.649	212.562
Small Diesel	281.649	212.562
Small PHEV	248.534	196.211
Small BEV	222.373	171.685

Source: (Plötz P. et al, 2013), (Auto Revue), (ADAC)

Table 21
Adjusted maintenance costs, €/quarter

Segment\ Source	*Auto Revue, ADAC*
Bus Petrol	423.789
Bus Diesel	423.789
Bus PHEV	362.231
Bus BEV	331.363
Medium Petrol	357.023
Medium Diesel	357.023
Medium PHEV	295.282
Medium BEV	276.434
Small Petrol	281.649
Small Diesel	281.649
Small PHEV	248.534
Small BEV	222.373

Source: (Auto Revue), (ADAC)

Values in Table 21 allow constructing the scenarios of maintenance costs. For the Pro-EV scenario, assume that costs will increase by 20% by 2019 for ICEVs and decrease by 20% for PHEVs and BEVs. The opposite assumptions were made for the Contra-EV scenario. For both scenarios, costs develop linearly 2014 – 2019. The Middle scenario was built by assuming the values to stay constant up to 2019. Values for the scenarios are given in Figure 36, Figure 37, Figure 38 and in Table 61, Table 62 and Table 63 in Appendix 1: Data tables.

Figure 36
Maintenance costs, Pro-EV scenario

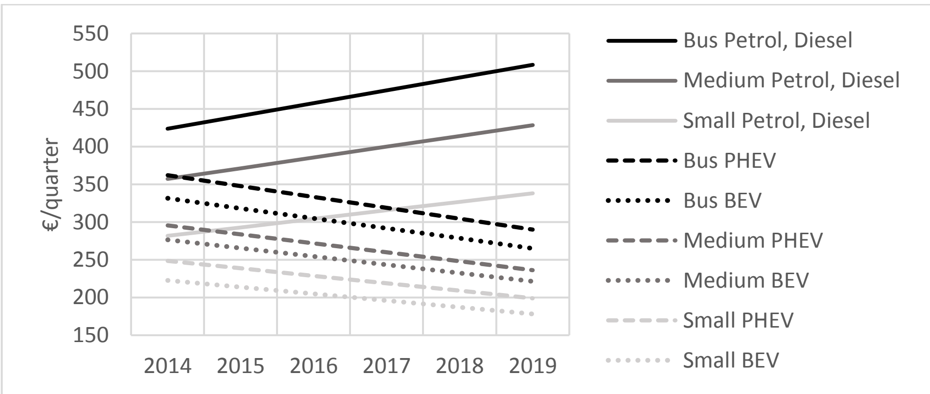


Figure 37
Maintenance costs, Middle scenario

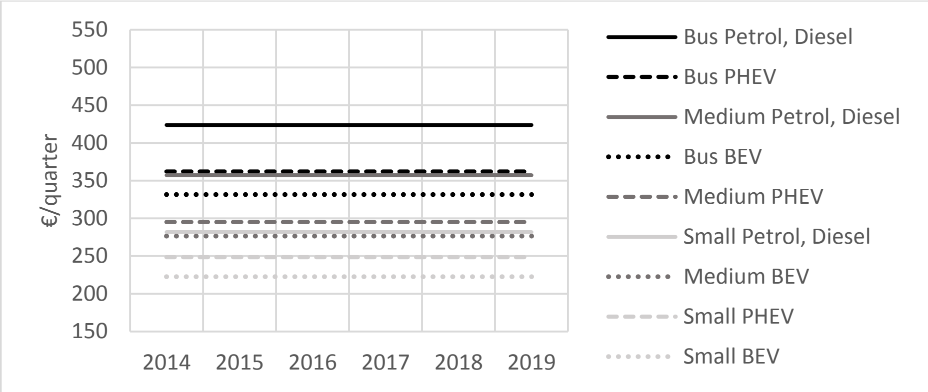
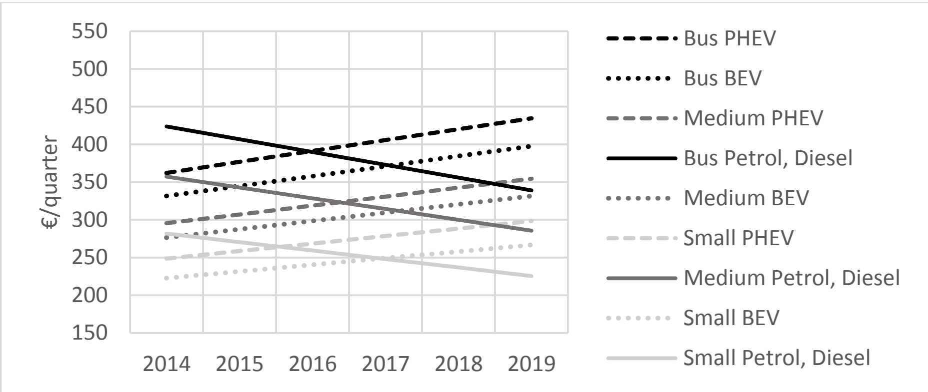


Figure 38
Maintenance costs, Contra-EV scenario



3.19 Public transport costs

Since public transport is considered in the model as an alternative transportation facility, its costs have to be addressed. An expert estimation of costs will be applied. It will be argued to use a single scenario of public transport costs.

Partners involved in our project possess an expert estimation of the costs. They assume costs to be equal to 0.0029 €/km or 0.003 €/km rounded to three decimal places. This value is assumed to stay constant for the Middle scenario.

A reasonable assumption for the Pro-EV scenario could be an increase of the cost by 15% by 2019, which equals to the same 0.003 €/km rounded to three decimal places. Since the numbers are so small, their increase or decrease by a moderate percentage has no effect. Consequently, it makes sense to assume public transport costs to stay constant at 0.003 €/km 2015 – 2019 for all the scenarios.

3.20 Scenarios combinations

This section is devoted to creating of scenarios combinations (master scenarios), which include all the individual parameters discussed above. One could make all the possible combinations of 18 parameters, 17 of which have three scenarios each, and one has a single scenario. That corresponds to 3^{17} or 129,140,163 master scenarios. It would take too much time and effort to asses such a large number of scenarios. Besides, it would result in a very large number of candidate solutions; meanwhile a decision-maker prefers to have a moderate amount of potential choices.

One of the methods to decrease the amount of master scenarios is to group parameters in blocks in such a way that all parameters in a block develop under the same individual scenario. For instance, let parameters 1-4 belong to a group "A". Parameters 1-4 in the group "A" have to follow the same scenarios. The basement of forming a block has to be well defined and explained.

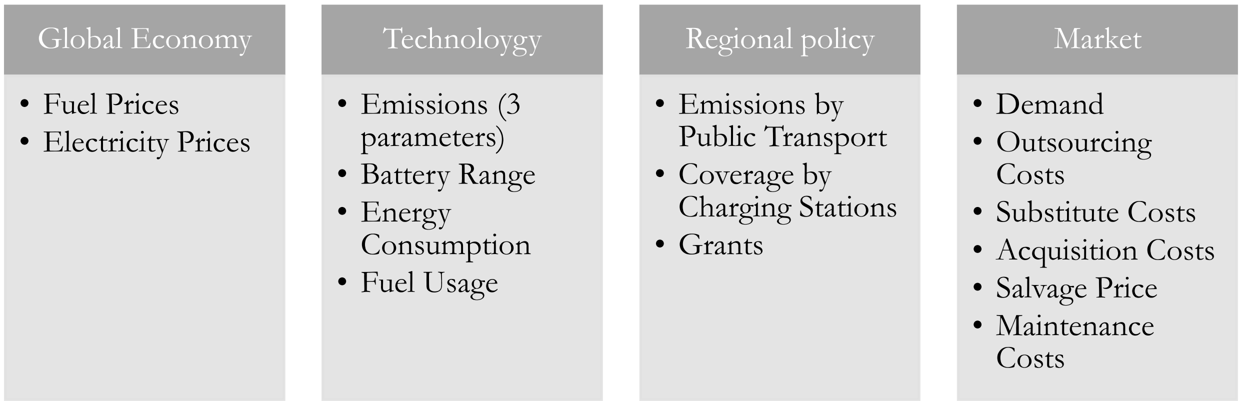
Two parameters Fossil Fuel Prices and Electricity Prices can be grouped together in a block "Global economy". They represent basic worldwide-standardised commodities demanded worldwide. It is argued that these parameters change in the same manner over time in the long run. This point of view is supported by Bencivenga C. et al and Albrecht U. et al who claim that a moderate correlation is present.

The second block "Technology" joins parameters related to technological development such as Emissions by Outsourcing, Emissions of the Substitute, Emissions Using Fuel, Energy Consumption, Battery Range, and Fuel Usage. The interdependence of those related to emissions is obvious since all of them depend on emissions of vehicles. As it was shown in the section "3.12 Emissions using fuel", emissions and fuel usage are connected. Nowadays main players on the car market are involved in production of EVs and PHEVs as well as in research and development related to their crucial characteristics (Battery Range and Energy Consumption). Meanwhile, European Commission targets to lower CO_2 emissions of vehicles by 2020. Goals of governments of European countries to increase the number of EVs support development of EVs as well as fuel-efficiency of ICEVs.

A ground for the next block "Regional policy" could be an idea that parameters included (Emissions by Public Transport, Coverage by Charging Stations, Grants) depend on decisions of local government. Emissions of Public Transport are determined by strategy to purchase more or less environmentally friendly vehicles. Public transport companies are controlled or strongly influenced by government. Local authorities play a crucial role in development of recharging infrastructure because this business is unprofitable for commercial companies so far. Grants for purchasing an EV also mainly depend on government structures as well. It is unlikely that these parameters will develop in different directions since they serve the same goals (better environment and lower dependence on fossil fuels).

Demand, Outsourcing Costs, Cost of the Substitute, Acquisition Costs, Salvage Price and Maintenance Costs can be grouped in a block "Market". A simplified approach is taken and, for instance, for the Pro-EV Scenario a “market situation” is assumed that favours electrical vehicles. All the parameters included in the block take values from the Pro-EV Scenario. Similar argumentation is applied for the other scenarios. Figure 39 displays the blocks. The applied grouping results in a radical reduction of the number of master scenarios to 3^4, which equals to 81.

Figure 39
Blocks of parameters



A Java program was written in order to combine blocks’ scenarios and construct master scenarios. This way is more preferable as compared to filling data manually. Firstly, filling data manually might result in large number of mistakes that are hard to detect. Secondly, in case of altering of data values or its formatting, it is less labour-intensive to modify the program’s code rather than changing data manually.

The general concept of the program is as follows. Parameter scenarios were copied to a conveniently formatted Excel file, which serves as a data source for the algorithm. The first part of the program reads parameters’ values from the Excel file and stores them in the corresponding data arrays. The main part of the Java algorithm enumerates all the combinations of the parameters’ blocks. Finally, 81 master scenarios are written to the output text file in a form of SQL query, which can be run to import data to a SQL database.

4 Analysis of influence of master scenarios on solutions

4.1 Introduction: Chapter 4

Master scenarios developed in the previous chapter act for the decision-making application as a tool to simulate stochasticity of input data. Each master scenario corresponds to a unique solution, and these solutions are analysed in the given section. The main goal is to reveal how algorithm’s parameters effect total emissions, total costs and fleet composition.

The piece of software can be represented as a mathematical model that has two objective functions: minimization of total costs and total emissions. Consequently, each solution is a point in a twodimensional space with corresponding costs and emissions. Sets of solutions for all the master scenarios in a form of Pareto fronts are shown in Figure 40. The figure gives a general overview over the entire solution set. It can be seen that solutions vary significantly. There are solutions with high total costs and high emissions, low costs and low emissions, low costs and high emissions and vice versa. The first rather obvious conclusion is that variation of the scenarios' parameters has a considerable impact on the resulting solutions.

In this section, two different approaches are used to isolate the influence of scenarios' parameters on total costs and emissions. Additionally, a correlation between scenarios' parameters and resulting share of EVs and PHEVs in fleet is examined. Further, fleet compositions of four different scenarios are compared, and their similarities and distinctions are discussed. It has to be noted that the final version of the software package did not take into account outsourcing of vehicles.

4.2 Influence of parameters' blocks on solutions

The main goal of the chapter is to figure out which parameters of the scenarios influence solutions the most. Previously at the stage of master scenarios design, it was decided to group the 18 parameters in four blocks. All the parameters within a block were assumed to follow the same scenario. Consequently, it is possible to observe the influence of a whole block on solution, not of an individual parameter. Further analysis is based on an attempt to separate the effect of each block on solutions. This idea was taken from the articles by Jabali et al and Pradhananga R. et al where a sensitivity analysis of parameters was conducted. For this purpose, scatter plots in Figure 41 and Figure 42 as well as box plots in Figure 43 were made.

In Figure 41, all fronts are grouped according to a block's scenario. In Figure 42 a similar approach is applied, but in a different way. In the picture "Global economy" all the other blocks, except the one under considerations, are fixed to Middle scenario. Resulting three Pareto fronts correspond to Pro-EV, Middle and Contra-EV scenarios of "Global economy". The change of EVs' and PHEVs' share in fleet is displayed in Figure 43.

Figure 40
Total costs and emissions of the solutions

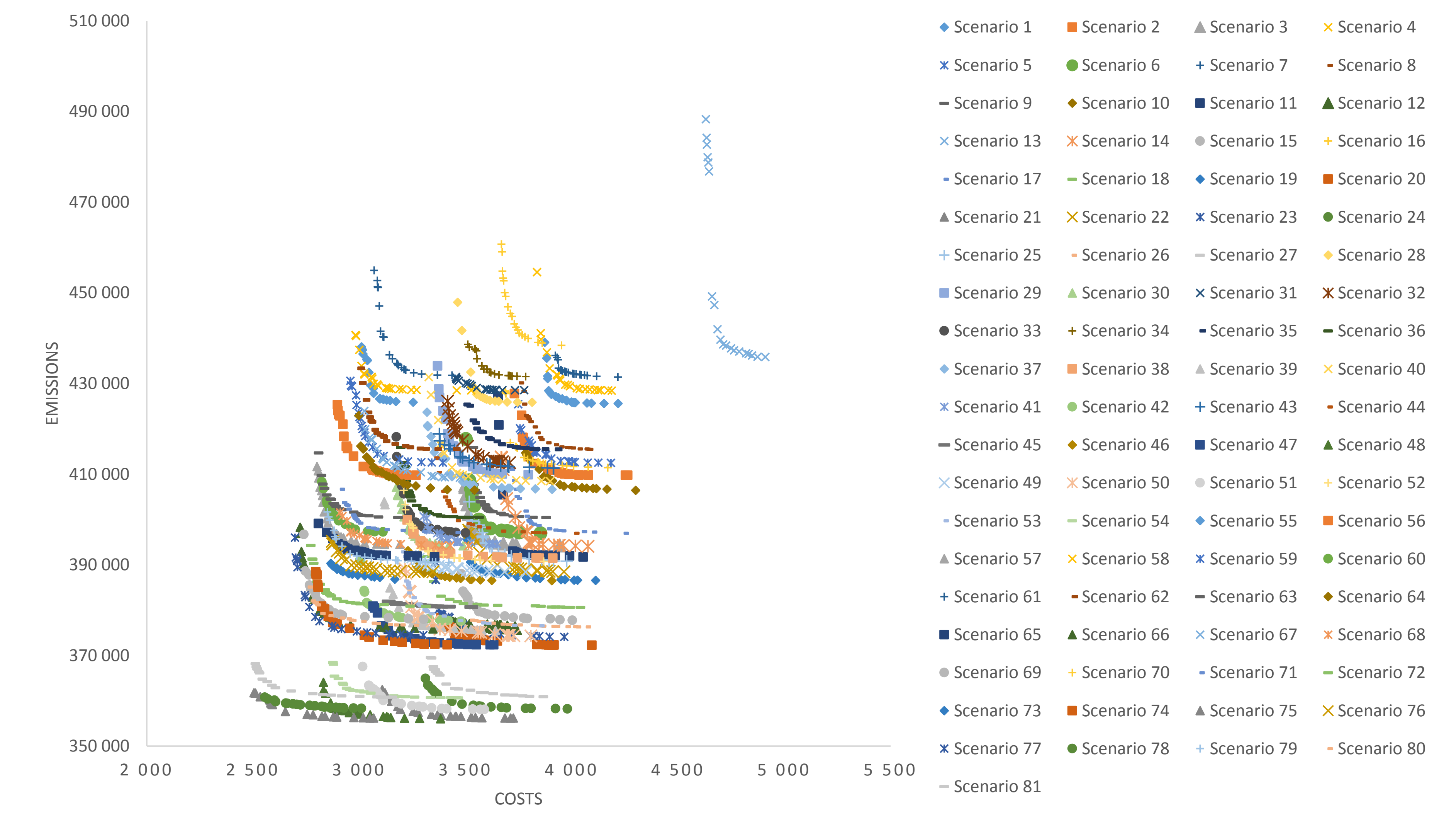


Figure 41
Solutions grouped by parameter blocks, type 1

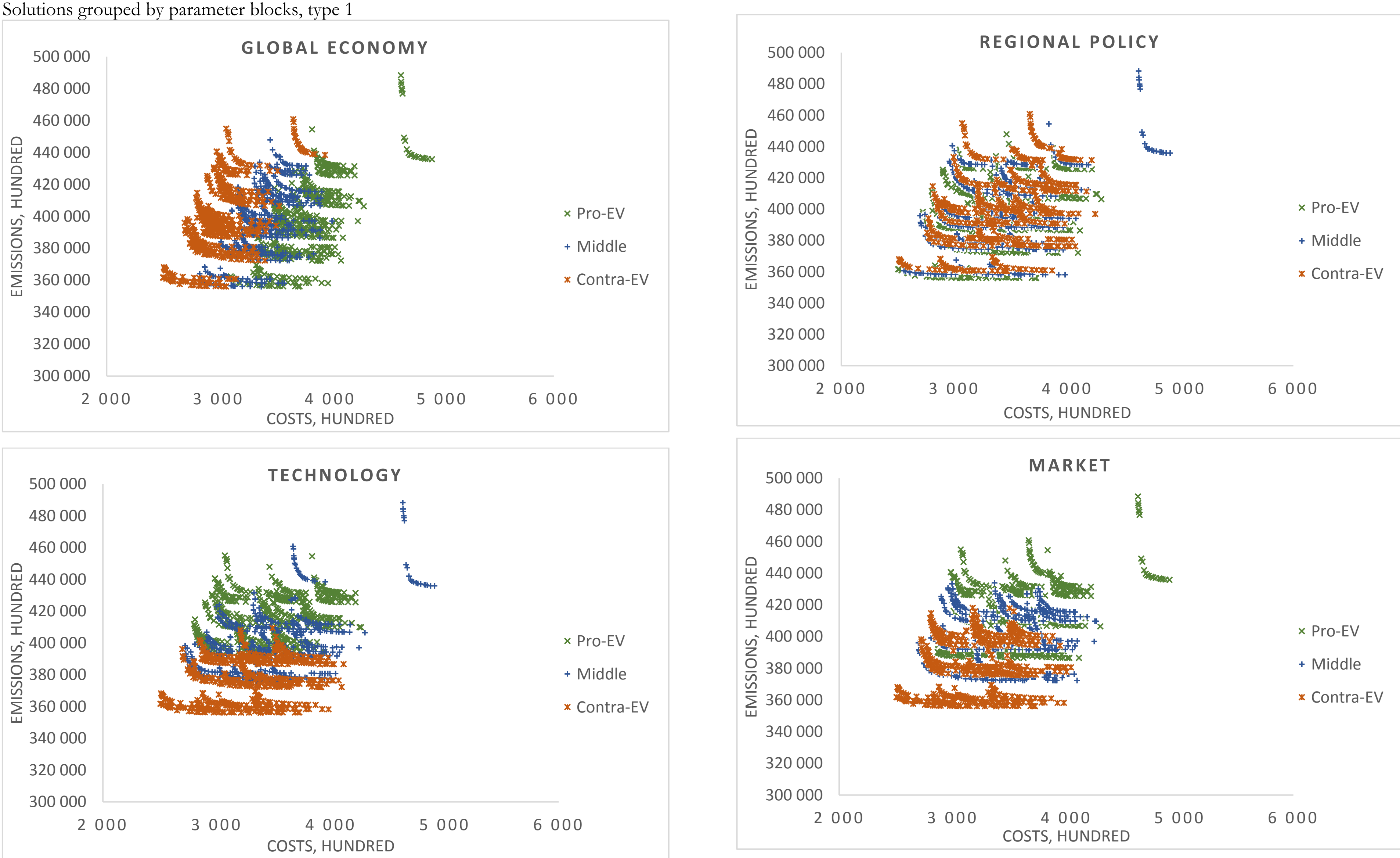


Figure 42
Solutions grouped by parameter blocks, type 2

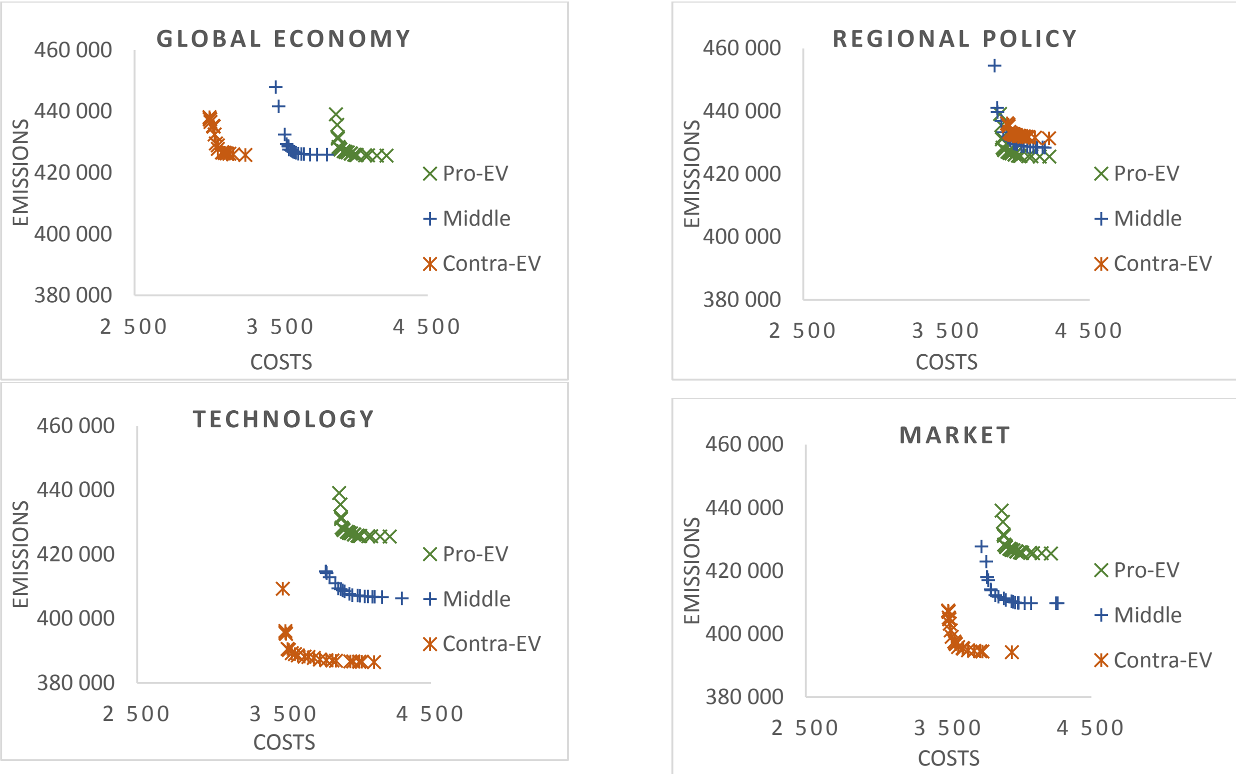


Figure 43
Share of EVs and PHEVs by blocks

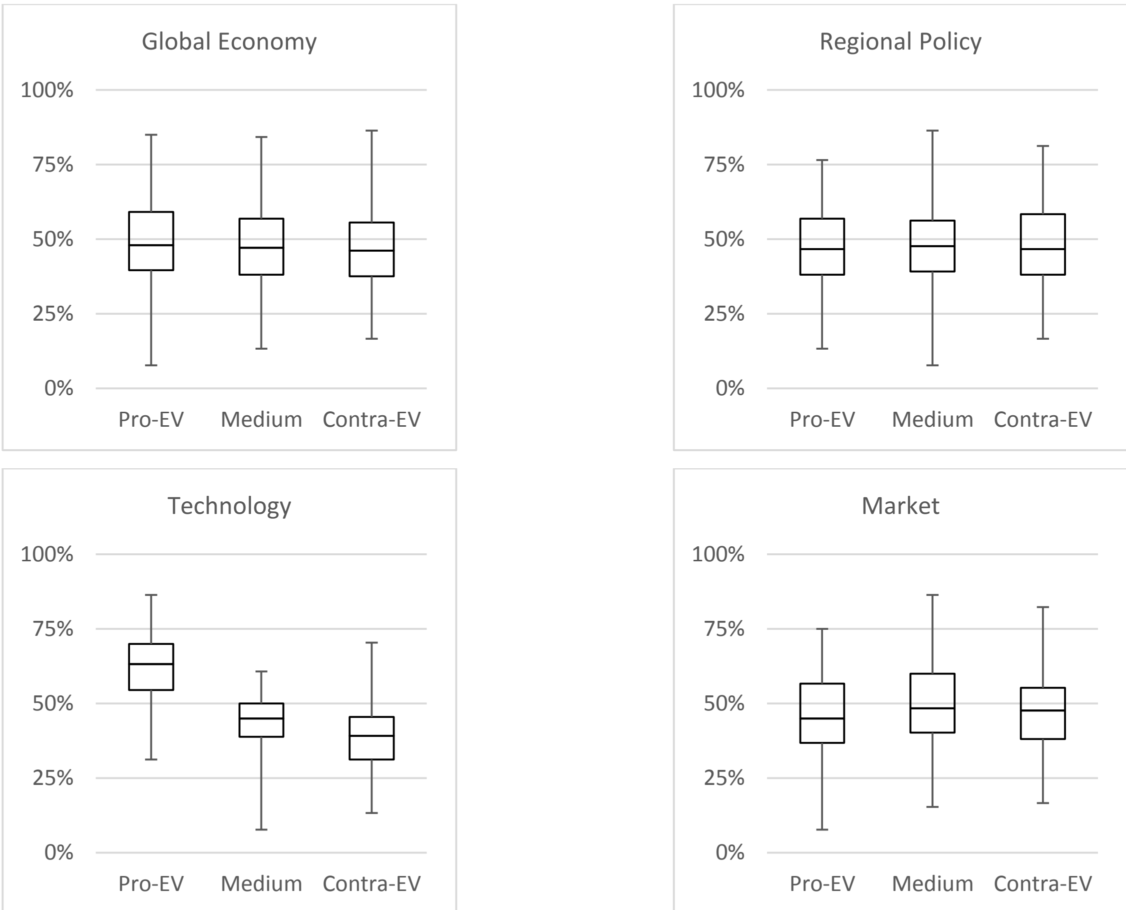


Table 22
Extreme scenarios

Scenario	*Name*	*Total costs*	*Emissions*
13	Costly and polluting	High	High
24	Costly and clean	High	Low
61	Cheap and polluting	Low	High
75	Cheap and clean	Low	Low

Figure 44
Extreme scenarios and the other solutions

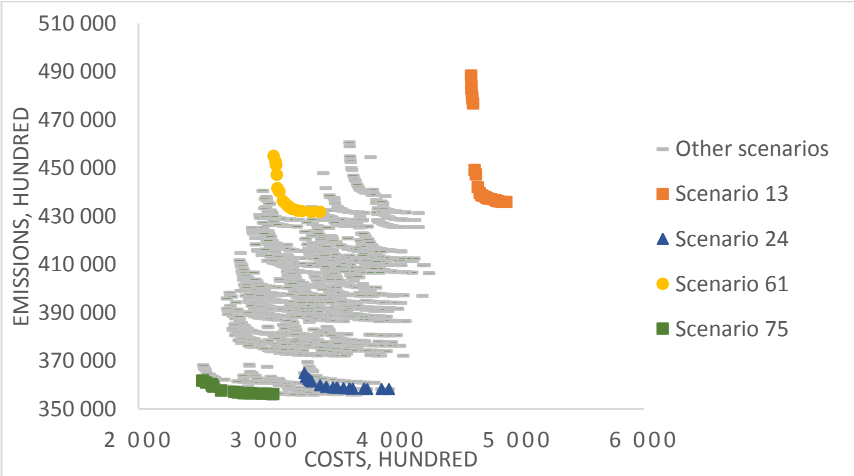
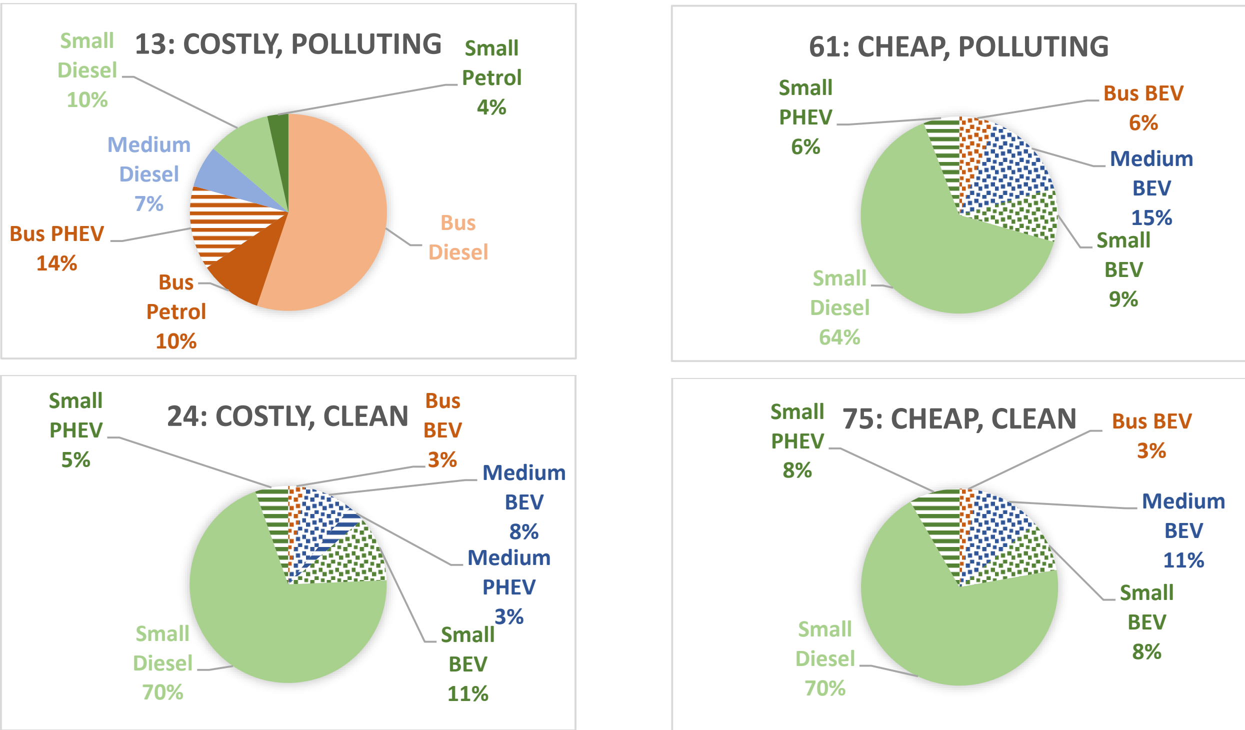


Figure 45
Fleet composition of extreme scenarios



Fossil fuel prices and electricity prices constitute the block "Global economy". For relative values of the parameters refer to Table 23. Consider the scatter plot Global economy in Figure 41. It can be clearly seen that all three groups of fronts are shifted away from each other along the axis of total costs. It indicates that the parameters have a significant influence on the costs. Costs of Contra-EV are lower than Pro-EV, obviously, because fuel prices are lower in Contra-EV. Here fuel and electricity prices have reverse effects, i.e. for the Contra-EV fuel prices decrease the costs whereas electricity prices increase. The effect of low fuel prices is stronger because more than a half of fleet are conventional vehicles running on fossil fuel as can be seen in Figure 43; and fossil fuel is significantly more expensive than electricity.

Surprisingly enough, all the three scenarios are equally spread along the emissions axis. Moreover, the boxplot "Global economy" in Figure 43 shows that the average share of EVs and PHEVs is just slightly greater in Pro-EV scenario than in Contra-EV. This leads to conclusion that alteration of fuel and electricity prices has a weak effect on emissions as well as on adoption of EVs and PHEVs.

The second block "Regional policy" consists of parameters: Coverage by charging stations, amount of financial incentives to purchase an EV or a PEHV (grants) and public transport emissions. A summary of parameters' values is presented in Table 24.

Table 23
Global economy, parameters' values

Parameter\ Scenario	*Pro-EV*	*Middle*	*Contra-EV*
Fuel prices	High	Med	Low
Electricity prices	Low	Med	High

Table 24
Regional policy, parameters' values

Parameter\ Scenario	*Pro-EV*	*Middle*	*Contra-EV*
Coverage by charging stations	High	Med	Low
Grants	High	Med	Low
Public transport emissions	High	Med	Low

Both Figure 41 and Figure 42 show no significant change of total costs effected by the block. In Figure 41 the effect of "Regional policy" on emissions can hardly be seen. However, Figure 42 provides a closer look and shows that Contra-EV has the highest emissions, Pro-EV – the lowest. Since the share of EVs stays stable and in Pro-EV scenario public transport emissions are high, a possible explanation of the emissions' decrease could be a more intensive use of EVs and PHEVs due to high coverage of charging stations. Again, note that the block under consideration only slightly changes the share of EVs and PHEVs in the fleet.

Parameters Emissions, Battery range, Energy Consumption and Fuel usage are allocated in a block "Technology". In Table 25 an overview of parameter's values is given. Figure 41 indicates that the block under consideration has some effect on total costs. This is supported by Figure 42 where the influence is more evident. High emissions and fuel usage together with low energy usage and high battery range of the Pro-EV scenario result in higher total costs as well as higher emissions.

Furthermore, it dramatically increases the share of EVs and PHEVs in fleet. Taking these observations into account brings the following conclusions.

Costs are high because of high fuel consumption that leads to more resources spent on fuel. Another reason for that might be the high share of EVs and PHEVs since they are more expensive than ICEVs. Total emissions reach high values due to the direct effect of high emissions of vehicles. Such a high share of EVs and PHEVs can be explained by improved battery range and energy usage that and make electricity-powered vehicles more favourable for commercial use. This supports the discussed studies that expect EVs to increase their market share under condition of driving range improvement.

Among the parameters within a block "Market" are Demand on transportation service, Outsourcing costs, Acquisition costs, Salvage price and Maintenance costs. For the relative values of the parameters see Table 26 where EVs for EVs and PHEVs.

Table 25
Technology, parameters' values

Parameter\ Scenario	*Pro-EV*	*Middle*	*Contra-EV*
Emissions outsourcing	High	Med	Low
Battery range	High	Med	Low
Energy Usage	Low	Med	High
Fuel usage	High	Med	Low
Emissions ICEV	High	Med	Low

Table 26
Market, parameters' values

Parameter\ Scenario	*Pro-EV*	*Middle*	*Contra-EV*
Demand	High	Med	Low
Outsourcing costs	High	Med	Low
Acquisition costs, ICEVs	Med	Med	Med
Acquisition costs, EVs	Low	Med	High
Salvage price, ICEVs	Low	Med	High
Salvage price, EVs	High	Med	Low
Maintenance costs, ICEVs	High	Med	Low
Maintenance costs, EVs	Low	Med	High

Figure 41 and Figure 42 clearly indicate that Market moderately changes total costs. High demand, outsourcing costs, EV salvage price, ICEV maintenance costs, and low EV acquisition costs, ICEV salvage price, EV maintenance costs of the Pro-EV scenario correspond to higher costs and emissions.

Share of EVs has ambiguous behaviour, and it might require more information (size of fleet, total distance travelled, for instance) in order to explain it.

4.3 Analysis of scenarios' fleet composition

A closer look at scenarios' fleet compositions will be taken in the following paragraph. Fleet compositions of four so-called "extreme" scenarios are considered. Their total costs and emissions are described in Table 22 and their position relative to the other solutions is given in Figure 44. In Table 22 names are assigned to the scenarios for convenience. Each scenario is represented by a set of solutions making a Pareto front. In order to analyse a chosen scenario, average shares of vehicle types across all its fronts are calculated (see Figure 45).

All the scenarios in Figure 45 have a variety of 5-6 different vehicle types. Each scenario has one strongly dominating vehicle: Small Diesel in scenarios 24, 61 and 75, and Bus Diesel in scenario 13.

Another common feature is that Medium vehicles play a modest role in all the scenarios, their share is within 7-15%. Additionally, scenarios 24, 61 and 75 share quite a similar fleet structure.

It can be seen that costly and polluting scenario 13 dramatically differs from the other three scenarios. The largest share of scenario 13 are buses in contrast to small vehicles that dominate in scenarios 24, 61 and 75. Costly and polluting scenario has four vehicle types that are not present in the others and shares only Small diesel. Another notable feature of scenario 13 is its relatively low share of EVs and PHEVs. Their share is 14%, whereas the other scenarios have more than two times larger share (30-46%) of EVs and PHEVs. The share of PHEVs is the largest in scenarios 13.

Scenarios 24 and 75 are positioned close to each other in the solution set, and this corresponds to such a little difference between their structures. However, costly and clean scenario 24 encloses a vehicle type (Medium PHEV) which is not present in any other one. Cheap and polluting scenario 61 resembles cheap and clean scenario 75. They share the same vehicle types, but the overall share of EVs and PHEVs is greater in scenario 61.

Table 27 provides an overview of parameter blocks of the scenarios under discussion. Values of parameters are given in Table 28 using relative labels: High, Med and Low.

Table 27
Blocks of extreme scenarios

Scenario\Block	*Name*	*Global economy*	*Regional policy*	*Technology*	*Market*
13	Costly and polluting	Pro-EV	Middle	Middle	Pro-EV
24	Costly and clean	Pro-EV	Contra-EV	Middle	Contra-EV
61	Cheap and polluting	Contra-EV	Pro-EV	Contra-EV	Pro-EV
75	Cheap and clean	Contra-EV	Contra-EV	Pro-EV	Contra-EV

Table 28
Parameters of extreme scenarios

Block	*Parameter\Scenarios*	*13: Costly and polluting*	*24: Costly and clean*	*61: Cheap and polluting*	*75: Cheap and clean*
Global economy	Fuel price	High	High	Low	Low
	Electricity price	Low	Low	High	High
Regional policy	Charg. Stations coverage	Med	Low	High	Low
	Grants	Med	Low	High	Low
	Pub. transp. emissions	Med	Low	High	Low
	Emissions outsourcing	Med	Med	Low	High
Technology	Battery range	Med	Med	Low	High
	Energy Usage	Med	Med	High	Low
	Fuel usage	Med	Med	Low	High
	Emissions ICEV	Med	Med	Low	High
Market	Demand	High	Low	High	Low
	Outsourcing costs	High	Low	High	Low
	Acquisit. costs, ICEVs	Med	Med	Med	Med
	Acquisition costs, EVs	Low	High	Low	High
	Salvage price, ICEVs	Low	High	Low	High
	Salvage price, EVs	High	Low	High	Low
	Maint. costs, ICEVs	High	Low	High	Low
	Maintenance costs, EVs	Low	High	Low	High

4.4 Possible recommendations

The following recommendations are formed based on the analysis conducted in the previous sections. Two parties are considered: government authorities and fleet managers. The former tend to pursue a decrease of total emissions and increase of AFVs' adoption. The letter are interested to decrease total costs generated by vehicle fleet under control.

Government regulates fuel and electricity prices through taxes and excise-duties. Our analysis showed that these prices seem to have very limited effect on total emissions. Efforts to rise coverage by charging stations for EVs and a more generous financial support of potential EVs byers can decrease emissions more considerably. The most effective tool to limit emissions would be supporting research and development of EVs and PHEVs, particularly those that improve their driving range and battery recharge time.

Fleet managers should concentrate on keeping fuel expenditures low since they have a strong correlation with costs. The analysis also proved economic gain of introduction of new fuel-efficient vehicles in fleet.

5 Conclusions

In this thesis, an attempt was taken to contribute to the development of methods of fleet management. A literature research was done in order to define cost parameters that influence decision of a fleet professional. Different approaches a fleet manager may use to choose a vehicle to purchase and three replacement strategies were discussed. Market barriers for EVs and PHEVs and their possible elimination were addressed based on the literature. These speculations were supported by discussion of the papers related to possible future of AFVs on the car market. Researchers from AIT considered our findings while developing parameters for their fleet management software package. Further work was done with the parameters of that application. Three scenarios of possible development of each parameter were constructed using available literature. In order to produce a moderate number of master scenarios, parameters were grouped in blocks. Colleagues from AIT used these scenarios as input data for their piece of software. Solutions proposed by the application for each master scenario were analysed. Influence of groups of parameters on the total costs, emissions and fleet structure was discussed.

The key findings of this thesis include an aggregative list of cost parameters related to vehicle fleet: operating expenses, investment cost, salvage price, depreciation, insurance, administrative expenses, licences and taxes, parking and tolls. The understanding of fleet manager's decision process was improved by considering three replacement strategies applicable in business. The first strategy is based on using vehicle models with the minimal total cost of ownership. Another policy sets a boundary on the vehicle's age or mileage. The last one features tracking the change of downtime and maintenance costs for each vehicle in comparison to the other vehicles in fleet.

A valuable contribution of this work is the discussion of the role of EVs and PHEVs in commercial fleets. It was concluded that EVs and PHEVs are suitable for some companies, and adoption of AFVs is expected to grow in the future.

One of the advantages of given thesis is the implemented method to group the related parameters in blocks. A Java program was written to generate all possible (81) combinations (master scenarios) of four blocks each having three scenarios. A manual method to construct master scenarios was avoided because it could result in a bigger number of mistakes and require more time to modify or correct scenarios.

The analysis of influence of the parameter groups on solutions showed that fuel prices and electricity prices strongly effect total costs and have little influence on total emissions. Parameters coverage by charging stations, grants and public transport emissions have almost no impact on total costs, but they effect emissions. Total costs depend only marginally on the block "Technology", while emissions and share of AFVs demonstrate a much wider variation. It was difficult to observe the influence of the block of market related parameters.

As to the fleet structure, "Small diesel" turned out to be the dominating vehicle segment (64-70%) for 3 out of 4 analysed solutions. Medium and big vehicles play only a modest role. Considered solutions feature a significant share of EVs and PHEVs at the level of 14-46%.

Based on these results, government was recommended not to try lowering emissions by increasing fuel related taxes. Charging stations infrastructure and financial incentives for EVs and PHEVs should be addressed instead. The greatest emissions' reduction could be reached by supporting R&D of AFVs. Experiments proved that transportation companies would benefit from adoption of modern fuel-efficient conventional vehicles.

Reader can notice several drawbacks of this thesis. Firstly, weak assumptions were made during calculations for some parameters. It was hard to find data for parameters such as coverage of charging stations or public transport emissions. Moreover, Pro-EV and Contra-EV scenarios occasionally lack a firm basis, whereas creation of Middle scenario is typically well motivated. The design feature of master scenarios, i.e. grouping parameters in blocks, prevents the observation of the influence of a single parameter. Lastly, fleet structure only of 4 out of 81 solutions was considered in detail.

The possible further work on the topic could include discussion of findings of this thesis with practicing fleet managers. A more detailed analysis of the response of solutions to the change of individual parameters should be carried out. It could be probably done in a form of sensitivity analysis.

Another topic development is a study of parameters' volatility; they should be ranked according to their volatility and impact on solutions.

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Appendix 1: Data tables

Table 29
Fuel prices in Germany, €/l

Parameter, Scenario\ Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Petrol price, Pro-EV	1.55	1.57	1.61	1.63	1.65	1.68	1.7	1.73	1.75	1.79
Diesel oil price, Pro-EV	1.42	1.45	1.49	1.52	1.56	1.59	1.63	1.67	1.7	1.73
Petrol price, Middle	1.55	1.56	1.57	1.58	1.59	1.61	1.62	1.63	1.64	1.65
Diesel oil price, Middle	1.42	1.44	1.45	1.48	1.49	1.51	1.52	1.55	1.56	1.58
Petrol price, Contra-EV	1.55	1.55	1.55	1.55	1.54	1.54	1.54	1.54	1.54	1.54
Diesel oil price, Contra-EV	1.42	1.42	1.42	1.43	1.43	1.43	1.43	1.43	1.43	1.43

Source: (Plötz P. et al, 2013)

Table 30
Scenarios for petrol and diesel oil prices in Austria 2014 – 2020

Parameter\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Petrol price, €/l (Pro-EV)	1.344	1.386	1.430	1.475	1.521	1.569	1.618
Diesel oil price, €/l (Pro-EV)	1.298	1.340	1.384	1.429	1.476	1.524	1.574
Petrol price, €/l (Middle)	1.344	1.367	1.391	1.416	1.441	1.466	1.492
Diesel oil price, €/l (Middle)	1.298	1.322	1.347	1.373	1.399	1.425	1.452
Petrol price, €/l (Contra-EV)	1.344	1.344	1.344	1.344	1.344	1.344	1.344
Diesel oil price, €/l (Contra-EV)	1.298	1.298	1.298	1.298	1.298	1.298	1.298

Table 31
Electricity prices in Germany, €/kWh

Scenario\ Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Middle and Pro-EV	0.195	0.198	0.2	0.201	0.203	0.206	0.208	0.211	0.213	0.215
Contra-EV	0.195	0.201	0.207	0.213	0.219	0.226	0.232	0.238	0.244	0.25

Source: (Plötz P. et al, 2013)

Table 32
Electricity prices for commercial companies in Austria 2013-2014, €/kWh

Scenario\Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Pro-EV	0.106	0.107	0.108	0.109	0.111	0.112	0.113	0.114
Middle	0.106	0.107	0.108	0.109	0.111	0.112	0.113	0.114
Contra-EV	0.106	0.109	0.112	0.115	0.119	0.122	0.125	0.128

Table 33
Outsourcing emissions, Pro-EV scenario

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Diesel	124.826	124.826	124.826	124.826	124.826	124.826	124.826	124.826
Medium Diesel	108.255	108.255	108.255	108.255	108.255	108.255	108.255	108.255
Small Diesel	95.614	95.614	95.614	95.614	95.614	95.614	95.614	95.614

Table 34
Outsourcing emissions, Middle scenario

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Diesel	124.826	122.739	120.652	118.564	116.477	114.389	112.302	110.215
Medium Diesel	108.255	106.653	105.051	103.449	101.847	100.245	98.643	97.040
Small Diesel	95.614	94.352	93.091	91.829	90.568	89.307	88.045	86.784

Table 35
Outsourcing emissions, Contra-EV scenario

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Diesel	124.826	121.165	117.503	113.841	110.179	106.517	102.855	99.193
Medium Diesel	108.255	105.267	102.278	99.290	96.302	93.313	90.325	87.336
Small Diesel	95.614	93.112	90.611	88.110	85.609	83.108	80.607	78.105

Table 36
Public transport emissions scenarios, g CO_2/km

Scenario\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Pro-EV	14.409	14.409	14.409	14.409	14.409	14.409	14.409
Middle	14.409	13.928	13.448	12.968	12.488	12.007	11.527
Contra-EV	14.409	13.688	12.968	12.247	11.527	10.807	10.086

Table 37
Relative coverage of recharging stations at trip stops, share

Scenario\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Pro-EV	0.788	0.820	0.851	0.883	0.914	0.946
Middle	0.788	0.804	0.820	0.835	0.851	0.867
Contra-EV	0.788	0.788	0.788	0.788	0.788	0.788

Table 38
Fixed outsourcing costs, Pro-EV scenario, €

Segment\ Year	*2015*	*2016*	*2017*	*2018*	*2019*
Bus	143.177	146.140	149.166	152.253	155.405
Middle	104.660	106.826	109.038	111.295	113.599
Small	94.990	96.956	98.963	101.012	103.103

Table 39
Fixed outsourcing costs, Middle scenario, €

Segment\ Year	*2015*	*2016*	*2017*	*2018*	*2019*
Bus	143.177	145.754	148.377	151.048	153.767
Middle	104.660	106.544	108.462	110.414	112.401
Small	94.990	96.700	98.440	100.212	102.016

Table 40
Fixed outsourcing costs, Contra-EV scenario, €

Segment\ Year	*2015*	*2016*	*2017*	*2018*	*2019*
Bus	143.177	145.367	147.591	149.850	152.142
Middle	104.660	106.261	107.887	109.538	111.214
Small	94.990	96.443	97.919	99.417	100.938

Table 41
Variable outsourcing costs, €/km

Segment\ Year	*2015*	*2016*	*2017*	*2018*	*2019*
Bus	0.060	0.061	0.061	0.061	0.061
Medium	0.053	0.053	0.053	0.053	0.053
Small	0.047	0.047	0.047	0.047	0.048

Table 42
Energy consumption, kWh/100 km

Segment\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Großklassewagen PHEV	23.800	23.500	23.200	22.900	22.600	22.300	22.000	21.700	21.400
Großklassewagen BEV	25.100	24.800	24.500	24.200	23.900	23.600	23.300	23.000	22.700
Mittelklassewagen PHEV	22.000	21.725	21.450	21.175	20.900	20.625	20.350	20.075	19.800
Mittelklassewagen BEV	22.300	22.150	22.000	21.850	21.700	21.550	21.400	21.250	21.100
Kleinwagen PHEV	17.800	17.563	17.325	17.088	16.850	16.613	16.375	16.138	15.900
Kleinwagen BEV	19.100	18.863	18.625	18.388	18.150	17.913	17.675	17.438	17.200

Source: (Plötz P. et al, 2013)

Table 43
Energy consumption, Pro-EV scenario, kWh/100 km

Car\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	23.800	23.233	22.665	22.098	21.530	20.963	20.395	19.828	19.260
Bus BEV	25.100	24.516	23.933	23.349	22.765	22.181	21.598	21.014	20.430
Medium PHEV	22.000	21.478	20.955	20.433	19.910	19.388	18.865	18.343	17.820
Medium BEV	22.300	21.886	21.473	21.059	20.645	20.231	19.818	19.404	18.990
Small PHEV	17.800	17.364	16.928	16.491	16.055	15.619	15.183	14.746	14.310
Small BEV	19.100	18.648	18.195	17.743	17.290	16.838	16.385	15.933	15.480

Table 44
Energy consumption, Middle scenario, kWh/100 km

Car\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	23.800	23.500	23.200	22.900	22.600	22.300	22.000	21.700	21.400
Bus BEV	25.100	24.800	24.500	24.200	23.900	23.600	23.300	23.000	22.700
Medium PHEV	22.000	21.725	21.450	21.175	20.900	20.625	20.350	20.075	19.800
Medium BEV	22.300	22.150	22.000	21.850	21.700	21.550	21.400	21.250	21.100
Small PHEV	17.800	17.563	17.325	17.088	16.850	16.613	16.375	16.138	15.900
Small BEV	19.100	18.863	18.625	18.388	18.150	17.913	17.675	17.438	17.200

Table 45
Energy consumption, Contra-EV scenario, kWh/100 km

Car\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	23.800	23.800	23.800	23.800	23.800	23.800	23.800	23.800	23.800
Bus BEV	25.100	25.100	25.100	25.100	25.100	25.100	25.100	25.100	25.100
Medium PHEV	22.000	22.000	22.000	22.000	22.000	22.000	22.000	22.000	22.000
Medium BEV	22.300	22.300	22.300	22.300	22.300	22.300	22.300	22.300	22.300
Small PHEV	17.800	17.800	17.800	17.800	17.800	17.800	17.800	17.800	17.800
Small BEV	19.100	19.100	19.100	19.100	19.100	19.100	19.100	19.100	19.100

Table 46
Battery range Pro-EV scenario, km

Segment\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	54.622	55.956	57.357	58.830	60.381	62.016	63.741	65.566	67.497
Bus BEV	111.554	114.210	116.996	119.921	122.996	126.233	129.645	133.246	137.053
Medium PHEV	45.455	46.560	47.721	48.942	50.226	51.580	53.008	54.518	56.117
Medium BEV	107.623	109.658	111.771	113.967	116.251	118.628	121.105	123.687	126.382
Small PHEV	39.326	40.314	41.353	42.447	43.600	44.818	46.106	47.470	48.917
Small BEV	104.712	107.253	109.920	112.724	115.674	118.782	122.063	125.530	129.199

Table 47
Battery range Middle scenario, km

Segment\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	54.622	55.319	56.034	56.769	57.522	58.296	59.091	59.908	60.748
Bus BEV	111.554	112.903	114.286	115.702	117.155	118.644	120.172	121.739	123.348
Medium PHEV	45.455	46.030	46.620	47.226	47.847	48.485	49.140	49.813	50.505
Medium BEV	107.623	108.352	109.091	109.840	110.599	111.369	112.150	112.941	113.744
Small PHEV	39.326	39.858	40.404	40.966	41.543	42.137	42.748	43.377	44.025
Small BEV	104.712	106.030	107.383	108.770	110.193	111.654	113.154	114.695	116.279

Table 48
Battery range Contra-EV scenario, km

Segment\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus PHEV	54.622	54.622	54.622	54.622	54.622	54.622	54.622	54.622	54.622
Bus BEV	111.554	111.554	111.554	111.554	111.554	111.554	111.554	111.554	111.554
Medium PHEV	45.455	45.455	45.455	45.455	45.455	45.455	45.455	45.455	45.455
Medium BEV	107.623	107.623	107.623	107.623	107.623	107.623	107.623	107.623	107.623
Small PHEV	39.326	39.326	39.326	39.326	39.326	39.326	39.326	39.326	39.326
Small BEV	104.712	104.712	104.712	104.712	104.712	104.712	104.712	104.712	104.712

Table 49
Fuel consumption, l/100 km

Vehicle\ Year	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	10.200	9.988	9.775	9.563	9.350	9.138	8.925	8.713	8.500
Bus Diesel	7.600	7.475	7.350	7.225	7.100	6.975	6.850	6.725	6.600
Bus PHEV	8.900	8.738	8.575	8.413	8.250	8.088	7.925	7.763	7.600
Medium Petrol	7.600	7.463	7.325	7.188	7.050	6.913	6.775	6.638	6.500
Medium Diesel	6.000	5.913	5.825	5.738	5.650	5.563	5.475	5.388	5.300
Medium PHEV	7.000	6.888	6.775	6.663	6.550	6.438	6.325	6.213	6.100
Small Petrol	6.100	6.013	5.925	5.838	5.750	5.663	5.575	5.488	5.400
Small Diesel	4.800	4.738	4.675	4.613	4.550	4.488	4.425	4.363	4.300
Small PHEV	5.600	5.513	5.425	5.338	5.250	5.163	5.075	4.988	4.900

Source: (Plötz P. et al, 2013)

Table 50
Fuel consumption Pro-EV scenario, l/100 km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	6.618	6.618	6.618	6.618	6.618	6.618	6.618	6.618
Bus Diesel	4.728	4.728	4.728	4.728	4.728	4.728	4.728	4.728
Bus PHEV	5.259	5.259	5.259	5.259	5.259	5.259	5.259	5.259
Medium Petrol	5.557	5.557	5.557	5.557	5.557	5.557	5.557	5.557
Medium Diesel	4.101	4.101	4.101	4.101	4.101	4.101	4.101	4.101
Medium PHEV	3.900	3.900	3.900	3.900	3.900	3.900	3.900	3.900
Small Petrol	4.450	4.450	4.450	4.450	4.450	4.450	4.450	4.450
Small Diesel	3.622	3.622	3.622	3.622	3.622	3.622	3.622	3.622
Small PHEV	3.400	3.400	3.400	3.400	3.400	3.400	3.400	3.400

Table 51
Fuel consumption Middle scenario, l/100 km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	6.618	6.477	6.336	6.196	6.055	5.914	5.773	5.632
Bus Diesel	4.728	4.649	4.570	4.491	4.412	4.333	4.254	4.175
Bus PHEV	5.259	5.161	5.063	4.966	4.868	4.770	4.672	4.574
Medium Petrol	5.557	5.454	5.352	5.250	5.147	5.045	4.942	4.840
Medium Diesel	4.101	4.040	3.979	3.919	3.858	3.797	3.736	3.676
Medium PHEV	3.900	3.836	3.773	3.709	3.645	3.581	3.518	3.454
Small Petrol	4.450	4.385	4.320	4.255	4.191	4.126	4.061	3.996
Small Diesel	3.622	3.574	3.526	3.478	3.431	3.383	3.335	3.287
Small PHEV	3.400	3.346	3.292	3.238	3.184	3.130	3.076	3.022

Table 52
Fuel consumption Contra-EV scenario, l/100 km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	6.618	6.397	6.175	5.954	5.733	5.512	5.290	5.069
Bus Diesel	4.728	4.590	4.451	4.312	4.173	4.035	3.896	3.757
Bus PHEV	5.259	5.096	4.933	4.770	4.606	4.443	4.280	4.117
Medium Petrol	5.557	5.385	5.214	5.042	4.871	4.699	4.528	4.356
Medium Diesel	4.101	3.987	3.874	3.761	3.648	3.535	3.421	3.308
Medium PHEV	3.900	3.787	3.674	3.561	3.448	3.335	3.222	3.109
Small Petrol	4.450	4.328	4.206	4.084	3.962	3.840	3.719	3.597
Small Diesel	3.622	3.527	3.432	3.338	3.243	3.148	3.053	2.959
Small PHEV	3.400	3.303	3.206	3.109	3.011	2.914	2.817	2.720

Table 53
Emissions using fuel Pro-EV scenario, g CO_2/km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	154.199	154.199	154.199	154.199	154.199	154.199	154.199	154.199
Bus Diesel	124.826	124.826	124.826	124.826	124.826	124.826	124.826	124.826
Bus PHEV	122.537	122.537	122.537	122.537	122.537	122.537	122.537	122.537
Medium Petrol	129.470	129.470	129.470	129.470	129.470	129.470	129.470	129.470
Medium Diesel	108.255	108.255	108.255	108.255	108.255	108.255	108.255	108.255
Medium PHEV	90.870	90.870	90.870	90.870	90.870	90.870	90.870	90.870
Small Petrol	103.676	103.676	103.676	103.676	103.676	103.676	103.676	103.676
Small Diesel	95.614	95.614	95.614	95.614	95.614	95.614	95.614	95.614
Small PHEV	79.220	79.220	79.220	79.220	79.220	79.220	79.220	79.220

Table 54
Emissions using fuel Middle scenario, g CO_2/km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	154.199	150.919	147.638	144.357	141.076	137.795	134.514	131.234
Bus Diesel	124.826	122.739	120.652	118.564	116.477	114.389	112.302	110.215
Bus PHEV	122.537	120.258	117.979	115.700	113.421	111.142	108.863	106.584
Medium Petrol	129.470	127.085	124.699	122.314	119.928	117.542	115.157	112.771
Medium Diesel	108.255	106.653	105.051	103.449	101.847	100.245	98.643	97.040
Medium PHEV	90.870	89.386	87.901	86.417	84.933	83.449	81.964	80.480
Small Petrol	103.676	102.168	100.659	99.150	97.641	96.132	94.624	93.115
Small Diesel	95.614	94.352	93.091	91.829	90.568	89.307	88.045	86.784
Small PHEV	79.220	77.963	76.705	75.448	74.190	72.933	71.675	70.418

Table 55
Emissions using fuel Contra-EV scenario, g CO_2/km

Segment\ Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Bus Petrol	154.199	149.044	143.888	138.733	133.577	128.421	123.266	118.110
Bus Diesel	124.826	121.165	117.503	113.841	110.179	106.517	102.855	99.193
Bus PHEV	122.537	118.735	114.934	111.132	107.331	103.529	99.727	95.926
Medium Petrol	129.470	125.474	121.477	117.480	113.484	109.487	105.491	101.494
Medium Diesel	108.255	105.267	102.278	99.290	96.302	93.313	90.325	87.336
Medium PHEV	90.870	88.236	85.602	82.968	80.334	77.700	75.066	72.432
Small Petrol	103.676	100.837	97.998	95.159	92.320	89.481	86.642	83.803
Small Diesel	95.614	93.112	90.611	88.110	85.609	83.108	80.607	78.105
Small PHEV	79.220	76.957	74.693	72.430	70.166	67.903	65.639	63.376

Table 56
Battery prices, €/kWh

Scenario\ Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Pro-EV	698	470	394	351	323	302	285	272	260	251
Middle	798	521	437	390	359	336	318	304	292	281
Contra-EV	898	577	483	431	397	371	352	336	322	311

Source: (Plötz P. et al, 2013)

Table 57
Acquisition costs, Pro-EV scenario, €

Segment\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	39294.798	39428.734	39562.670	39696.605	39830.541	39964.477
Bus Diesel	42135.877	42269.812	42403.748	42537.684	42671.620	42805.555
Bus PHEV	51060.495	50597.165	50249.668	49968.360	49753.243	49554.673
Bus BEV	52519.221	51521.280	50772.823	50166.930	49703.600	49275.911
Medium Petrol	21997.568	22047.069	22096.571	22146.072	22195.573	22245.074
Medium Diesel	24781.367	24830.868	24880.369	24929.870	24979.371	25028.873
Medium PHEV	32618.942	32262.535	31995.229	31778.838	31613.363	31460.617
Medium BEV	33688.165	32832.787	32191.253	31671.916	31274.776	30908.185
Small Petrol	13852.479	13964.083	14075.687	14187.291	14298.895	14410.499
Small Diesel	16356.144	16465.470	16574.797	16684.124	16793.450	16902.777
Small PHEV	22685.350	22435.865	22248.751	22097.278	21981.445	21874.523
Small BEV	23293.789	22580.974	22046.362	21613.582	21282.632	20977.139

Table 58
Acquisition costs, Middle EV scenario, €

Segment\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	39294.798	39428.734	39562.670	39696.605	39830.541	39964.477
Bus Diesel	42135.877	42269.812	42403.748	42537.684	42671.620	42805.555
Bus PHEV	51705.848	51192.875	50812.283	50514.428	50282.763	50084.193
Bus BEV	53909.211	52804.347	51984.610	51343.076	50844.105	50416.416
Medium Petrol	21997.568	22047.069	22096.571	22146.072	22195.573	22245.074
Medium Diesel	24781.367	24830.868	24880.369	24929.870	24979.371	25028.873
Medium PHEV	33115.367	32720.773	32428.010	32198.890	32020.687	31867.940
Medium BEV	34879.585	33932.559	33229.927	32680.041	32252.352	31885.761
Small Petrol	13852.479	13964.083	14075.687	14187.291	14298.895	14410.499
Small Diesel	16356.144	16465.470	16574.797	16684.124	16793.450	16902.777
Small PHEV	23032.848	22756.632	22551.698	22391.314	22266.571	22159.649
Small BEV	24286.639	23497.451	22911.924	22453.685	22097.278	21791.785

Table 59
Acquisition costs, Contra EV scenario, €

Segment\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	39294.798	39428.734	39562.670	39696.605	39830.541	39964.477
Bus Diesel	42135.877	42269.812	42403.748	42537.684	42671.620	42805.555
Bus PHEV	52384.295	51821.680	51391.445	51077.043	50812.283	50580.618
Bus BEV	55370.483	54158.697	53232.037	52554.862	51984.610	51485.639
Medium Petrol	21997.568	22047.069	22096.571	22146.072	22195.573	22245.074
Medium Diesel	24781.367	24830.868	24880.369	24929.870	24979.371	25028.873
Medium PHEV	33637.250	33204.469	32873.519	32631.671	32428.010	32249.806
Medium BEV	36132.104	35093.430	34299.150	33718.715	33229.927	32802.238
Small Petrol	13852.479	13964.083	14075.687	14187.291	14298.895	14410.499
Small Diesel	16356.144	16465.470	16574.797	16684.124	16793.450	16902.777
Small PHEV	23398.166	23095.219	22863.554	22694.261	22551.698	22426.955
Small BEV	25330.405	24464.843	23802.943	23319.247	22911.924	22555.516

Table 60
Residual value, Middle scenario, share

Vehicle type\ Years old	*0*	*1*	*2*	*3*	*4*
ICEV	0.820	0.700	0.580	0.500	0.420
EV, PHEV	0.705	0.585	0.465	0.385	0.305

Table 61
Maintenance costs, Pro-EV scenario, €/quarter

Segment/ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	423.789	440.740	457.692	474.643	491.595	508.546
Bus Diesel	423.789	440.740	457.692	474.643	491.595	508.546
Bus PHEV	362.231	347.742	333.253	318.764	304.274	289.785
Bus BEV	331.363	318.109	304.854	291.599	278.345	265.090
Medium Petrol	357.023	371.304	385.585	399.866	414.147	428.428
Medium Diesel	357.023	371.304	385.585	399.866	414.147	428.428
Medium PHEV	295.282	283.471	271.659	259.848	248.037	236.226
Medium BEV	276.434	265.377	254.319	243.262	232.205	221.147
Small Petrol	281.649	292.915	304.181	315.447	326.713	337.979
Small Diesel	281.649	292.915	304.181	315.447	326.713	337.979
Small PHEV	248.534	238.593	228.651	218.710	208.769	198.827
Small BEV	222.373	213.478	204.583	195.688	186.793	177.898

Table 62
Maintenance costs, Middle scenario, €/quarter

Segment/ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	423.789	423.789	423.789	423.789	423.789	423.789
Bus Diesel	423.789	423.789	423.789	423.789	423.789	423.789
Bus PHEV	362.231	362.231	362.231	362.231	362.231	362.231
Bus BEV	331.363	331.363	331.363	331.363	331.363	331.363
Medium Petrol	357.023	357.023	357.023	357.023	357.023	357.023
Medium Diesel	357.023	357.023	357.023	357.023	357.023	357.023
Medium PHEV	295.282	295.282	295.282	295.282	295.282	295.282
Medium BEV	276.434	276.434	276.434	276.434	276.434	276.434
Small Petrol	281.649	281.649	281.649	281.649	281.649	281.649
Small Diesel	281.649	281.649	281.649	281.649	281.649	281.649
Small PHEV	248.534	248.534	248.534	248.534	248.534	248.534
Small BEV	222.373	222.373	222.373	222.373	222.373	222.373

Table 63
Maintenance costs, Contra-EV scenario, €/quarter

Segment/ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Bus Petrol	423.789	406.837	389.886	372.934	355.982	339.031
Bus Diesel	423.789	406.837	389.886	372.934	355.982	339.031
Bus PHEV	362.231	376.721	391.210	405.699	420.188	434.678
Bus BEV	331.363	344.618	357.872	371.127	384.381	397.636
Medium Petrol	357.023	342.743	328.462	314.181	299.900	285.619
Medium Diesel	357.023	342.743	328.462	314.181	299.900	285.619
Medium PHEV	295.282	307.093	318.905	330.716	342.527	354.338
Medium BEV	276.434	287.492	298.549	309.606	320.664	331.721
Small Petrol	281.649	270.383	259.117	247.851	236.585	225.319
Small Diesel	281.649	270.383	259.117	247.851	236.585	225.319
Small PHEV	248.534	258.476	268.417	278.358	288.300	298.241
Small BEV	222.373	231.268	240.162	249.057	257.952	266.847

Appendix 2: Intermediate calculations

Table 64
Comparing petrol and diesel oil prices in Austria and Germany

Parameter\ Year	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
AT Benzin, €/l	1.072	1.091	1.131	1.236	1.086	1.193	1.363	1.453	1.392	1.344						
AT Diesel, €/l	1.023	1.045	1.104	1.258	1.015	1.120	1.331	1.414	1.358	1.298						
DE Benzin, €/l	1.236	1.328	1.383	1.331	1.284	1.398	1.532	1.649	1.594	1.540						
AT/DE Ratio	0.868	0.822	0.818	0.929	0.846	0.853	0.889	0.881	0.873	0.873	0.885	0.889	0.893	0.896	0.900	0.904
AT Diesel/Petrol ratio	0.954	0.958	0.976	1.018	0.934	0.939	0.977	0.973	0.975	0.966	0.970	0.971	0.971	0.972	0.972	0.973

Table 65
Rental car price index scenarios

Scenario\ Year	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Pro-EV	1.000	0.950	0.950	0.940	0.900	0.906	0.912	0.918	0.924	0.930	0.936
Middle	1.000	0.950	0.950	0.940	0.900	0.880	0.860	0.840	0.820	0.800	0.780
Conta-EV	1.000	0.950	0.950	0.940	0.900	0.854	0.808	0.762	0.716	0.670	0.624

Table 66
Outsourcing costs intermediate calculations

Parameter\ Year	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Rent Price index, DE, 1 day Pro-EV	0.900	0.906	0.912	0.918	0.924	0.930	0.936
Rent Price index, DE, 1 day Middle	0.900	0.880	0.860	0.840	0.820	0.800	0.780
Rent Price index, DE, 1 day Conta-EV	0.900	0.854	0.808	0.762	0.716	0.670	0.624
Rent Prices, AT, € Pro EV	49.050	49.377	49.704	50.031	50.358	50.685	51.012
Rent Prices, AT, € Middle	49.050	47.960	46.870	45.780	44.690	43.600	42.510
Rent Prices, AT, € Contra-EV	49.050	46.543	44.036	41.529	39.022	36.515	34.008
Distance travelled, km	100	100	100	100	100	100	100
Diesel price, AT, €/l	1.30	1.32	1.35	1.37	1.40	1.43	1.45
Fuel costs, AT, €	7.560	7.587	7.612	7.636	7.658	7.678	7.696
Fuel consumption (diesel), l/100 km	5.825	5.738	5.650	5.563	5.475	5.388	5.300
Rent + fuel AT, € Pro-EV	56.610	56.964	57.316	57.667	58.016	58.363	58.708
Rent + fuel AT, € Middle	56.610	55.547	54.482	53.416	52.348	51.278	50.206
Rent + fuel AT, € Contra-EV	56.610	54.130	51.648	49.165	46.680	44.193	41.704
Rent + fuel AT, €/km Pro-EV	0.566	0.570	0.573	0.577	0.580	0.584	0.587
Rent + fuel AT, €/km Middle	0.566	0.555	0.545	0.534	0.523	0.513	0.502
Rent + fuel AT, €/km Conta-EV	0.566	0.541	0.516	0.492	0.467	0.442	0.417
Relative change: rent+fuel\km Pro-EV	-	0.006	0.006	0.006	0.006	0.006	0.006
Relative change: rent+fuel\km Middle	-	-0.019	-0.019	-0.020	-0.020	-0.020	-0.021
Relative change: rent+fuel\km Conta-EV	-	-0.044	-0.046	-0.048	-0.051	-0.053	-0.056

Table 67
Quarter maintenance cost derivation

Vehicle segment, class	*Quantity*	*Maintenance costs monthly DE (15000 km), €*	*Maintenance costs monthly AT (12000 km), €*	*Weight DE*	*Weight AT*	*Weighted maintenance costs monthly DE, €*	*Weighted maintenance costs monthly AT, €*
Klein	**24517**					**43.063**	**45.427**
Minis							-
VW Up	2950	38	51	0.120	0.120	4.572	6.137
Fiat 500	1601	52	37	0.065	0.065	3.396	2.416
Toyota Aygo	1555	34	49	0.063	0.063	2.156	3.108
Renault Twingo	1537	44	57	0.063	0.063	2.758	3.573
Skoda Citigo	1313	42	42	0.054	0.054	2.249	2.249
Kleinwagen							-
VW Polo	3724	37	43	0.152	0.152	5.620	6.531
Skoda Fabia	3297	42	39	0.134	0.134	5.648	5.245
Opel Corsa	3293	55	47	0.134	0.134	7.387	6.313
BMW Mini	2751	50	47	0.112	0.112	5.610	5.274
Seat Ibiza, Cordoba	2496	36	45	0.102	0.102	3.665	4.581
Mittel	**58172**					**56.827**	**57.584**
Kompaktklasse							-
BMW 1	6532	55	57	0.112	0.121	6.176	6.902
VW Golf, Jetta	10666	48	51	0.183	0.198	8.801	10.084
MB A	4231	62	-	0.073	-	4.509	
Ford Focus	3283	50	59	0.056	0.061	2.822	3.591
Opel Astra	3412	59	62	0.059	0.063	3.461	3.922
Mittelklasse							-
VW Passat	6042	58	61	0.104	0.112	6.024	6.833

Vehicle segment, class	*Quantity*	*Maintenance costs monthly DE (15000 km), €*	*Maintenance costs monthly AT (12000 km), €*	*Weight DE*	*Weight AT*	*Weighted maintenance costs monthly DE, €*	*Weighted maintenance costs monthly AT, €*
BMW 3	6047	64	60	0.104	0.112	6.653	6.726
Audi A4, S4, RS4	4255	59	64	0.073	0.079	4.316	5.048
MB C	3 598	72	62	0.062	0.067	4.453	4.136
Hyundai i 40	1455	54	53	0.025	0.027	1.351	1.430
<u>Mini-vans</u>							-
MB B	3224	65	62	0.055	0.060	3.602	3.706
Ford Focus C-Max	1605	50	54	0.028	0.030	1.380	1.607
Opel Meriva	1488	52	51	0.026	0.028	1.330	1.407
Renault Scenic	1252	50	53	0.022	0.023	1.076	1.230
Ford B-Max	1082	47	48	0.019	0.020	0.874	0.963
Groß	**17659**					**67.697**	**68.353**
<u>Obere mittelklasse</u>							-
BMW 5	3877	75	73	0.220	0.231	16.466	16.888
MB E	2694	72	81	0.153	0.161	10.984	13.021
Audi A6, S6, RS6, A7	2457	65	73	0.139	0.147	9.044	10.702
Volvo 70	268	64	65	0.015	0.016	0.971	1.039
Jaguar XF	209	106	69	0.012	0.012	1.255	0.860
<u>Oberklasse</u>							-
MB CLS	422	63	88	0.024	0.025	1.506	2.216
BMW 7	405	105	88	0.023	0.024	2.408	2.127
Porsche Panamera	190	135	-	0.011	-	1.453	
Audi A8, S8	184	77	115	0.010	0.011	0.802	1.263
MB S	182	104	84	0.010	0.011	1.072	0.912
<u>Grossraum-vans</u>							-
VW Touran	3107	44	49	0.176	0.185	7.742	9.084
Opel Zafira	1420	70	59	0.080	0.085	5.629	4.999

Vehicle segment, class	Quantity	Maintenance costs monthly DE (15000 km), €	Maintenance costs monthly AT (12000 km), €	Weight DE	Weight AT	Weighted maintenance costs monthly DE, €	Weighted maintenance costs monthly AT, €
VW Sharan	970	59	58	0.055	0.058	3.241	3.357
MB Viano	710	83	-	0.040	-	3.337	
Seat Alhambra	564	56	56	0.032	0.034	1.789	1.885

Table 68
Derivation of maintenance cost AT/DE ratio

Segment	Per km maintenance costs DE, €/km	Quarterly maintenance costs DE, €	Per km maintenance costs AT, €/km	Quarterly maintenance costs AT, €	Ratio: maintenance costs AT/DE
Klein	0.034	213.593	0.045	281.649	1.319
Mittel	0.045	281.864	0.058	357.023	1.267
Groß	0.054	335.778	0.068	423.789	1.262

Table 69
Fuel usage intermediate calculations

Vehicle segment, class	Quantity	Petrol consumption, l/100 km	Diesel consumption, l/100 km	Weight Petrol	Weight Diesel	Weighted petrol consumption, l/100 km	Weighted diesel consumption, l/100 km
Klein	**35 916**					**4.450**	**3.622**
Minis							-
VW Up	5 130	4.100	3.900	0.143	0.188	0.586	0.734
Fiat 500	2 796	4.000	-	0.078	-	0.311	-
Smart Fortwo	2 063	4.250	-	0.057	-	0.244	-
Opel Adam	2 049	4.200	-	0.057	-	0.240	-
Hyundai i10	1 743	4.700	-	0.049	-	0.228	-
Kleinwagen							-
VW Polo	5 591	4.700	3.400	0.156	0.205	0.732	0.697
Skoda Fabia	4 046	4.700	3.400	0.113	0.148	0.529	0.505
Opel Corsa	5 565	4.500	3.800	0.155	0.204	0.697	0.776
BMW Mini	3 302	4.650	3.450	0.092	0.121	0.428	0.418
Ford Fiesta	3 631	4.500	3.700	0.101	0.133	0.455	0.493

Vehicle segment, class	Quantity	Petrol consumption, l/100 km	Diesel consumption, l/100 km	Weight Petrol	Weight Diesel	Weighted petrol consumption, l/100 km	Weighted diesel consumption, l/100 km
Mittel	**73 489**					**5.557**	**4.101**
Kompaktklasse							-
Audi A3	5 806	4.850	3.850	0.079	0.079	0.383	0.304
VW Golf	19 826	4.900	3.800	0.270	0.270	1.322	1.025
BMW 1	5 263	5.600	4.200	0.072	0.072	0.401	0.301
Ford Focus	5 480	4.800	3.800	0.075	0.075	0.358	0.283
Opel Astra	5 170	7.100	3.900	0.070	0.070	0.499	0.274
Mittelklasse							-
VW Passat	6 049	6.150	4.250	0.082	0.082	0.506	0.350
BMW 3	5 706	5.850	4.350	0.078	0.078	0.454	0.338
Audi A4, S4, RS4	4 004	7.000	4.900	0.054	0.054	0.381	0.267
MB C	4 180	5.250	4.000	0.057	0.057	0.299	0.228
Opel Insignia	2 106	5.700	3.700	0.029	0.029	0.163	0.106
Mini-vans							-
MB B	3 455	6.050	4.300	0.047	0.047	0.284	0.202
Ford Focus C-Max	1 467	5.200	4.600	0.020	0.020	0.104	0.092
Opel Meriva	2 019	5.600	4.500	0.027	0.027	0.154	0.124
Renault Scenic	1 728	6.100	5.600	0.024	0.024	0.143	0.132
Skoda Roomster	1 230	6.200	4.500	0.017	0.017	0.104	0.075
Groß	**20 903**					**6.618**	**4.728**
Obere mittelklasse							-
BMW 5	3 518	7.000	4.400	0.168	0.168	1.178	0.741
MB E	3 250	6.350	5.250	0.155	0.155	0.987	0.816
Audi A6, S6, RS6, A7	3 628	5.950	4.500	0.174	0.174	1.033	0.781
Volvo 70	233	6.000	4.500	0.011	0.011	0.067	0.050
Jaguar XF	255	8.900	5.100	0.012	0.012	0.109	0.062
Oberklasse							-
MB CLS	357	6.900	5.200	0.017	0.017	0.118	0.089

Vehicle segment, class	Quantity	Petrol consumption, l/100 km	Diesel consumption, l/100 km	Weight Petrol	Weight Diesel	Weighted petrol consumption, l/100 km	Weighted diesel consumption, l/100 km
Audi A7	316	7.700	5.300	0.015	0.015	0.116	0.080
Porsche Panamera	233	11.300	6.500	0.011	0.011	0.126	0.072
Audi A8, S8	368	7.850	5.950	0.018	0.018	0.138	0.105
MB S	754	6.550	4.450	0.036	0.036	0.236	0.161
Grossraum-vans							-
VW Touran	3 928	6.400	4.600	0.188	0.188	1.203	0.864
Opel Zafira	1 894	6.600	4.100	0.091	0.091	0.598	0.371
Ford Grand C-max	757	5.200	4.600	0.036	0.036	0.188	0.167
Ford S-max	546	8.200	5.400	0.026	0.026	0.214	0.141
Seat Alhambra	866	7.400	5.500	0.041	0.041	0.307	0.228

Table 70
Vehicle prices comparison in Austria and Germany

Vehicle model	Austria	Germany	AT/DE Ratio
VW Golf Brutto	20242.50	18745.00	1.080
Hyundai ix35 Brutto	23990.00	24170.00	0.993
Fiat 500 Brutto	12650.00	12250.00	1.033
Ford Focus Brutto	17650.00	16450.00	1.073
Renault Clio Brutto	14850.00	12690.00	1.170
Average ratio	-	-	1.070