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PLANETS Probabilistic Long-term Assessment of New Energy Technology Scenarios

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Wednesday June 23rd – parallel sessions (first part)

Time	**A5** Climate Change - Mitigation and adaptation **Room E31**	**B5** Energy and transport modelling **Room E32**	**C5** Economics of low carbon technologies **Room E35**	**D5** Modelling uncertainty in climate change analysis (PLANETS special session) **Room E2**	**E5** Climate Change - Mitigation and adaption **Room E36**
	Chair: ***Alison Hughes***	**Chair:** ***Valerie Roy***	**Chair:** ***Johanna Pohjola***	**Chair:** ***Steve Pye***	**Chair:** ***Michael D. Gerst***
13:20	Global supply potential from sectoral crediting in post-Kyoto climate policy ***Geoffrey Blanford***	Quantifying the energy & carbon emission implications of a 10% electric vehicle target ***Aoife Foley****, Hannah Daly, Eamon McKeogh, Brian Ó Gallachóir*	Scaling dynamics of energy technologies: using historical patterns to validate low carbon scenarios ***Charlie Wilson***	Uncertain long-run emissions targets, CO2 price and global energy transition: a general equilibrium approach ***Olivier Durand-Lasserve****, Axel Pierru, Yves Smeers*	Escaping the climate-change quagmire – a North-South-OPEC model of fossil fuel use and greenhouse gas emissions ***Jim Gaisford****, Julia Sagidova, David Still*
13:45	The potential for CO2 abatement in the Taiwan electric system ***Delavane Diaz****, Steve Wan*	The potential of technological innovations for CO2 emissions mitigation in global passenger cars use ***Ina Meyer****, Jürgen Scheffran*	Willingness to pay for a climate backstop: liquid fuel producers and direct CO2 air capture ***Gregory F. Nemet,*** *Adam R. Brandt*	Perspectives of CCS power plants in Europe, considering uncertain power plant parameters ***Tom Kober****, Markus Blesl*	Global oil markets revisited – cartel or Stackelberg market? *Daniel Huppmann,* ***Franziska Holz***
14:10	Abatement options and the economy-wide impact of climate policy ***Olga Kiuila****, Thomas Rutherford*	The effects of policy, energy prices and technological learning on the passenger vehicle sector in Austria – a model-based analysis ***Maximilian Kloess****, Andreas Müller, Reinhard Haas*	TIMES model for the Reunion Island: addressing reliability of electricity supply ***Mathilde Drouineau****, Nadia Maïzi, Edi Assoumou, Vincent Mazauric*	Deterministic models are going stochastic: designing stochastic experiments with deterministic models ***Oleg Lugovoy***	Hedging fuel price in transport industry: estimating a structural model of gasoline-crude crack spreads ***Hamed Ghoddusi****, Sheridan Titman, Stathis Tompaidis*
14:35 15:00	CO2 Mitigation targets and technological limits: prospective analysis with the TIMES integrated assessment model (TIAM-FR) ***Sandrine Selosse****, Edi Assoumou, Nadia Maïzi*	Gas release and transport capacity investment as instruments to foster competition in gas markets *Corinne Chaton,* ***Farid Gasmi****, Marie-Laure Guillerminet, Juan Daniel Oviedo*	Law and economic analysis on CDM practice of China in year 2007 ***Jinshan Zhu***	Probabilistic analysis of strategic reserve *Alexander Golub,* ***Nat Keohane***	A numerical analysis of optimal extraction and trade of oil under climate policy ***Fabio Sferra****, Emanuele Massetti*

Coffee Break

THE EFFECTS OF POLICY, ENERGY PRICES AND TECHNOLOGICAL LEARNING ON THE PASSENGER VEHICLE SECTOR IN AUSTRIA – A MODEL-BASED ANALYSIS

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1. Introduction

The main objective of this paper is to analyse under which framework conditions and in which time frame can efficient vehicle technologies diffuse into the car fleet and how they would affect its energy consumption and greenhouse gas (GHG) emissions. Also, the paper will address the following questions:

- What are the main factors that influence the diffusion of hybrid and electric vehicles?
- What role can policy play for their diffusion and for the efficiency of the sector as a whole?
- What are possible time frames in which considerable market shares of hybrid and electric vehicles can be achieved?
- How does large scale introduction of hybrid and electric vehicles influence the energy demand of the car fleet?
- What is their potential of cutting GHG emissions within the transport sector?

To answer these questions a model based analysis was performed using a simulation model for the Austrian passenger vehicle sector. The model can be mainly seen as a bottom-up model of the Austrian vehicle fleet with detailed coverage of vehicle specifications, technologies and user behaviour, combined with a top down model of transport demand shifts. The effects of changing political, economical and technological framework conditions on the passenger car fleet can be simulated with the model. The impact of different fossil fuel price levels and different levels of fuel- and vehicle taxation on the passenger vehicle fleet in terms of fleet size, vehicle specifications, efficiency, vehicle use and diffusion of technologies can be analysed with the help of different scenarios. The effects on energy consumption and greenhouse gas emissions can be illustrated on a well-to-wheel basis. The model helps identify the main driving forces for the diffusion of efficient vehicles and can help to find optimal policy strategies that enable them.
Powertrain systems with different degrees of electrification were considered covering the entire range from conventional internal combustion engines up to pure electric vehicles. The selection was made in accordance with automotive experts and represents the propulsion systems that are most promising and feasible for the time frame 2010-2050 [1]. This includes the following technologies:

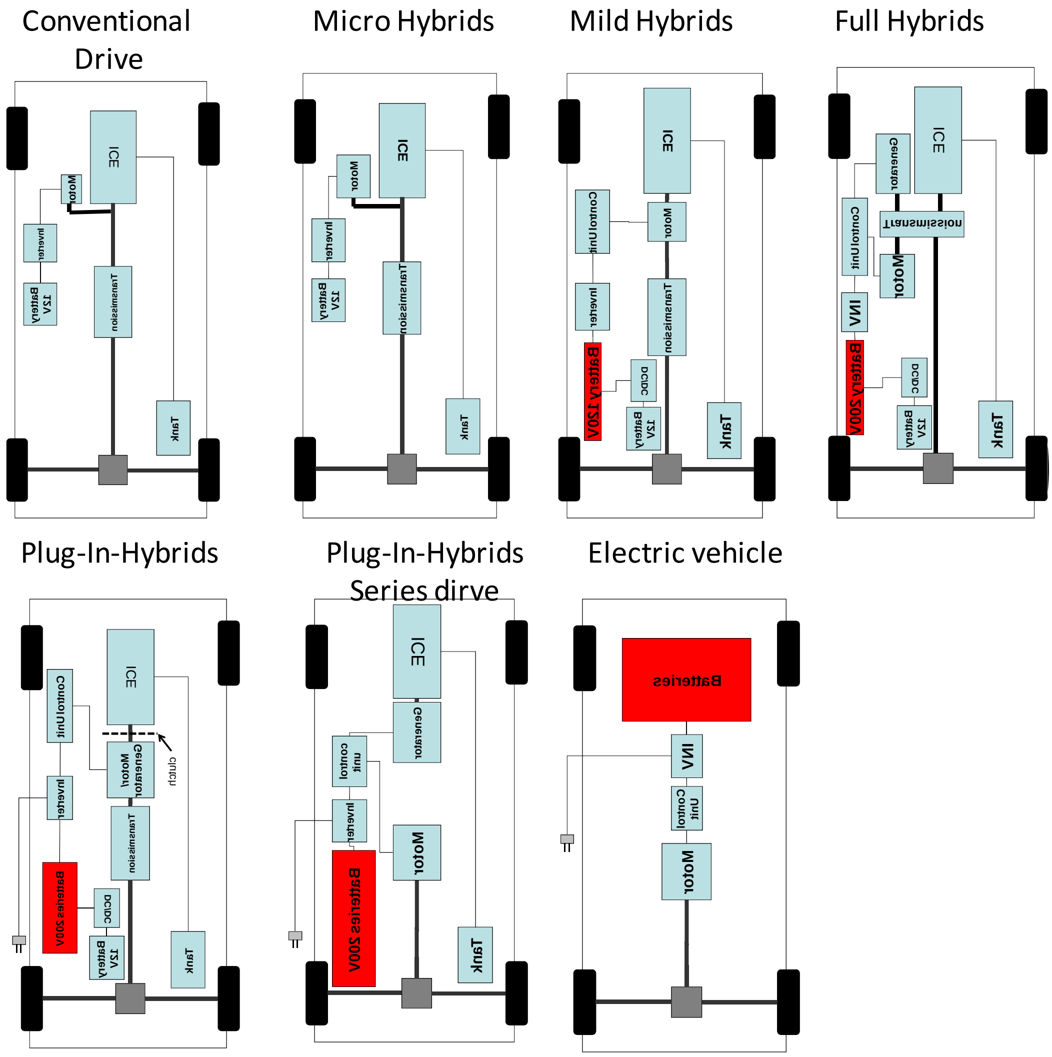

Figure 1: Analyse vehicle propulsion technologies

2. Methodology

The global structure of the model is depicted in Figure 2. It consists of four main modules. There is a so called “vehicle technology model” where different vehicle powertrain options are modelled bottom-up to analyse the influence of technological progress on their costs (see section 3.1).

In the second module market shares of technologies are derived from their specific service costs considering different levels of willingness to pay. The heterogeneity in consumer preferences was modelled using a logit model approach with the specific service costs as the main parameter (see section 2.1). To consider the specific competitive disadvantages of alternative propulsion technologies that might arise from limitations in performance characteristics or lack of availability, diffusion barriers were used (see section 2.2). The influences of income, fuel prices and fixed cost on the demand for passenger car transport represented by fleet size, vehicle characteristics and user behaviour are modelled top down in the third module.

The fourth module is a bottom-up fleet model of the Austrian passenger car fleet. The fleet is modelled in detail considering age structure, user categories and main specifications of the vehicles (e.g. engine power, curb weight, propulsion technology, specific fuel consumption, greenhouse gas emissions etc.). The settings are based on a data pool including detailed information about the fleet today and time series of historic developments [2].

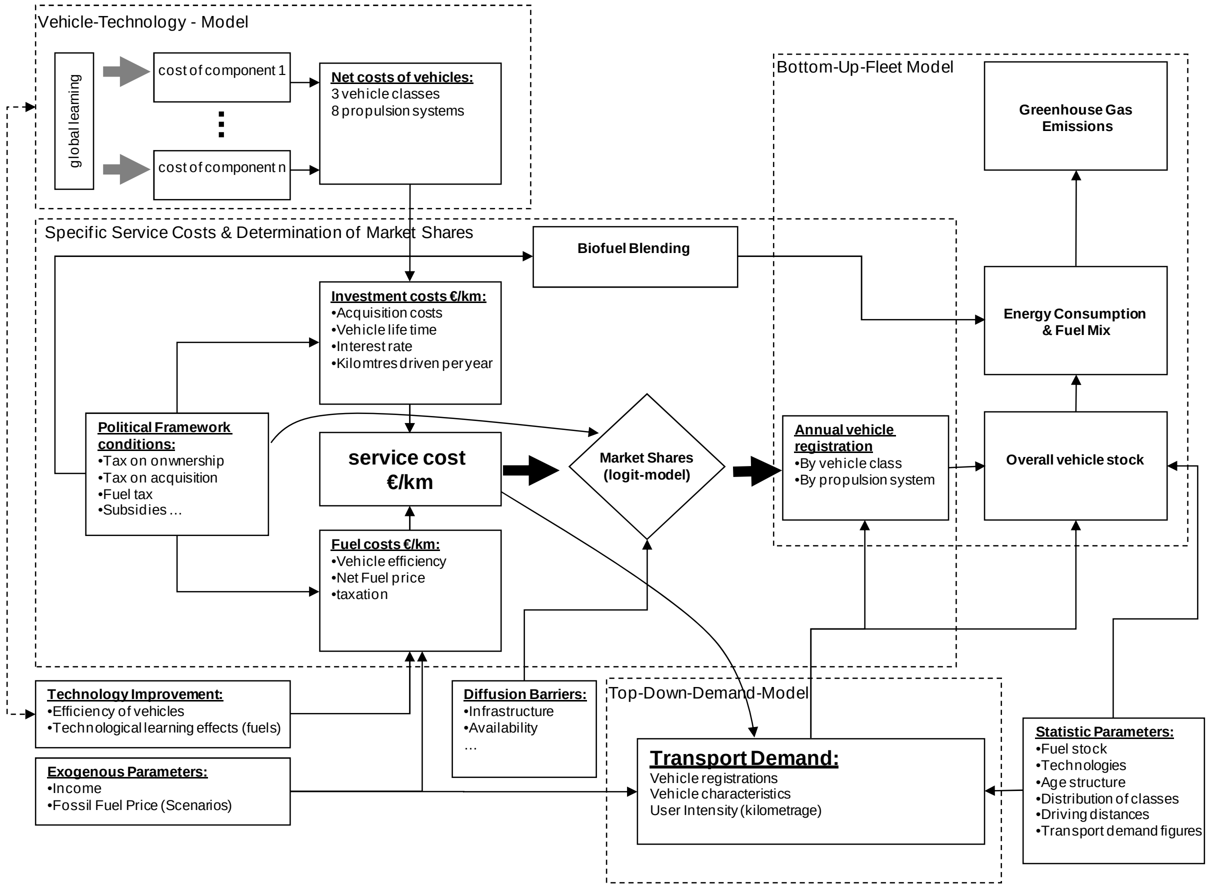

Figure 2: Scheme of the model

2.1. Market shares of technologies

In the applied approach it was assumed that the customer's main decision criteria concerning propulsion technologies are of economic nature. Therefore it was assumed that when it comes to choosing a vehicle propulsion system the main criteria for the customer are the specific costs, especially when different options offer the same service level. Moreover, it was assumed that there are different levels of willingness-to-pay (WTP). For example there are consumer groups who are willing to pay for an advanced vehicle technology, which is environmentally benign even if it is not the best economic option. Therefore, even technologies which are not cost efficient achieve a certain market share.

In this case those different levels of willingness-to-pay were modelled using a logit-model-approach. Hereby, the market share z_j of a technology is given by a function of the likelihood w that the technology is been chosen by the customer on the basis of its specific costs SC_j. Moreover it is influenced by the specific cost of competing technologies and the so called reference technology SC_{j_ref}, which is defined as the technology with the highest market share the year before:

$$z_{j(t)}[\%] = f(w(SC_{j(t)}, SC_{1(t)}, ...SC_{n(t)}, SC_{j\_ref(t)}, b), SC_{j(t-1)}, a_j) \quad \textbf{(1)}$$

Z_j … market share of the technology j.
SC_j … specific service costs of technology
SC_n … specific service costs of competing technologies
SC_{j_ref}… specific service costs of the reference technology
a_j … diffusion barriers of the technology

The parameter *b* defines the steepness of the logit-function and is determined by using historic data of the Austrian car market. Furthermore, the market share in the previous year has an influence on the technology's market share and diffusion barriers are summarized with the variable a_j.

2.2. Diffusion Barriers

In the model the market shares of technologies is also affected by so called diffusion barriers. In the case of vehicle powertrain technologies, these barriers can have different causes, e.g. an incomplete infrastructure for a certain type of fuel. Lock-in and lock-out phenomena are often a reason why new technologies have problems entering the market even if they offer clear advantages compared to the established options [3]. This limitation can be represented by the classical s-shaped curves of technological diffusion [4]. Figure 3 shows the technology diffusion curves that were used in the model as upper diffusion boundary. The shortest possible period that a technology needs to fully penetrate the market was set at approximately 10 years (Technology type A) for a technology that has clear technological and economical advantages and no adoption barriers. See for example the diffusion of downsized diesel engines described in [5].

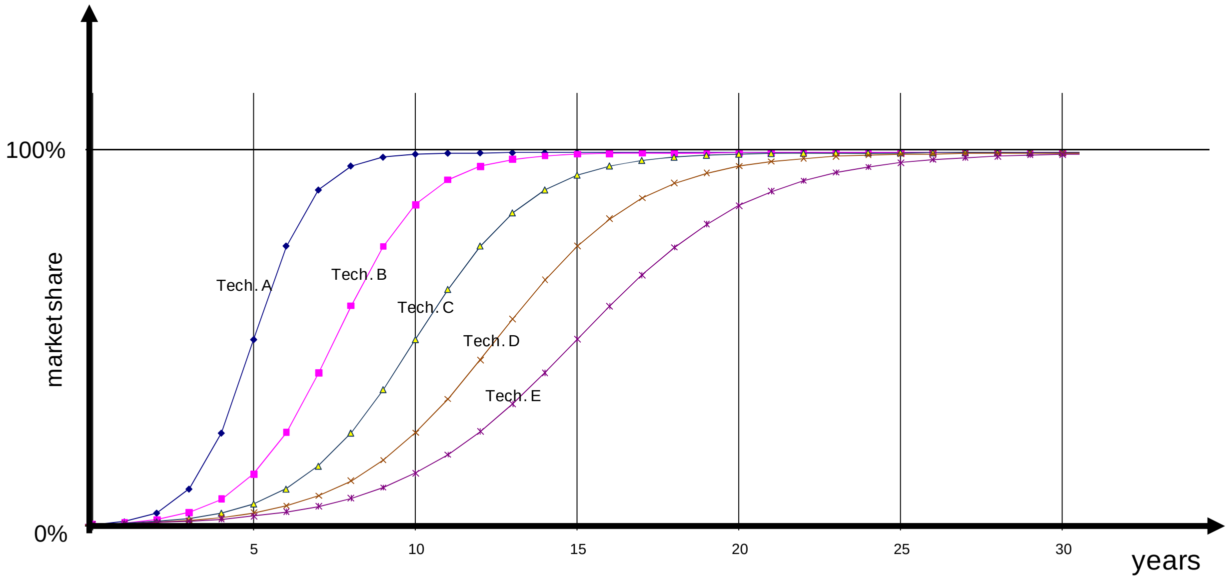

Figure 3: Diffusion curves for vehicle propulsion technologies

2.3. Demand for passenger vehicles

There are several parameters that influence the demand for individual motorised transport. The most important drivers are the cost of energy service and income level.

In the model the demand for mobility is expressed by user intensity of the vehicles in the fleet and by the number and the attributes of the vehicles registered in that period. The number of cars registered every year in the model depends on the development of the overall fleet and the number of cars scrapped. The fleet growth is determined by the income development, expressed by the GDP, the fuel price and the fixed costs. Thus the development of the annual vehicle demand is given by the elasticity of fuel price ε_{FP}, vehicle price ε_{IC} and income ε_y (see equation 2 & 3).

The elasticity of the car stock with respect to fuel costs was set at -0.2 and to fixed costs at -0.5 which is in the range of values found in international analysis e.g. [6].

$$\Delta Z_{(t)} = Z_{(t)} - Z_{(t-1)} + Z_{SCRAP\,(t)} \quad \textbf{(2)}$$

$$\frac{Z_t}{Z_{t-1}} = (\frac{FP_t}{FP_{t-1}})^{\alpha_{FP}} \cdot (\frac{CC_t}{CC_{t-1}})^{\alpha_{IC}} \cdot (\frac{GDP_t}{GDP_{t-1}})^{\alpha_\gamma} \quad (3)$$

α_{FP} =-0.2

α_{IC} =-0.5

β_y = 0.5

$Z_{(t)}$……vehicle registration per year
$\Delta Z_{(t)}$….shift in vehicle registration per year
$Z_{SCRAP(t)}$ … cars scrapped per year
CC … capital costs (fixed costs)
FP … fuel price
GDP … gross domestic product
α_{FP} … fuel price elasticity
α_{IC} … elasticity on fixed costs
α_y … income elasticity

2.4. Distribution of vehicle classes

The specific service costs are not only affecting the yearly car sales but also the characteristics of the vehicles sold (e.g. average vehicle weight and engine power). For example at high service cost levels, as consequence of high fuel prices or high taxes, customers tend to choose smaller cars with lower engine power an effect that is also reflected in Austrian sales statistics [7]. This means that changes in framework conditions that are affecting the specific service costs, also affect the customer behaviour when choosing a vehicle category.
In the model there are three categories of vehicles, and consumers are choosing for one of those three options when purchasing a car. The specifications were set in such way as to represent the Austrian vehicles stock. Each vehicle class was defined by vehicle mass and engine power and a minimum driving range required (see Table 1). The current customer preferences concerning vehicle categories in Austria were determined by historical data sets derived from statistical data [2] and were used as a basis for the model settings.

Table 1: vehicle classes & user groups

vehicle classes:	reference weight	reference power	**user groups:**	kilometrage
	[kg]	[kW]		[km year-1]
compact class	1,000	50	weekend user	10,000
middle class	1,500	75	regular user	15,000
upper class	2,000	120	commuter	20,000

To model the effect of fuel price and income on the mean vehicle specifications a factor F_t was introduced representing average mass and engine power of the vehicles sold. It was assumed that the specifications of sold cars are distributed around the mean value F_t in a distribution with positive skew. From that distribution the shares of the three vehicle classes are derived (see equation 4). In the model the development of this parameter F_t is determined by Income and fuel prices (see equation 5).

$$z_{i(t)}[\%] = f(F_{(t)}, p(F_{(t)}, F_i)) \quad (4)$$

$z_i(t)$ … share of the vehicle class i
F_i … specification of the vehicle class

p … distribution of sold vehicles around the average (in terms of specifications)
F(t)…Vehicle Specification Factor

$$\frac{F_t}{F_{t-1}} = (\frac{FP_t}{FP_{t-1}})^{\beta_{FP}} \cdot (\frac{GDP_t}{GDP_{t-1}})^{\beta_\gamma} \quad (5)$$

$\beta_{FP} = -0.3$

$\beta_y = 0.3$

β_{FP}…price elasticity
β_y….income elasticity

The elasticities used in the model were determined through calibration runs using historic data on Austrian passenger car sales. Also the distribution *p* representing the allocation of vehicle specification around the yearly mean F_t was determined based on statistic data [8] [7].

2.5. Modelling of the vehicle user behaviour

Shifts in economic framework conditions have short run influence on the behaviour of consumers. Car owners react to price changes in the cost of the energy service by adapting their use intensity expressed in kilometres travelled per year. This correlation was modelled by elasticities of fuel price and income. The elasticities were set according to [9], where price elasicities on mean driving distance range from -0.35 to -0.05 and income elasticities from -0.1 to 0.35 and were tested in calibration runs comparing model results with real statistic data:

$$\frac{D_t}{D_{t-1}} = (\frac{FC_t}{FC_{t-1}})^{\omega_{FP}} \cdot (\frac{GDP_t}{GDP_{t-1}})^{\omega_\gamma} \quad (6)$$

$\omega_{FP} = -0.3$

$\omega_y = 0.3$

$D_{(t)}$….distance travelled by year
FC…fuel cost
GDP…gross domestic product
ω_{FC}…price elasticity
ω_y….income elasticity

2.6. Bottom-Up Fleet Model

Due to a tardily modernization the passenger car fleet is reacting very slowly to shifts in framework conditions. Once registered a car usually remains in the fleet from 10 to 15 years. To represent this inertness correctly a detailed fleet model was created using statistic data on the Austrian fleet [2]. In the model the fleet is divided into three vehicle categories and three user groups each with a specific user pattern represented by the yearly kilometrage (see Table 1). Moreover, there is a detailed coverage of vehicle efficiency and technologies in the fleet model.
The actual fleet CAP_t is determined by the surviving cars of all the previous 30 generations. This means that in the model the stock consists of those 30 vehicle generations. The fleet structure can be expressed as follows:

$$CAP_t = \sum_{n=0}^{n=30} SZ_n \quad (7)$$

CAP … car fleet
SZ_n … survivors of an age group n.

The yearly falling out of cars is determined by the likelihood of mechanical failure modelled through a Weibull distribution. Similar approaches were used in other models to represent the scrapping of vehicles in the fleet [10] [11].

2.7. Energy Consumption and greenhouse gas emissions of the vehicle fleet

Based on the detailed fleet model the cumulative energy consumption and the greenhouse gas (GHG) emissions were determined. An important aspect here is the differentiation between tank-to-wheel (TTW) and well-to-wheel (WTW) energy balances and emissions. Usually, energy consumption and the GHG-emissions of vehicles are expressed in the TTW view in litres per 100km and gram CO_2 per kilometre. However, for a reliable analysis it is necessary to consider the entire energy conversion pathway represented in the well-to-wheel balances. Detailed data of the WTW emissions and consumptions for all incorporated energy conversion chains were used for this purpose. The necessary data was provided by the project partner JOANNEUM Research who determined the energy and emission balance of all conversion chains based on life cycle analysis (LCA) [1]. The Life-Cycle-Data includes production, transport and conversion of the fuel in the car and the embodied energy of the car [12].

3. Service Costs of passenger car mobility

As mentioned above specific service costs were considered as the main cause for developments in the passenger car sector and they are a critical parameter in the model. The specific costs of all powertrain options within the three vehicle classes were calculated dynamically for the time frame 2010-2050, considering shifts in fuel prices, technological costs, taxation and income.
The specific service costs *SC* of each vehicle of the vehicle class *i*, with the technology *j* are determined by their specific fuel costs *FC*, specific fixed operations costs *OC* and specific capital costs *CC* as follows:

$$SC_{ij} = CC_{ij} + OC_{ij} + FC_{ijh} \text{ [EUR km}^{-1}\text{]} \quad (8)$$

To calculate the specific service costs a standard depreciation time of 10 years and an interest rate of 5% were used. It is evident that the economic performance of a propulsion system is dependent on the yearly driving distance of the user and will therefore be different in the mentioned user categories (see Table 1).
To make the different powertrain systems comparable they were all based on reference specifications of the respective vehicle class. Apart from size and performance characteristics this also includes a minimal required driving range. The detailed specifications of the classes and their corresponding vehicles and different powertrain systems are presented in Table 2 on the example of the middle class.

Table 2: Specifications of middle class vehicles with different propulsion systems 2010

	electric range	overall range	power		battery capacity		fuel consumption	
			engine	e-motor	[kWh]		[l;kg;kWh 100km-1]	
	[km]	[km]	[kW]	[kW]	2010	2030	2010	2030
Conventional Drive - Gasoline		700	75				7.5	6.8
Conventional Drive - Diesel		700	75				6.0	5.6
Conventional Drive - CNG		700	75				5.2	4.7
Micro Hybrid - Gasoline		700	75				6.9	6.2
Mild Hybrid - Gasoline		700	65	20			6.4	5.6
Full Hybrid - Gasoline		700	50	50			5.9	5.2
Plug-In-Hybrid - Gasoline	40	700	50	50	10	10	5.9	5.2/20.4
Series Hybrid - Gasoline	80	700	40	75	20	20	5.5	4.7/20.4
Electric Vehicle	200	200		75	50	50	22.2	20.4

3.1. Net capital costs for vehicles

Capital costs are the most important cost category (see Figure 8). For electrified vehicles they represent a major barrier to a potential market introduction. To identify the main cost drivers and to assess their potential for cost reduction, the cars were divided in their main components. The capital cost was analysed on a component basis [13]. The component groups are defined as follows:

- **Vehicle basis** (all non propulsion relevant components)
- **Internal combustion engine & transmission** (including the fuel tank)
- **Electric drive components**
- **Battery System**

The component-based analysis shows that the high capital costs of electric vehicles are mainly caused by the high cost of lithium ion batteries (see Figure 5). Their specific costs in 2010 were set at 700€ kWh^{-1} according to [14].

3.1.1. Learning effects

Technological learning effects were considered when estimating the cost development. Hence, all components of a passenger car experience specific learning effects when their production volume increases, causing a cost reduction. Today's passenger vehicle components are very mature and are not expected to experience high cost reductions , e.g. internal combustion engine, but there are also components that are new in this field and have a high potential of cost reduction like lithium ion batteries.

According to the technological learning theory the future cost *C* is a function of the costs of the first unit built *a*, the cumulative production x and the learning index *b* [4].

$$C(x) = a * x^{-b} \qquad \textbf{(9)}$$

Clearly, the cumulative production on one hand and the learning index on the other represent uncertainties. The approach of technological substitution was applied to estimate the global cumulative production of electricity storage systems. This approach postulates that today we are at the beginning of the technological substitution process where internal combustion engines slowly but steadily get substituted by electrified drive systems (Hybrids & Elelctric Drives) on a global level. The electric propulsion system follows the classical S-shaped curve of technological life cycles [4]. The technology is currently in an early phase, the so called Introduction or childhood phase. The increasing shares of hybrid vehicles and the emerging of pure electric vehicles can be seen as indicators for this development [15]. The other critical factor for the cost development is the learning index *b* that can also be expressed by the so called progress ratio *p* or the learning rate *LR*.

$$p = 2^{-b} \tag{10}$$

$$LR = 1 - 2^{-b} \tag{11}$$

The range of learning rates for energy related technologies extends from 5% to 25%, with an average of around 16-17% [16]. Every technology has a certain share of base cost that arises from raw material and energy consumption. To consider those base costs in the learning rate approach the costs were separated in a fixed part C_{fix} and another part that is affected by learning effects C_{learn}:

$$C = C_{fix} + C_{learn} \tag{12}$$

To determine the fixed cost part results of bottom-up analysis have to be used that give a qualified outlook on the long-term cost potential of the technology. This approach turned out to be suitable for a better coverage of technology specific characteristics in the cost estimations and has also been applied in other models [17]. For lithium ion batteries base costs of 100€/kWh were used which correspond to the long term goals of battery developers [18].

A learning range of 15% was utilised for the variable part of the cost. The sensitivity of the model results to changes in the learning parameter was verified by analysing different learning rates (see section 5). Figure 4 illustrates the corresponding cost reductions that result from those learning rates in the time frame 2020-2050.

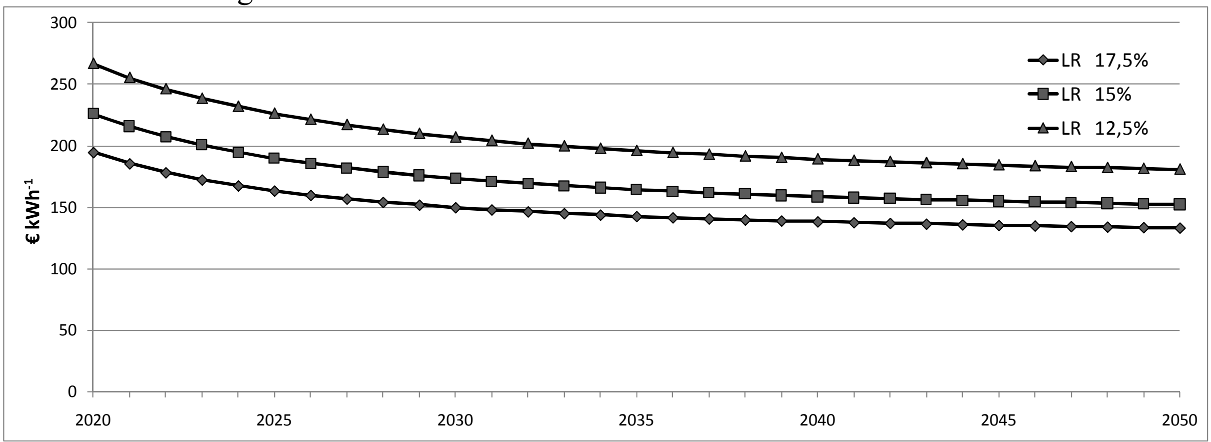

Figure 4: Learning curves for Li-Ion Batteries

In practice there are other components such as the internal combustion engine, the chassis etc. that are also showing some learning effects. Due to the already high cumulative global production those effects are much smaller and get compensated by the fact that these components are becoming more complex to meet their future requirements. This assumption is complying with the historical experience where the real price of passenger vehicles remained relatively the same while more comfort, better safety and increased efficiency is offered. This is why no cost reduction is expected for the internal combustion engine, the basic vehicle and the electric drive system. Figure 6 illustrates how the cost reduction affects the net capital costs of the different propulsion systems up to 2030. In spite of the reduction, batteries remain a significant cost driver making electric vehicles more expensive than conventional vehicles even in a long term period.

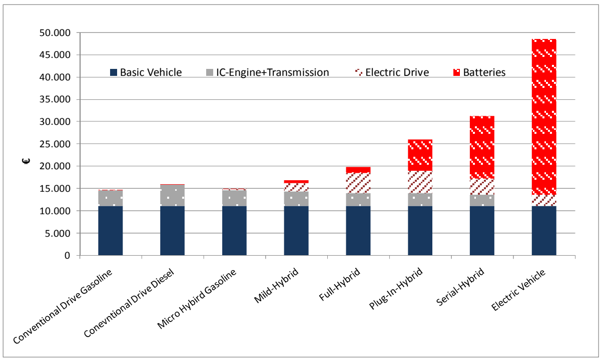

Figure 5: Net capital costs of middle class vehicles 2010

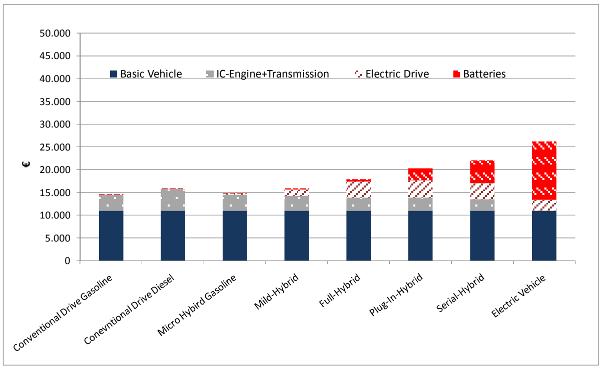

Figure 6: Net capital costs of middle class vehicles 2030

Table 3: Net capital costs development of vehicles (middle class)

net capital cost	2010	2020	2030	2050
	[€]	[€]	[€]	[€]
Conventional Drive - Gasoline	17,902	17,902	17,902	17,902
Conventional Drive - Diesel	19,071	19,071	19,071	19,071
Conventional Drive - CNG	19,595	19,481	19,366	19,136
Micro Hybrid - Gasoline	18,152	18,152	18,152	18,152
Mild Hybrid - Gasoline	19,765	19,135	18,934	18,812
Full Hybrid - Gasoline	22,705	21,372	20,928	20,659
Plug-In-Hybrid - Gasoline	28,805	24,297	23,269	22,710
Serial Hybrid - Gasoline	34,397	26,642	25,282	24,628
Electric Vehicle	51,762	32,559	29,259	27,691

3.2. Fuel operational costs

The fuel operational costs of the vehicles are determined by their fuel consumption and the fuel prices. The fuel efficiency of all vehicles was analysed by experts of AVL[1] an Austrian company specialised on automotive research and development [1]. They determined the fuel consumption based on the technological status of 2010 and estimated potential efficiency improvement up to 2050 (see Table 2).

Two main factors are important for the fuel pricing: the net fuel price and the taxation. The net price development of energy carriers in the time frame 2010 – 2050 was set according to the European Energy and Transport Price Scenario PRIMES-High [19]. The crude oil price is expected to increase from 76$/bbl for the base year 2010 to 109$/bbl in 2030 and up to 148$/bbl in 2050.

[1] AVL LIST GMBH

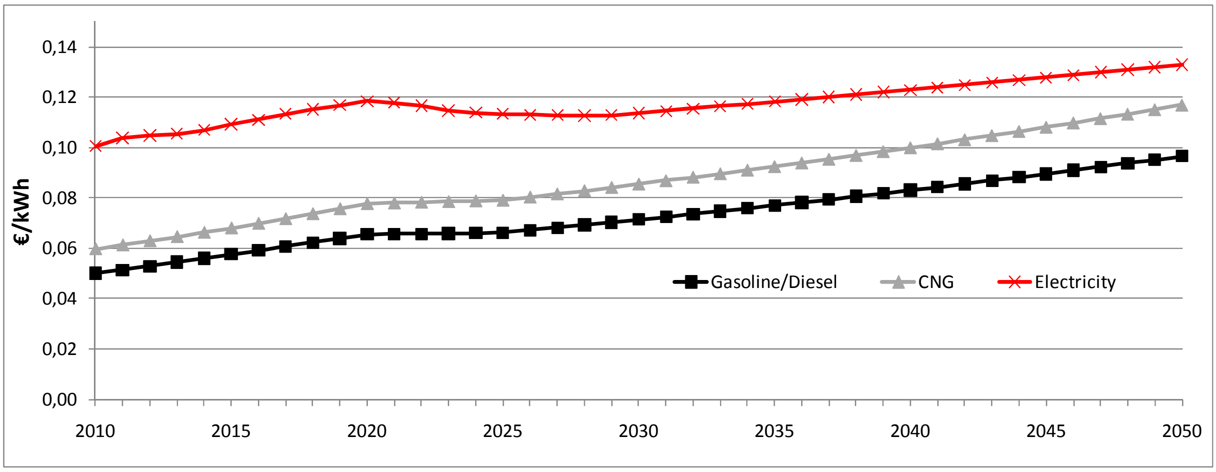

Figure 7: Price scenarios of final energy carriers

3.3. Total Costs

How the different cost categories contribute to the overall cost of the different powertrain systems at the political and economic framework condition of 2010 is depicted in Figure 8 for the case of a yearly kilometrage of 15 000km. Fuel costs and fixed operation costs (including maintenance, insurance and tax on ownership) are less important. Figure 8 exhibits that conventional drive vehicles with diesel engine are still the best option from an economic perspective. However, micro hybridisation is a cost effective measure to cut fuel consumption. If applied on a diesel engine it would be the best option in terms of overall cost. Mild hybrids are close to economic competitiveness, while more complex hybrid systems like full hybrids and fully electric drivetrains have significantly higher costs than conventional options due to their high capital costs.

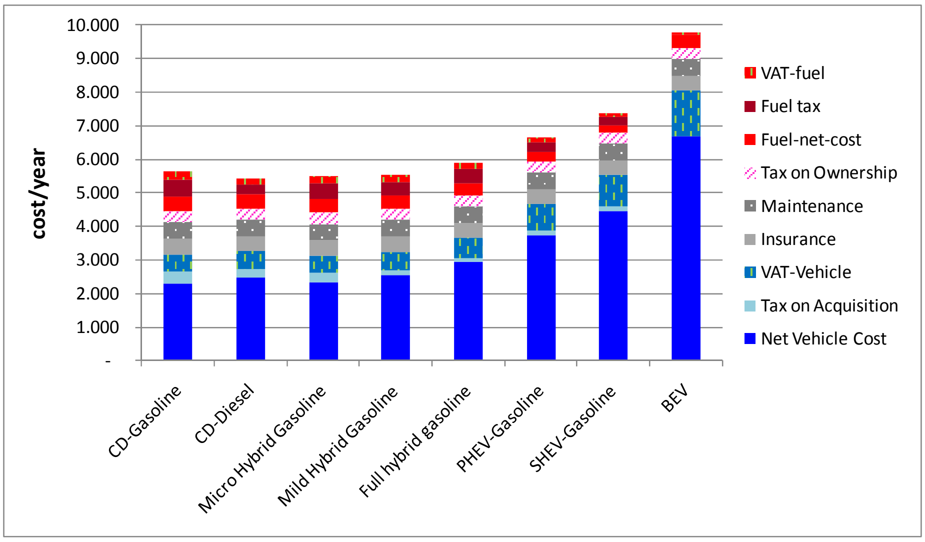

Figure 8: Total yearly cost of middle class vehicles with different propulsion systems 2010 (15 000km/year)

4. Political Framework Conditions in Austria

The structure of the yearly cost of ownership illustrated in Figure 8 shows the considerable influence of taxes on the total cost of passenger vehicle mobility. In Austria there are three main taxation instruments affecting the costs of passenger cars:

- Tax on Acquisition
- Tax on Ownership
- Tax on Fuels

Tax on Acquisition: This tax has to be paid just once when the vehicle is registered for the first time in the country. According to Austrian law a certain percentage of the purchase price has to be paid. The percentage depends on the fuel consumption of the vehicle and is caped with 16% of the purchase price. Also, there is an additional bonus/malus system on green house gas emissions. When the vehicle's emissions are below or above a certain threshold, the above mentioned tax is reduced or increased by 25€ g^{-1} CO_2. The upper threshold for the bonus in 2010 was 160g km^{-1}, the lower threshold for the malus was 120g km^{-1} (see Table 4). Moreover, there are special deductions for vehicles that use an alternative propulsion system (-500€) while zero emission vehicles pay no tax on acquisition at all.
Tax on Ownership: The height of this tax depends on the engine power of the vehicle and is paid on a yearly basis.
Tax on Fuels: the fuel tax in Austria is 0,447€/liter on gasoline and 0,347€/l on diesel. Biofuels and CNG are excluded from the fuel tax so far (see Table 5).

4.1. Scenarios of political framework conditions 2010 – 2050

One major objective of the model is to analyse the influence of policies on the development of the passenger car sector in the time frame 2010-2050. As demonstrated in Figure 8 taxes have considerable influence on the cost of passenger car mobility by affecting its cost. To analyse the effects of different policy strategies in the case of Austria two policy scenarios were developed with different political promotion strategies in the time frame 2010-2030. The analysis demonstrates how the two policy schemes affect the development of the passenger vehicle fleet in terms of energy consumption, energy carriers, efficiencies and greenhouse gas emissions up to 2050.

4.1.1. Business as usual scenario – BAU-Scenario:

In this scenario political framework conditions remain comparatively the same to the status of 2010. The only change was a slight adjustment of the fuel tax taking into account that CNG would be taxed with the same rate as diesel fuel starting in 2015. In Austria the strategies to fulfil the greenhouse gas reduction commitment for 2020 include no particular plan of measures in order to cut road transport emissions. The BAU scenario gives an outlook on the development if no additional policy measures are taken.

4.1.2. Policy scenario

The Policy Scenario proves how political framework can help reduce GHG emissions of the passenger car fleet in order to contribute to the country's emission reduction commitments. In this scenario major shifts within political framework conditions were adopted. Taxes are adapted with a clear focus on increasing energy efficiency and reduction of green house gas emissions of the sector. The instruments that were used were fuel taxes and tax on vehicle acquisition.
Taxes on fossil fuels are being raised stepwise between 2010 and 2020 and the tax on acquisition is being adapted to promote sales of efficient vehicles. In the Austrian taxation scheme that means that the upper threshold for greenhouse gas emissions is lowered and the charge for exceeding this threshold is raised, making inefficient vehicles more expensive (see Table 4 and Table 5).

Table 4: Political framework conditions within the two scenarios

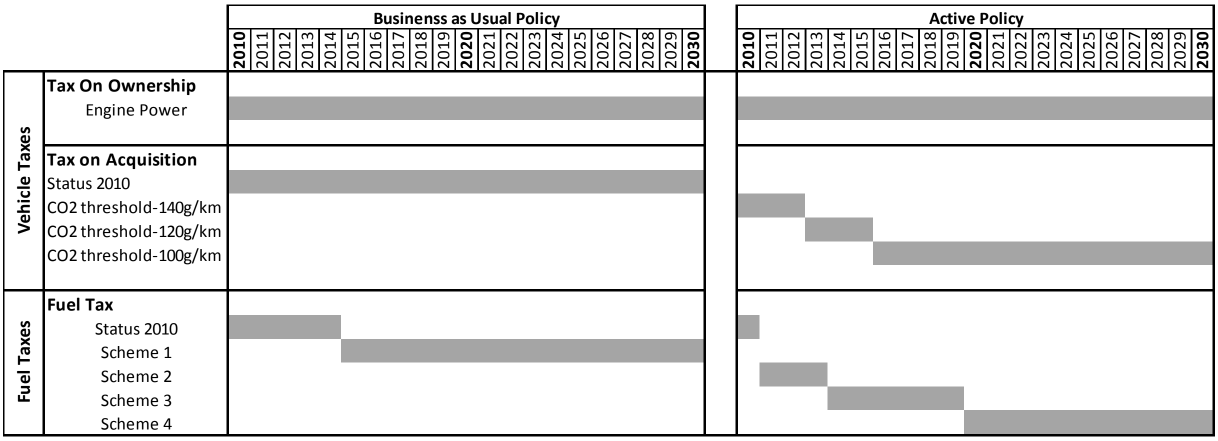

Table 5: Fuel taxation schemes

		Status 2010	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Gasoline	€/kWh	0.051	0.051	0.05	0.07	0.10
Diesel	€/kWh	0.036	0.036	0.05	0.07	0.10
CNG	€/kWh	0	0.036	0.05	0.07	0.10
Electricity	€/kWh	0	0	0	0	0.02

4.1.3. Energy Supply and Energy Carriers

For a complete assessment of energy consumption and greenhouse gas emissions the entire energy conversion chain has to be considered. This means that not only their direct emissions and consumptions have to be covered (Tank-to-wheel - TTW) but thde entire chain including production of fuels and vehicle, namely their well-to wheel (WTW) balances (see section 2.7). For the WTW balances the sources of the fuels are of crucial importance. In the model there are five main fuel types linked to specific vehicle technologies that can be chosen by consumers. Those fuels are gasoline, diesel, compressed natural gas (CNG) and electricity. All those can be produced from traditional fossil sources such as crude oil or natural gas, but they can also have fractions of alternative fuels based on renewable sources. In Austria there are obligatory rates for biofuel blending following the EU biofuel directive. The rate of 5.75% determined by this guideline has been met in Austria since 2008 by blending diesel with biodiesel and gasoline with first generation bioethanol [20]. In contrast to other countries, e.g. Brazil pure biofuels are barely available as all capacities are used for the large scale blending of gasoline and diesel. Thus, the use of pure biofuel was neglected in the model and their demand was solely determined by the regulatory rate of fuel blending.

It is to be expected that following the EU directive, the 2010 level of biofuel blending would be extended to 10% until 2020 [20]. After 2020 the 10% percent level of biofuel blending will be kept stable.

As illustrated in Table 6 biofuels and electricity can be based on various sources. To obtain a detailed view of the cumulated energy consumption and of GHG emissions it is necessary to consider the source they are based on, e.g. first generation ethanol, which is the standard option for blending of gasoline, is produced from three different sources with different proportions in Austria. In long-term scenarios, e.g. 2010-2050 the sources for fuels are likely to change due to economical and technological developments as well as political directives. The sources of the blends continuously shift to more advanced options, e.g. first generation biofuels like Biodiesel and first generation ethanol (Ethanol 1) are substituted by second generation biofuels like Fischer-Tropsch Diesel (FT-Diesel) and second generation ethanol (Ethanol 2) (see Table 6). In the case of CNG, the fuel will be blended with biogas and synthetic natural gas (SNG).

Table 6: Biofuel blending and biofuel types

			2010	2020	2030	2040	2050
Biofuel Blending							
	Share of Biofuels		5,75%	10%	10%	10%	10%
Biofuel blends							
	Gasoline Blends	Ethanol 1	100%	75%	50%	25%	0%
		Ethanol 2	0%	25%	50%	75%	100%
	Diesel Blends	Biodiesel	100%	75%	50%	25%	0%
		FT-Diesel	0%	25%	50%	75%	100%
	CNG-Blends	Biogas	100%	95%	80%	80%	80%
		SNG	0%	5%	20%	20%	20%

For electricity the sources are even more important. Differentiating between them, as each has a strong impact on both GHG emissions and primary energy consumption is essential. In this context there are different views on the question which electricity mix has to be applied when calculating emissions for electric vehicles. One approach expresses that the existing mix has to be employed, while the other conveys that existing capacities are already occupied and that additional capacities should be considered.
In this specific analysis simplified assumptions concerning the electricity supply mix for electric vehicles (EVs) were made. It was assumed that in a short term period as the required capacity is practically negligible; the supply would be based on the Austrian mix. In a mid to long term period an increasing share of the supply for EVs will have to be covered by additional capacities that can either be based on fossil or renewable sources. To this extend two supply scenarios were established:
Electricity "Fossil": In this scenario the electricity supply would be based on the Austrian mix first and, when demand increases, it would be complemented exclusively with fossil electricity from natural gas fired gas and steam plants.
Electricity "Renewable": In this scenario the supply for EVs will be shifted to a pure renewable mix, that implies a high share of decentral supply with shares of photovoltaics, hydro-energy, wind and biomass (see Table 7).

Table 7: Electricity supply scenarios

			2010	2020	2030	2040	2050
"Fossil" Supply Scenario							
	Electricity-Mix Austria		100%	90%	80%	70%	60%
	Fossil Sources	natural gas (gas & steam)	0%	10%	20%	30%	40%
"Renewable" Supply Scenario							
	Electricity-Mix Austria		100%	75%	50%	25%	0%
	Fossil Sources	natural gas (gas & steam)					
	Renewable Sources	hydro	0%	10%	25%	25%	25%
		wind	0%	7.5%	10%	20%	25%
		photovoltaics	0%	2.5%	10%	20%	25%
		biomass	0%	5%	5%	10%	25%

5. Results

The results indicate how different schemes of political intervention can affect energy consumption and greenhouse gas emissions of the Austrian passenger car fleet in an environment of increasing oil prices and in the time frame 2010-2050. They also indicate the high potential of alternative propulsion technologies and their corresponding fuels to contribute to the reduction of energy demand and GHG emissions. They comprise every aspect of how the car fleet responds to changes in framework conditions in terms of fleet size, user intensity, vehicle size and above all technologies. The model gives an outlook on how policies conduce to the achievement of national emission reduction goals.

5.1. Business as usual BAU – Scenario

In this scenario no considerable measures to promote efficient and alternative vehicle technologies are taken. In Figure 9 the development of market shares of propulsion technologies is illustrated, which shows a strong trend towards hybrid cars. This development is mainly driven by the improving economic competitiveness of hybrid powertrain systems in an environment of increasing fuel prices and by cost reduction resulting from learning effects of key components. This leads to a substitution of conventional powertrain systems by micro and mild hybrid systems. Both technologies are close related to conventional powertrain systems and can increase vehicle efficiency at relatively low additional cost. This evolution is a step towards cost efficiency.
In a mid to long term period technologies with a high degree of electrification, e.g. Plug-In Hybrids and Electric Vehicles, can only gain market shares in a slow pace. Figure 10 shows the corresponding development of the vehicle fleet in the BAU-Scenario. The vehicle fleet is growing constantly in the time frame 2010 – 2050. In this price scenario the demand for transport keeps increasing as a result of the relatively low cost of the transport, which is reflected in the growth of the car fleet. The increasing crude oil price that has been considered in this scenario is compensated by the improved efficiency of vehicles, keeping overall price of transport low.

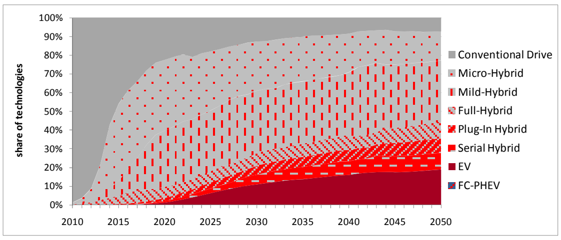

Figure 9: Market shares of propulsion technologies (BAU- Scenario)

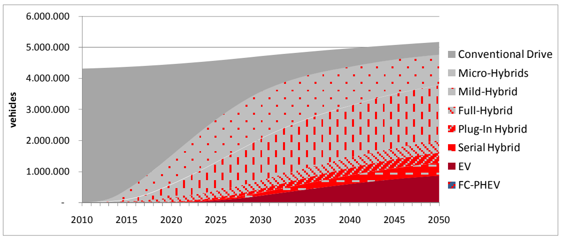

Figure 10: Passenger car (BAU- Scenario)

It is evident that cost reduction of batteries has a strong impact on the cost effectiveness of hybrid and electric powertrain systems and thereby on their market shares. The cost reductions were modelled with the help of technological learning effects and therefore depend strongly on the used learning parameter. A sensitivity analysis with respect to the learning rate was performed in order to check the resulting uncertainty. The results showed that the sensitivity of the shares of technologies to variations in the learning rate is moderate (see Figure 11).

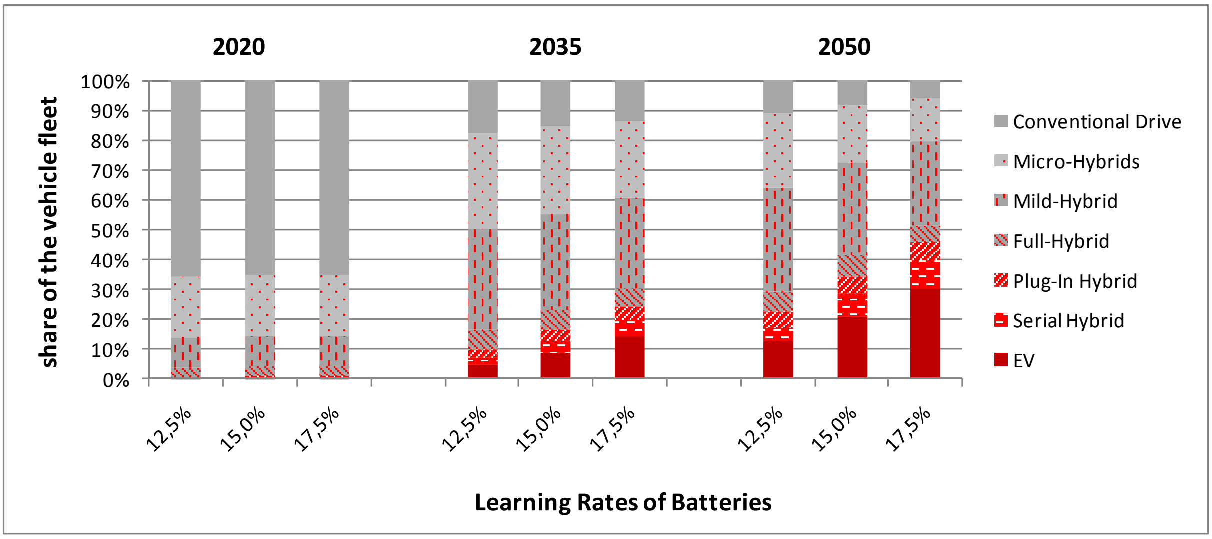

Figure 11: Sensitivity of the technology shares to the battery learning rate

The diffusion of efficient technologies, above all hybrid cars, leads to a slight reduction of final energy consumption in this scenario (see Figure 12). The energy carrier mix will remain dominated by gasoline and diesel fuels. Electricity becomes an important part of the mix only in a long term period. However, with electricity in the energy carrier mix the final energy balance is misleading as electricity production is not captured. In this case the entire energy balance (WTW) has to be considered. The WTW energy balance shows no reduction of energy consumption at all (Figure 13). The better efficiency of hybrid cars can compensate for the extra consumption caused by the increasing demand but cannot lead to a reduction. The renewable share in the energy balance comes mainly from the blending of biofuels with diesel and gasoline as well as from renewable shares of electricity.

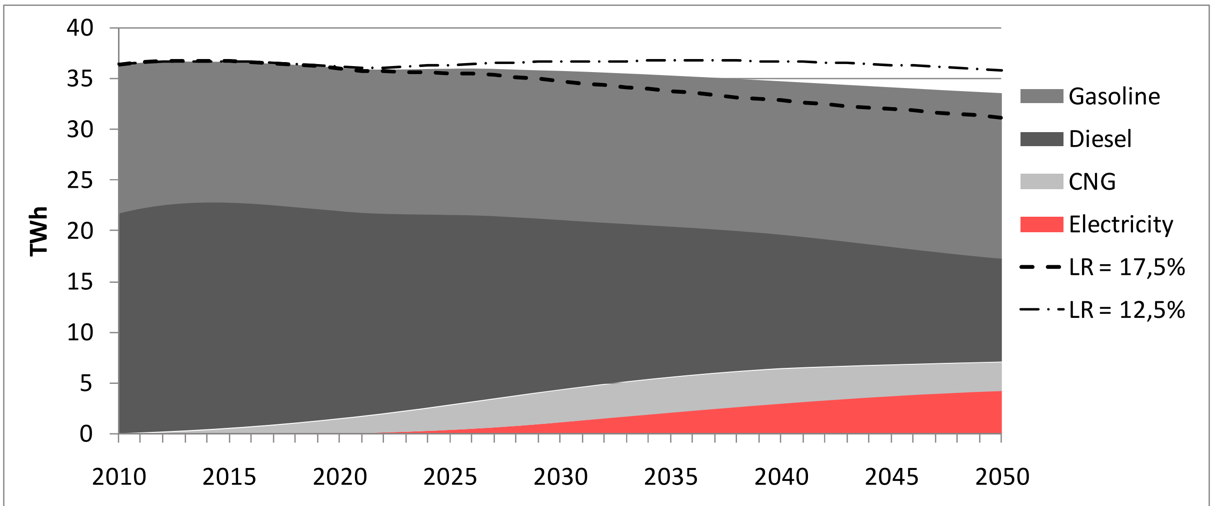

Figure 12: Final energy consumption and energy carriers (BAU - Scenario)

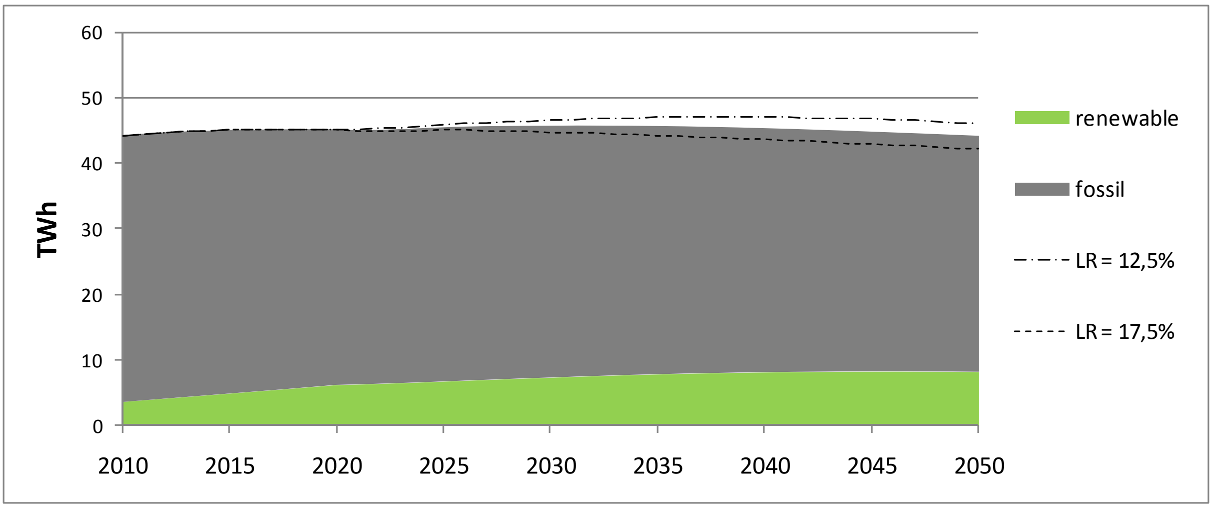

Figure 13: WTW energy demand (BAU- Scenario)

When it comes to greenhouse gas emissions it is even more important to us well-to-wheel (WTW) balances to get an unbiased view of the development. [1].
In Figure 14 the well-to-wheel (WTW) greenhouse gas emissions of the entire car fleet caused by burning of the fuel, fuel production and vehicle production are depicted. Altogether, there is only a slight reduction in GHG emissions.
In conclusion, the scenario shows that hybrid technology together with biofuel blending is not sufficient to achieve a reduction of GHG emissions. Furthermore, the car fleet remains highly dependent to crude oil based fuels.

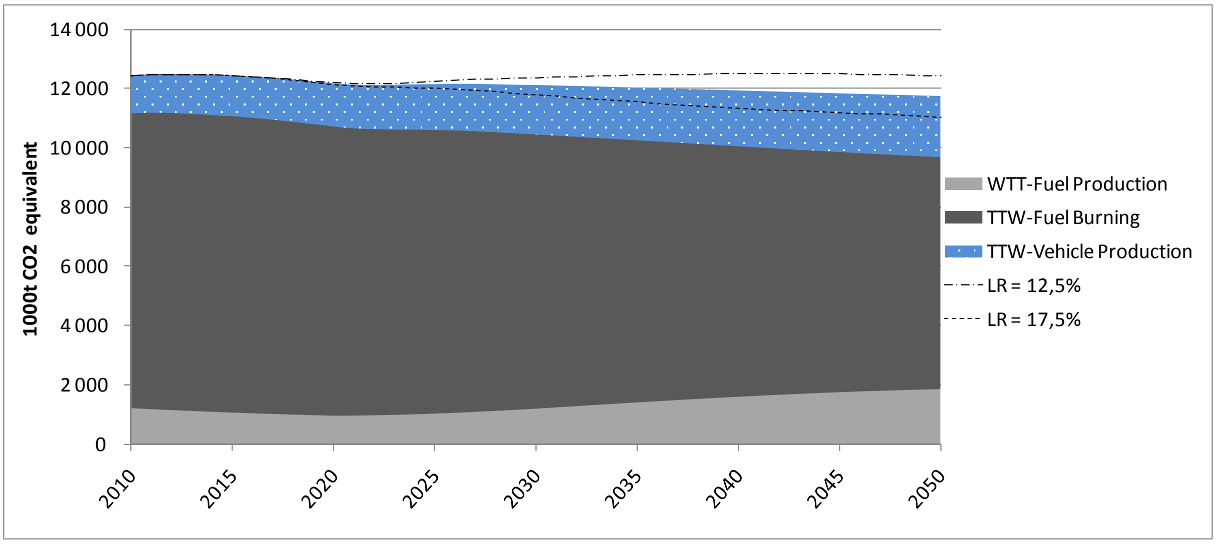

Figure 14: WTW greenhouse gas emissions (BAU-Scenario)

5.2. Policy Scenario

In the *Policy Scenario* higher taxes on fuels combined with tax reduction for efficient vehicles lead to an improvement of the competitiveness of electric propulsion technologies, especially higher taxes on fossil fuels (see Figure 15). Tax on acquisition has less impact which points out a fundamental weakness in the Austrian taxation scheme where the tax is paid as a percentage of the purchase price. Therefore, the lower tax percentage for efficient vehicles can equal in a higher corresponding absolute tax because of their purchase prices which are usually higher. This calls for a stronger leverage in the taxation scheme to really help promote efficient cars.

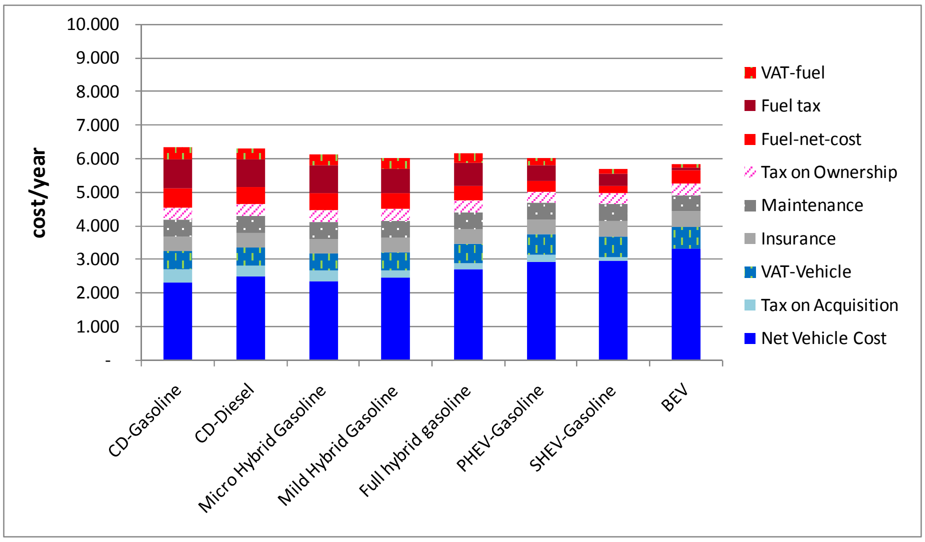

Figure 15: Total yearly cost of middle class vehicles with different propulsion systems 2030 (15 000km/year)

The better competitiveness of high efficient cars causes major shifts in the market shares of vehicle technologies (see Figure 16). In a short term period there is a similar development of hybridisation as in the BAU scenario with micro and mild hybrids massively gaining market shares. Starting 2020, there is a significant trend toward electric powertrain systems leading to a market share of electric cars of 50% in 2030. Plug-In Hybrid and Series Hybrid vehicles account for another 20% of the market.

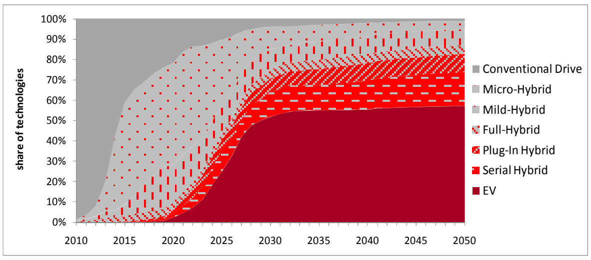

Figure 16: Market shares of propulsion technologies (Policy-Scenario)

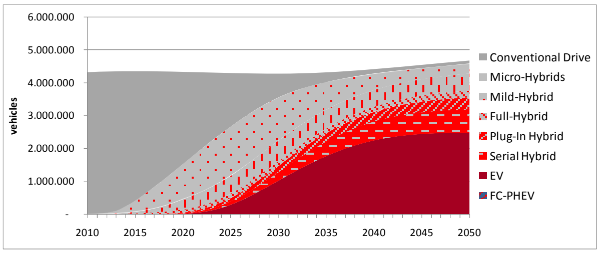

Figure 17: Passenger car fleet (Policy-Scenario)

In general, taxation of vehicles and fuels causes a rise in overall transportation costs which reduces the demand for passenger transport. This development causes the vehicle stock to stabilise at the level of 2010. Conventional drive systems are being replaced by hybrid systems in a short- to mid term period. In a long term period electrified vehicles like Serial Hybrids, Plug-In Hybrids and Battery Electric Vehicles gain a considerable share in the overall vehicle stock. Together they reach a share of almost 70% of the vehicles fleet in 2050 (Figure 17).

The final energy consumption in the *Policy Scenario* is decreasing by about 50% up to 2050 (see Figure 21). This development is driven by two factors: Firstly, the higher price level leads to a less intense use of the entire fleet and secondly the new vehicles are smaller and use more efficient technologies.

Figure 18 and Figure 19 illustrate how the different policy schemes affect the characteristics of new cars. In the BAU Scenario the average power remains relatively the same and vehicle mass slightly decreases as a consequence of enhanced use of light weight materials. In the Policy Scenario consumers tend to purchase smaller cars. This effect together with the diffusion of highly efficient propulsion systems like Plug-In-Hybrids and Electric vehicles causes a strong reduction of average emissions (see Figure 20). The emissions were compared on a well-to-wheel basis (without vehicle production), considering fossil pathways for both internal combustion engine cars (gasoline, diesel & CNG) and electric cars (electricity from natural-gas-fired gas and steam turbines). In the *BAU Scenario* the average GHG emissions of sold cars decrease from 180g km^{-1} to 140g km^{-1} up to 2030. In the *Policy Scenario* a substantial reduction is achieved with average emissions of around 110g km^{-1}in 2030.

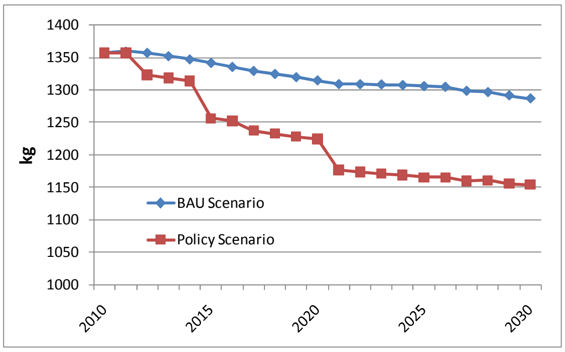

Figure 18: Development of average curb weight in the two scenarios

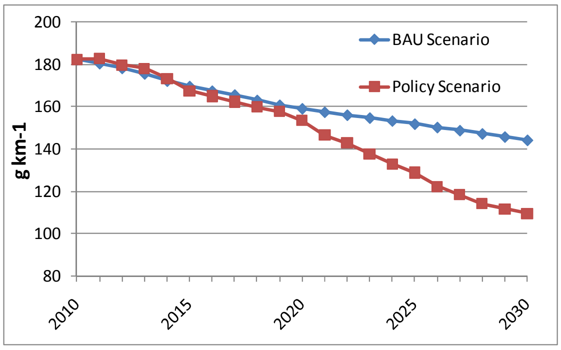

Figure 20: Development of average greenhouse gas emissions of new cars in the two scenarios (WTW without vehicle production)

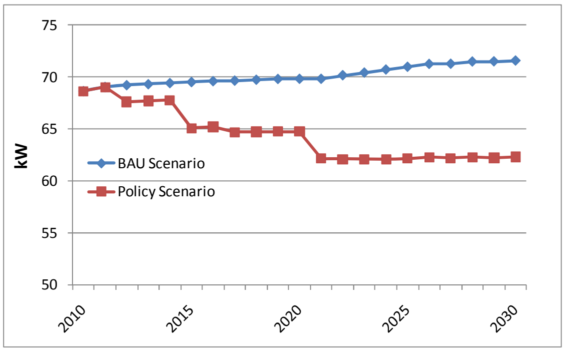

Figure 19: Development of average engine power in the two scenarios

In the *Policy-Scenario* the diffusion of electric vehicles leads to an increasing importance of electricity within the energy carrier mix. In 2050 electricity demand for the passenger transport sector reaches 7.5 TWh which is around 50% of final energy consumption. With such high shares of electricity in the energy carrier mix the WTW balance has to be taken into account for an unbiased view on the energy consumption. Figure 22 shows the WTW energy balance which is split-up in fossil and renewable fractions, for both the *fossil* and the *renewable* supply scenario (see Table 7). In the *renewable* supply scenario the demand for fossil energy of the passenger vehicle fleet can be reduced by about 75%.
The short term effects of the tax increases on fuel are visible in the energy balances. The resulting price increases affect the user intensity of all cars. This means that in the years where the tax is raised the overall fuel demand decreases.

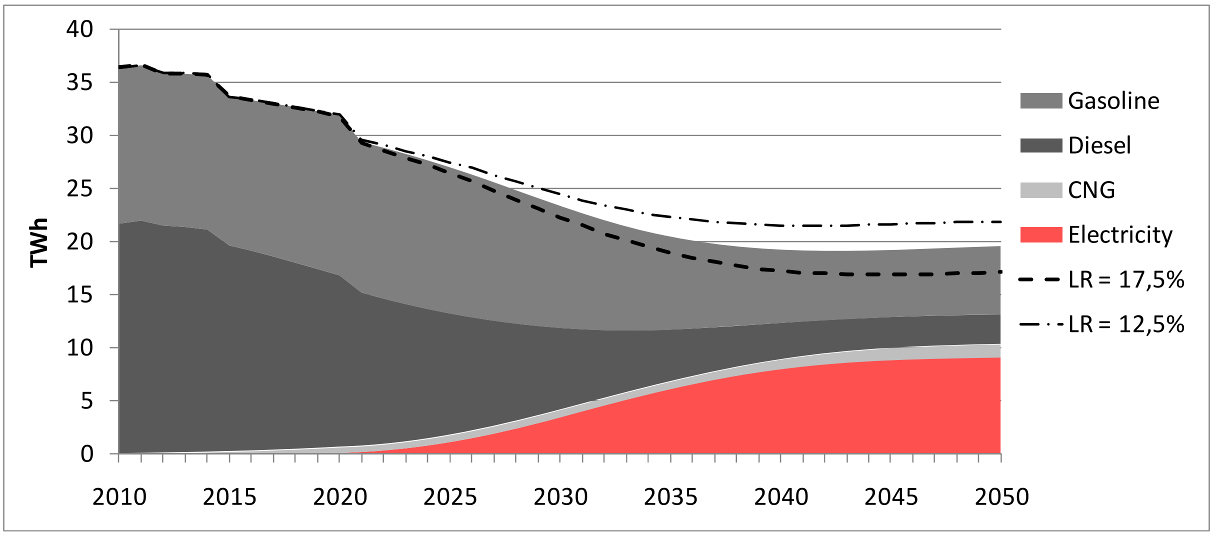

Figure 21: Final energy consumption and energy carriers (Policy-Scenario)

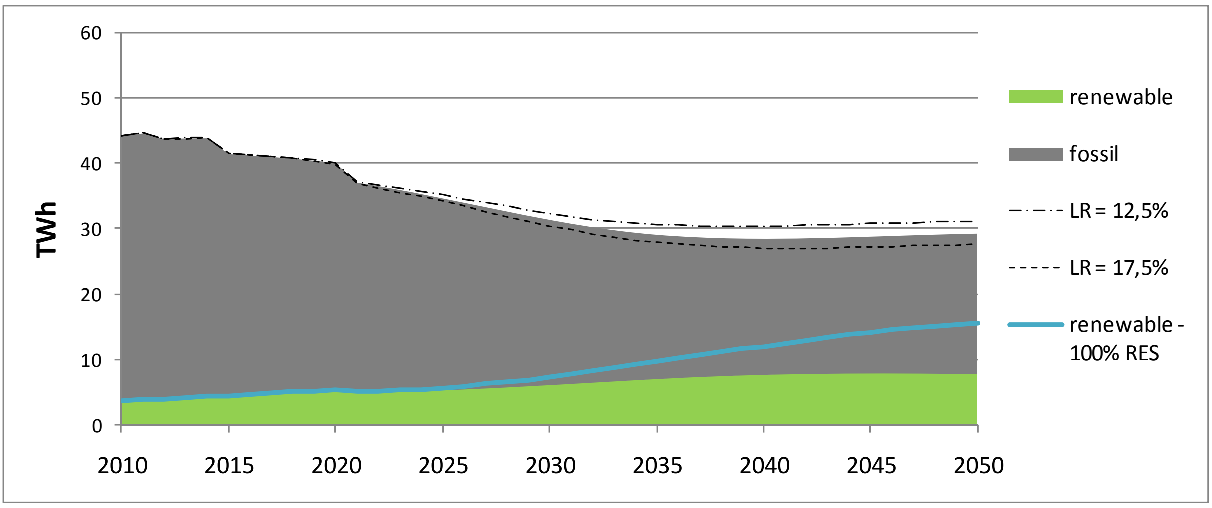

Figure 22: WTW energy demand (Policy-Scenario)

The better efficiency of cars and the less carbon intense fuels lead to a considerable reduction of GHG emissions in the *Policy-Scenario*. Figure 23 shows the corresponding WTW greenhouse gas balance for the fossil supply scenario and the renewable supply scenario (100% RES electricity). Driven by the growing demand for electricity, emissions from fuel production increase. Also, the emissions from vehicle production increase driven by the higher shares of electrified vehicles causing higher emissions in their production than conventional vehicles. Even with an electricity mix with high fossil shares the aggregate emissions can be significantly reduced through electricity based vehicles. These reach a reduction of 40% up to 2030 and by 2050 a reduction by half is achieved. When the electricity mix shifts toward a solely renewable supply mix the WTW-emissions can be reduced by two thirds until 2050.

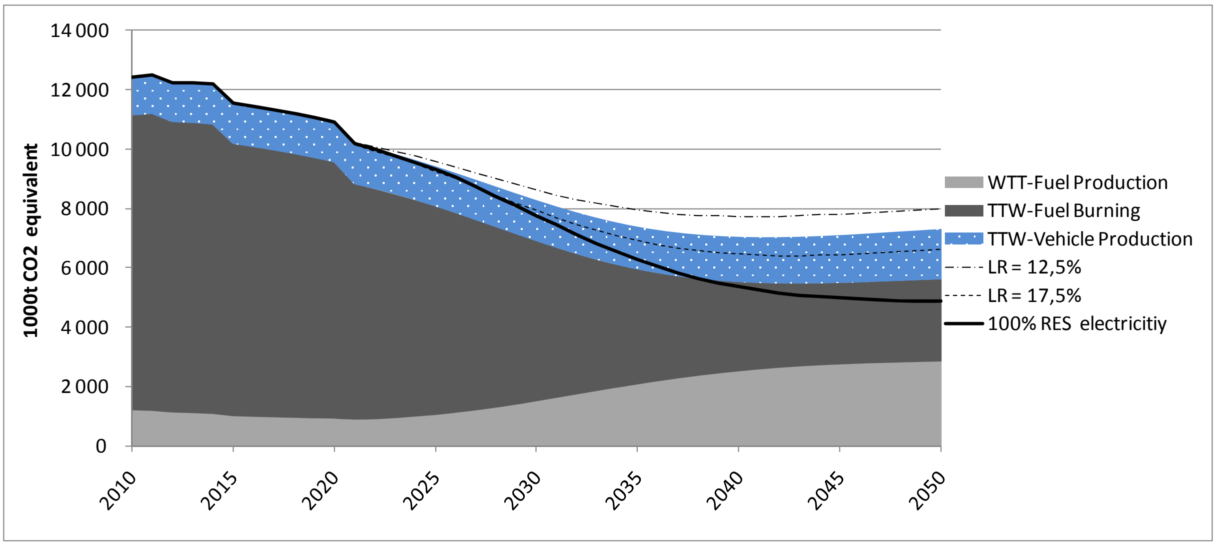

Figure 23: WTW greenhouse gas emissions (Policy-Scenario)

The results of the *Policy Scenario* give an impression on how policy can influence the development of the passenger car fleet in order to reduce greenhouse gas emissions. It demonstrates that a significant reduction of both fossil energy demand and greenhouse gas emissions is reachable through ambitious policy measures in the field.

6. Conclusions

The analysis shows that a reduction of GHG emissions and fossil fuel dependence can only be achieved by a combination of increase in efficiency and decrease in demand for passenger car transport. Policy measures and new efficient technologies are the main catalysts for this development.

Hybrid and electric propulsion systems are promising technology options in achieving these goals. The main problem of these vehicles is their cost, especially highly efficient vehicle propulsion technology remains too costly to be economically competitive at the framework conditions in Austria in 2010.

In the future technological progress will lead to a cost reduction for the key components of the propulsion systems that can improve their competitiveness. As demonstrated above increasing fossil fuel prices will promote alternative vehicle technologies. However, ambitious greenhouse gas reduction targets of countries like Austria are in need of additional measures. It is up to policy makers to set the appropriate framework conditions to achieve these targets. The result of the analysis drastically points out how different policy strategies can affect the mid-to long term development of the passenger vehicle sector in terms of efficiency, energy demand and greenhouse gas emissions.

There is one major trend that both scenarios have in common: a shift in the passenger car fleet towards hybrid vehicles. Hybridisation seems to be a robust trend that will greatly improve the efficiency of the fleet. The results of the *BAU-Scenario* show that energy demand and greenhouse gas emissions cannot be reduced by simply switching to hybrid technology.

For a substantial reduction of energy demand and GHG emissions to happen, better fuel economy is required that can only be provided by higher electrification of the powertrain. However, these cars will not become cost effective soon, unless they are supported by political framework conditions. In the *Policy-Scenario* political framework conditions were set with the scope of supporting efficient vehicles by using higher taxes on fuels and on low efficient cars, which result in significantly enforcing their market diffusion. These measures create additional effects that further reduce energy consumption and emissions. They lead to lower curb weights and power of cars sold, a generally smaller fleet and lower yearly kilometrage of cars.

All these measures lead to an immense reduction of energy demand of the fleet and an increasing importance of electricity within the energy carrier mix. However, to reach the full potential of electricity as an energy carrier for transport it is important to have a low carbon generation mix.
With a completely decarbonised electricity mix, the fossil fuel demand of the sector can be reduced by 75% and the greenhouse gas emissions by almost 70%. These numbers point out the high potential of savings that can be realised in the passenger car sector when appropriate measures are taken by public authorities.

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