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# ***POTENTIALS OF HYBRIDS AND ELECTRIC VEHICLES FOR THE PASSENGER VEHICLE SECTOR IN AUSTRIA – A MODEL BASED ANALYSIS***

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## **1. Overview**

Low efficiency of vehicles, dependence on fossil fuels and high emissions are serious problems of passenger vehicles today. Electrification of the powertrain is considered as one of the most promising approaches to alleviate these problems. Nowadays some car manufacturers already hold hybrid vehicles in their portfolio and several others are expected to follow within the next years. Some car makers even announce the introduction of pure electric vehicles.

Even though the expectations concerning those vehicles are high their future market development is highly uncertain.

The main objective of this paper is to give answer to the following questions:

- What are the main factors that influence the diffusion of hybrid and electric vehicles?
- What role can policy play in this shift?
- What are possible time frames where considerable shares of hybrid and electric vehicles within the vehicle stock can be reached?
- How does large scale introduction of hybrid and electric vehicles influence the energy demand of the sector? How much electricity will be needed?
- What are their potentials of cutting greenhouse gas emissions within the sector?

To answer those questions a model based analysis was performed based on a bottom up model of the Austrian vehicle stock. With this model scenarios of the diffusion of hybrid and electric powertrain systems could be created for the time frame 2010 – 2050. Based on those scenarios the effects of economic and political framework conditions on the diffusion of hybrid and electric powertrain systems could be simulated as well as their effect on the energy consumption and the greenhouse gas emissions of the entire vehicle fleet. This enabled the identification of the main drivers for the diffusion of hybrid and electrified vehicles.

For the analysis eight different powertrain systems with different degrees of electrification were analysed covering the entire range from conventional internal combustion engines up to pure electric vehicles:

- Conventional Drive
- Micro Hybrid
- Mild Hybrid
- Full Hybrid
- Plug-In-Hybrid
- Serial Hybrid (with plug-in)
- Electric Vehicle
- Fuel Cell Vehicle

Those technologies were considered to be possible choices for vehicle propulsion technologies for the time frame 2010-2050

The paper is based on a research project supported by the Austrian Ministry of Innovation, Transport and Technology, with the objective to identify potentials of vehicle powertrain systems from a technical, ecological and economic perspective<sup>1</sup>.

## 2. Methods

The approach consists of three main steps: Firstly a detailed technical, ecological and economical analysis of the vehicle powertrain technologies was performed to determine fuel consumption, greenhouse gas emissions and investment costs [2]. In the second step the overall costs per kilometre of the vehicles were analysed considering fuel costs and political framework conditions in a dynamic context. Thirdly the market shares and the stock penetration of those vehicle propulsion technologies were estimated based on a model of the Austrian vehicle stock [3]. This paper will focus on the modelling and the scenarios developed through the model.

For the modelling a bottom-up model of the Austrian vehicle stock was used. Within the model the vehicle stock was divided in three vehicle classes, (compact vehicles, middle class vehicles, upper class vehicles/SUVs) each class having specific characteristics, user groups and different sets of vehicle technologies available.

In the next step scenarios were developed to display the effects in medium to long term (2010-2050). Within this context the electricity consumption driven by vehicle electrification was a matter of particular interest.

### 2.1 Modelling Scheme

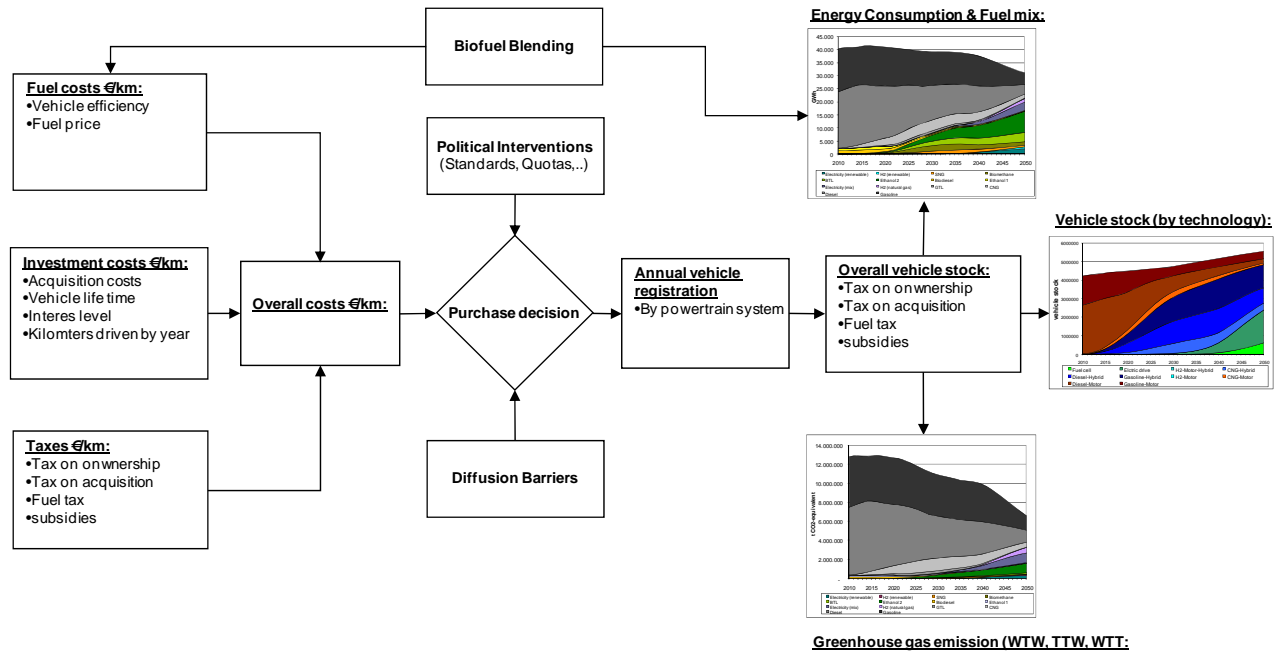
The basic methodical scheme of the model is showed in **Figure 1**. In a first step the overall costs per kilometre of each powertrain technology within each vehicle class were calculated. The relevant costs for this calculation were the investment costs, the fuel costs and the costs that arise from political framework conditions (e.g. taxes). Those costs add up to the overall costs per kilometre and represent the basis of the customer decision. For the customer decision it was assumed that there are different levels of willingness-to-pay. Even though the main criteria for the diffusion of powertrain technologies are the costs there are also some restrictions that can influence customer decision independently from costs. Such mandatory restrictions are for example standards and quotas and have also been considered in the model.

In the next step the annual shares of technologies within the yearly car registrations and the overall amount of vehicles registered were used for the modelling of the overall vehicle stock. To model the Austrian vehicle stock statistical data from Austria were used (e.g. age of the fleet, average life expectancy...) To represent the ageing of the vehicle stock it was assumed that vehicle life expectancy was determined by a Weibull distribution function.

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<sup>1</sup> Support programm: A3plus - Alternative Propulsion Systems and Fuels

Project Name: "Development of Scenarios of the dissemination of vehicles with partly and fully electrified powertrain under different political framework conditions – ELEKTRA"



**Figure 1: Scheme of the modelling**

To model the yearly demand for vehicles and therefore the overall car registrations an energy economic approach was applied: It was assumed that the development of annual vehicles registrations depends on the level of income, expressed by the GDP, the fuel price level and the level of investment cost.

Thus the development of the annual vehicle demand is given by the elasticity of fuels price  $\varepsilon_{FP}$ , elasticity of vehicle price  $\varepsilon_{IC}$  and income elasticity  $\varepsilon_{\gamma}$ . These elasticities have been derived from econometric time series analyses.

$$Z_{t+1} = Z_t \cdot \left(\frac{FP_{t+1}}{FP_t}\right)^{\varepsilon_{FP}} \left(\frac{IC_{t+1}}{IC_t}\right)^{\varepsilon_{IC}} \cdot \left(\frac{GDP_{t+1}}{GDP_t}\right)^{\varepsilon_{\gamma}}$$

$$\varepsilon_{FP} = -0,5$$

$$\varepsilon_{IC} = -1$$

$$\varepsilon_{\gamma} = 0,8$$

$Z$ ...vehicle registration per year

$IC$ ...investment costs

$FP$ ...fossil fuel price level

$GDP$ ...income level represented by the grand domestic product

$\varepsilon_{FP}$ ...price elasticity

$\varepsilon_{IC}$ ...elasticity on investment costs

$\varepsilon_{\gamma}$ ...income elasticity

## 2.2 Reference Vehicles

As mentioned above three classes of vehicles were distinguished:

- Compact class vehicles
- Middle class vehicles
- Upper class vehicles (including SUVs)

Each vehicle class was defined by vehicle mass and engine power. To determine those specifications and the allocation of each class within the vehicle stock and the yearly vehicle registrations for the particular case of Austria historic data was used.

Within the vehicle classes different powertrain technologies were considered including the entire spectrum from conventional drive with internal combustion engine to pure electric drive. The following systems were analysed:

- Conventional Drive
- Micro Hybrid
- Mild Hybrid
- Full Hybrid
- Plug-In-Hybrid
- Serial Hybrid (with plug-in)
- Electric Vehicle
- Fuel Cell Vehicle

The specific characteristics of the vehicles are showed in **Table 1**.

	curb weight	engine power	electr. mot. power (traction motor)	battery capacity (traction battery)	Battery mass (traction battery)	Fuel Cell System	electric range	overall range
	kg	kW	kW	kWh	kg	kW	km	km
Conventional Drive - Gasoline	1470	75	-	-	-	-	-	700
Conventional Drive - Diesel	1522	75	-	-	-	-	-	700
Conventional Drive - CNG	1533	75	-	-	-	-	-	700
Micro Hybrid - Gasoline	1470	75	-	-	-	-	-	700
Micro Hybrid - Diesel	1522	75	-	-	-	-	-	700
Micro Hybrid - CNG	1533	75	-	-	-	-	-	700
Mild Hybrid - Gasoline	1450	65	20	-	-	-	-	700
Mild Hybrid - Diesel	1495	65	20	-	-	-	-	700
Mild Hybrid - CNG	1513	65	20	-	-	-	-	700
Full Hybrid - Gasoline	1458	50	50	-	-	-	-	700
Full Hybrid - Diesel	1493	50	50	-	-	-	-	700
Full Hybrid - CNG	1521	50	50	-	-	-	-	700
Plug-In-Hybrid - Gasoline	1538	50	50	10	100	-	40	700
Plug-In-Hybrid - Diesel	1573	50	50	10	100	-	40	700
Plug-In-Hybrid - CNG	1601	50	50	10	100	-	40	700
Serial Hybrid - Gasoline	1623	40	75	20	200	-	80	700
Serial Hybrid - Diesel	1651	40	75	20	200	-	80	700
Serial Hybrid - CNG	1686	40	75	20	200	-	80	700
Electric Vehicle	1678	-	75	50	500	-	200	200
Fuel Cell Plug In Hybrid	1645	-	75	20	200	40	500	500

**Table 1: Vehicle Powertrain Specifications (middle class)**

## 2.3 Fuel costs

For the fuel costs of the vehicles two parameters are important: The fuel efficiency of the propulsion system and the fuel prices.

### 2.3.1 Fuel efficiency:

The data for the fuel efficiency of for all vehicles with different propulsion systems was provided by our project partner AVL<sup>2</sup> who is an expert on the field of automotive Research and Development [2]. In the following chart the tank-to-wheel (TTW) efficiencies of different powertrain systems are showed. It is obvious that the efficiency increases with the degree of electrification of the propulsion system.

<sup>2</sup> AVL LIST GMBH

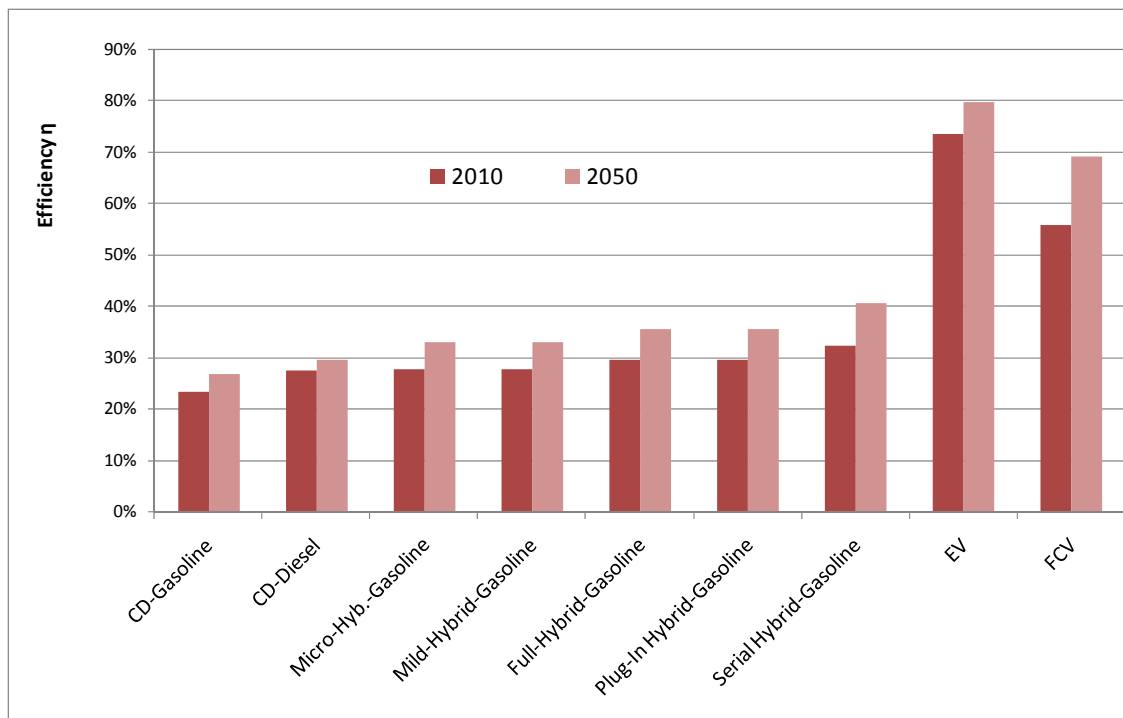


Figure 2: TTW Vehicles Efficiency 2010 and 2050

### 2.3.2 Fuel prices:

It was assumed that there would be a continuous increase in the price of vehicle fuels in the time frame 2010-2050 due to the increase of fossil fuel prices. For the analysis two basic fossil fuel price scenarios were determined both starting at the 2009 price level in 2010:

**Low-Price-Scenario:** in this scenario it is assumed that the fossil fuel price increases in a moderate manner.

**High-Price-Scenario:** in this scenario it is assumed that there would be a strong increase of the fossil fuel price level up to 2050.

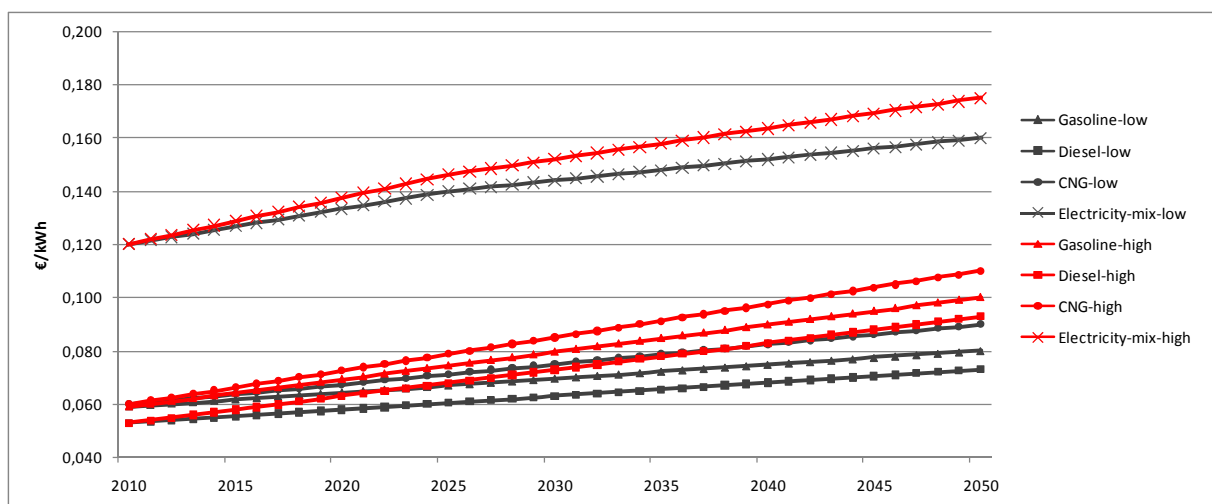
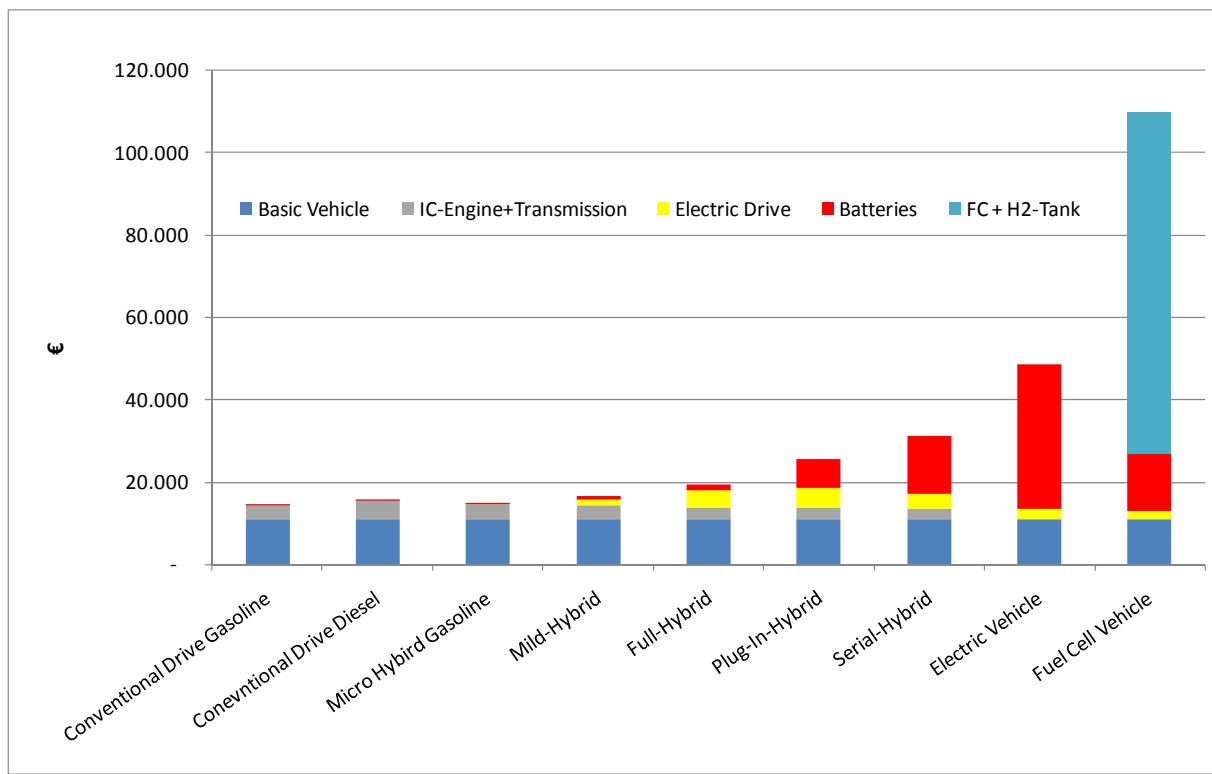


Figure 3: Net Fuel Price Scenarios

## 2.4 Investment costs

The analysis of the investment costs is based on the costs of the single components. The costs of the components were subject of detailed analysis within the project [2].

**Figure 4** shows how the different component groups contribute to the overall cost of the each vehicle technology. It shows that the overall investment costs increases with the degree of electrification of the propulsion system. The main driver of the investment costs are the batteries that are required to permit the desired electric range.



**Figure 4: Net costs of middle class vehicles 2010**

Therefore the costs of batteries (Lithium Ion Batteries) can be seen as the crucial factor within the investment costs of electrified vehicles. Their specific costs in 2010 were assumed to be at 700€/kWh. For the mid- to long term development of the costs of batteries the concept of technological learning was applied. To estimate the cumulative production of lithium ion traction batteries the scheduled introduction of major automotive producers was used for the time 2010-2015. For the years 2011-2030 it was assumed that the lithium ion batteries become the standard technology for both electric and hybrid electric vehicles and therefore follows the characteristic S-shape of a technological substitution process. Furthermore it is assumed that the trend towards hybridisation of vehicles was a robust process and would continue within the following decades.

The mathematical description of the learning curve is given by the exponential function.

$$C(x) = a * x^{-b}$$

$C$ .....cost per unit [EUR/unit]

$a$ .....cost of first unit produced [EUR/unit]

$x$ .....number of produced units

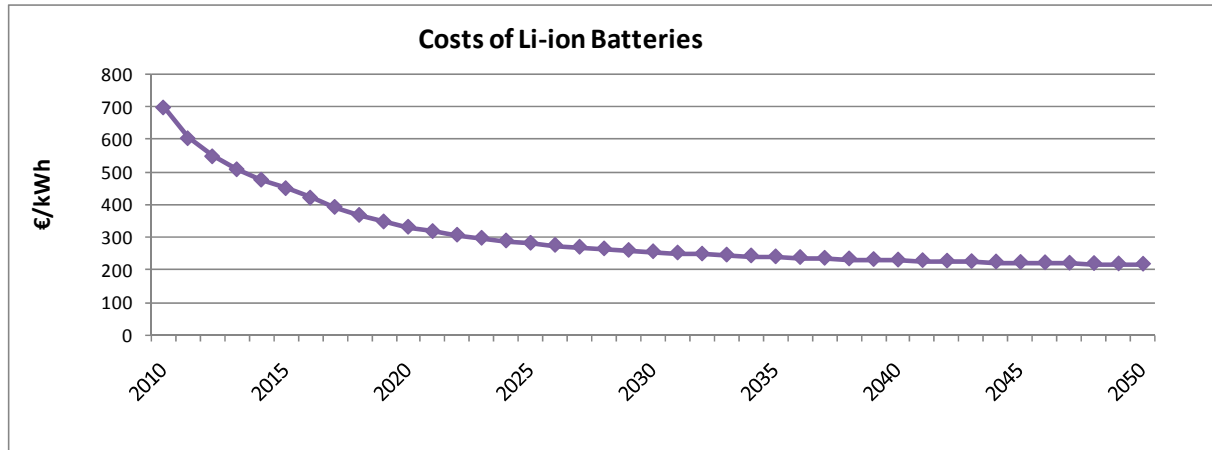
$b$ .....learning index [-]

It is evident that the cost reduction depends on the global cumulative production and the learning index. From the learning index the progress ratio  $p$  can be calculated. The progress ratio expresses what cost reduction would be caused by a doubling of cumulative production (percentage of former costs after a doubling of production).

$$p = 2^{-b}$$

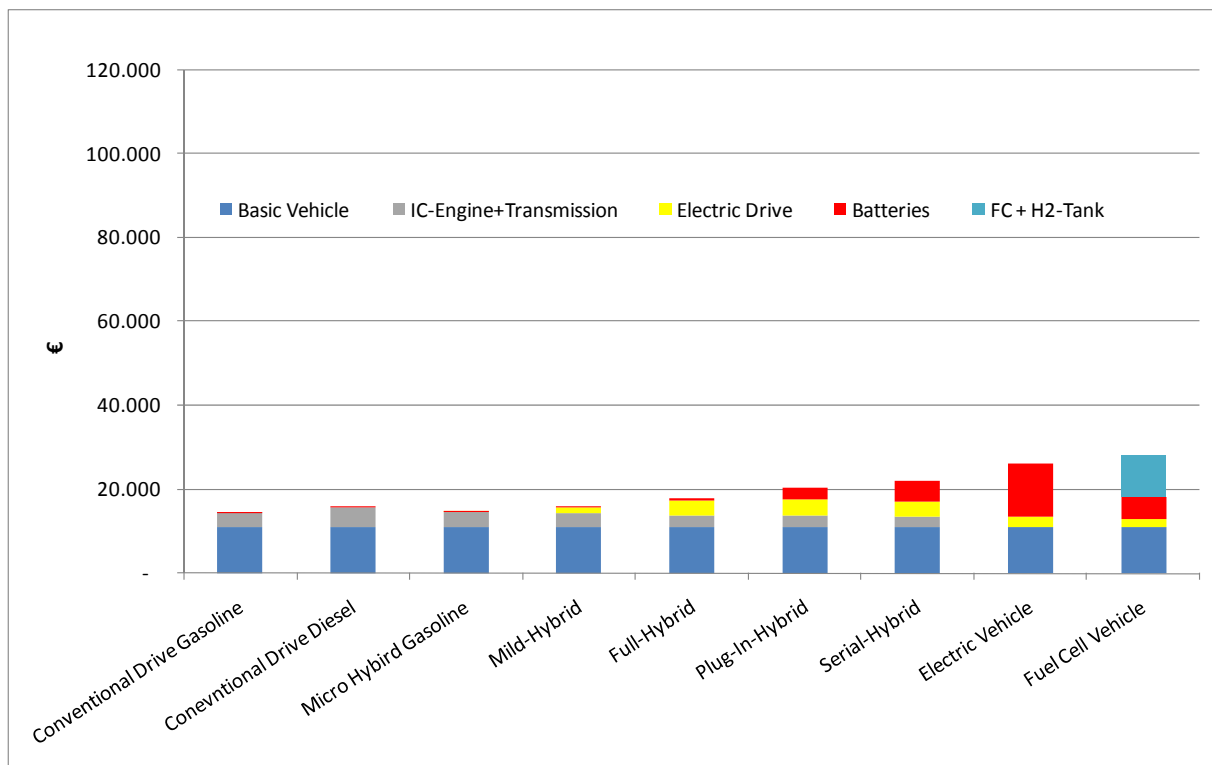
p.....progress ratio [-]

For the case of lithium Ion batteries a progress ratio of 92,5% was assumed. The cost reduction of lithium Ion batteries from 2010 to 2050 is depicted in figure **Figure 5**.



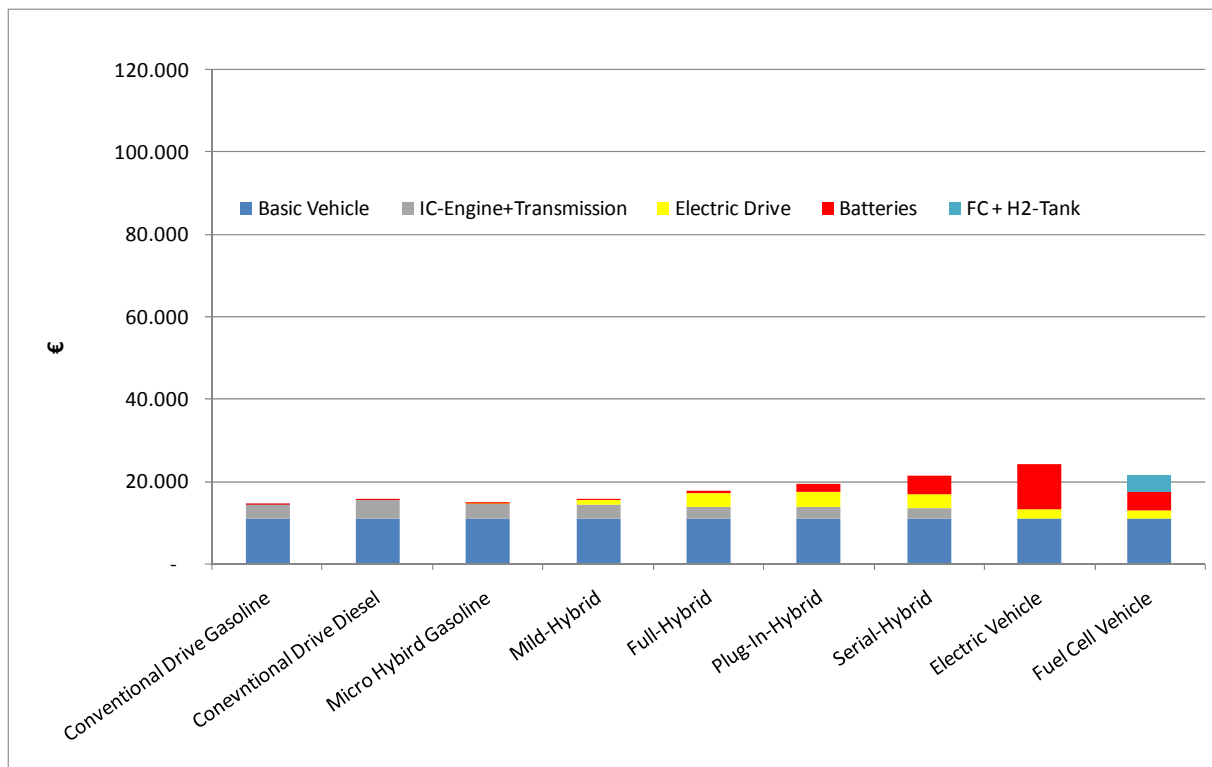
**Figure 5: Costs of Li-Ion Batteries 2010-2050**

The reduction of battery costs effect a significant reduction of overall vehicle costs of hybrid and electric vehicles up to 2030 and 2050 (see **Figure 6** & **Figure 7**). Therefore technological development of batteries has significant influence on their medium to long term diffusion.



**Figure 6: Net costs of middle class vehicles 2030**





**Figure 7: Net costs of middle class vehicles 2050**

## 2.5 Political framework conditions

Policy can play an important role for the diffusion of efficient vehicle powertrain systems in the passenger car sector and therefore for the energy efficiency and the greenhouse gas emissions of the sector as whole. The political framework conditions considered in this paper were those that influence the cost of transport directly (mainly taxes) and those that influence the price indirectly through compulsive restrictions (e.g. standards and quotas) For the present analysis only the first group was considered. The main taxes that are important for the passenger vehicle sector in Austria are:

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

**Tax on Acquisition:** this tax depends on the fuel consumption and the greenhouse gas emissions of the vehicle

**Tax on Ownership:** the height of this tax depends on the engine power of the vehicle

**Tax on Fuels:** in Austria fuels are taxed by unit (€/litre or €/kg)

It was assumed that the political framework conditions in 2010 are the same as they are now (2009). For the time frame 2010-2050 two main policy scenarios were defined:

**Business as usual scenario – BAU-Scenario:** In this scenario it was assumed that the political framework conditions remain on the 2010-level

**Policy scenario:** it was assumed that taxes would be adapted with regard to an increase in energy efficiency and a reduction of greenhouse gas emissions. Therefore taxation of hydrocarbon fuels and inefficient vehicles gets raised stepwise within the period.

## 2.6 Overall Costs

The service costs of each vehicle consists of it's fuel costs and it's capital costs. Those costs are added up as depicted in **Figure 1**. The mathematical definition is expressed by the following equations:

$$SC_j = EC_j + CC_{SP\_j} \text{ [EUR/km]}$$

SC.....service costs [EUR/km]

EC.....energy costs [EUR/km]

CC<sub>SP\_j</sub>.....specific capital costs of vehicle j [EUR/km]

$$EC_j = FC_j * FP_j \text{ [EUR/km]}$$

FC<sub>j</sub>.....energy consumption of vehicles j [kWh/km]

FP.....fuel price [EUR/kWh]

$$CC_{SP\_j} = (\alpha * (IC_j + TA_j) * (1 + VAT_j)) / S_{km} + TO_j \text{ [EUR/km]}$$

$$\alpha = \frac{(r * (1 + r)^{DT}}{(1 + r)^{DT} - 1}$$

r.....interest rate

DT.....depreciation time

$\alpha$  .....Annuity factor

IC<sub>j</sub>.....Investment costs of vehicles j (EUR/vehicle)

TA<sub>j</sub> .....tax on acquisition

TO<sub>j</sub>.....tax on ownership

VAT<sub>j</sub>... Value added tax

S<sub>km</sub>.....driven kilometres by year

In the model the economic performance of all vehicle classes with all propulsion systems was calculated at different yearly kilometrage rates. For the further employment in the model it was the costs were calculated in € per kilometre (€/km).

For the analysis an interest rate of 5% and a depreciation time of 14 years were considered.

The following figures shall give an overview on the development of overall costs in the time frame 2010 to 2050.

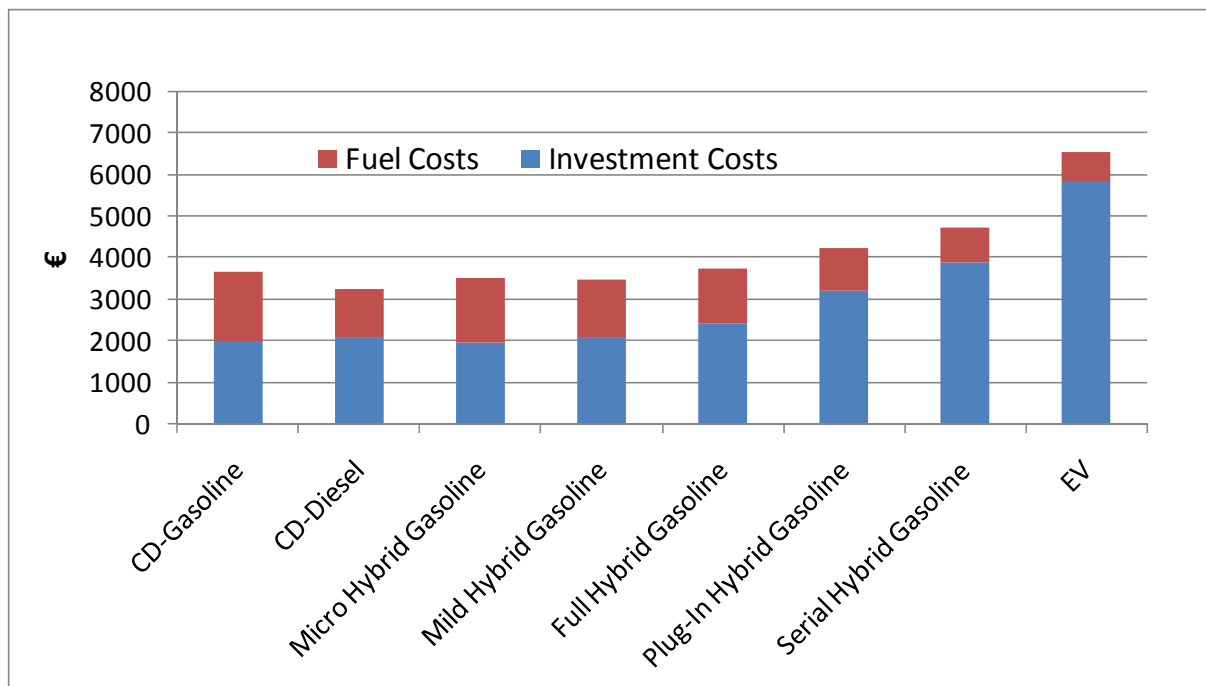


Figure 8: Yearly overall costs of vehicles at 20 000km/a – 2010

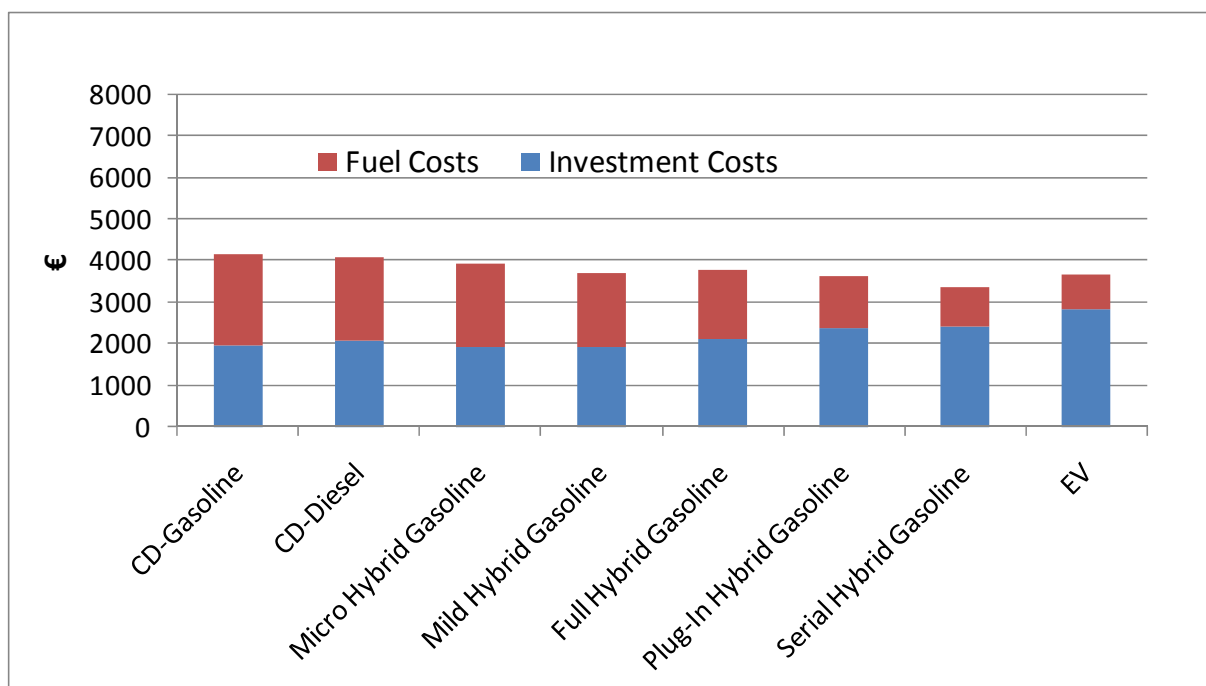


Figure 9: Yearly overall costs of vehicles at 20 000km/a – 2050 (Policy Scenario and high fuel price)

**Figure 8** and **Figure 9** indicate that today hybrid and electric vehicles are not competitive from an economic point of view, neither in the middle class segment nor in the compact class. Their high investment cost cannot be compensated by the fuel savings.

Until 2050, due to the reduction of the investment costs and the shift within the political and economic framework condition (Policy Scenario + high fossil fuel prices), the competitiveness of electrified vehicles improve strongly. By that time they are catching up with conventional technologies and some become even better.

## 2.7 Scenarios

To analyse the effect of policies and different fossil fuel price levels two basic scenarios were developed. The scenarios differ from each other in the way of the policies implemented and the fossil fuel price levels (see chapter 2.3.2 and 2.5):

**Scenario A:** BAU-Policy & Low fossil fuel level

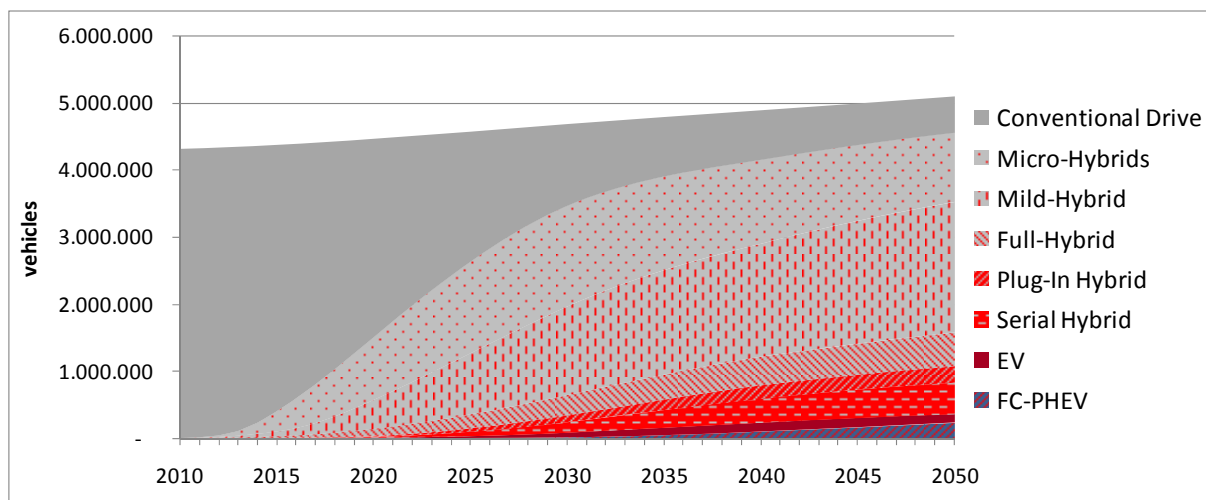
**Scenario D:** Active Policy & High fossil fuel price level

## 3. Results

Using the model it was possible to investigate the effectiveness of policies on the diffusion of efficient vehicle technologies on the one hand and the impact of further drivers, such as fuel prices and development of vehicle technologies on the other hand. The results of the model were also used to show the effects of the aforementioned drivers on the energy consumption and the greenhouse gas emissions.

### 3.1 Scenario A

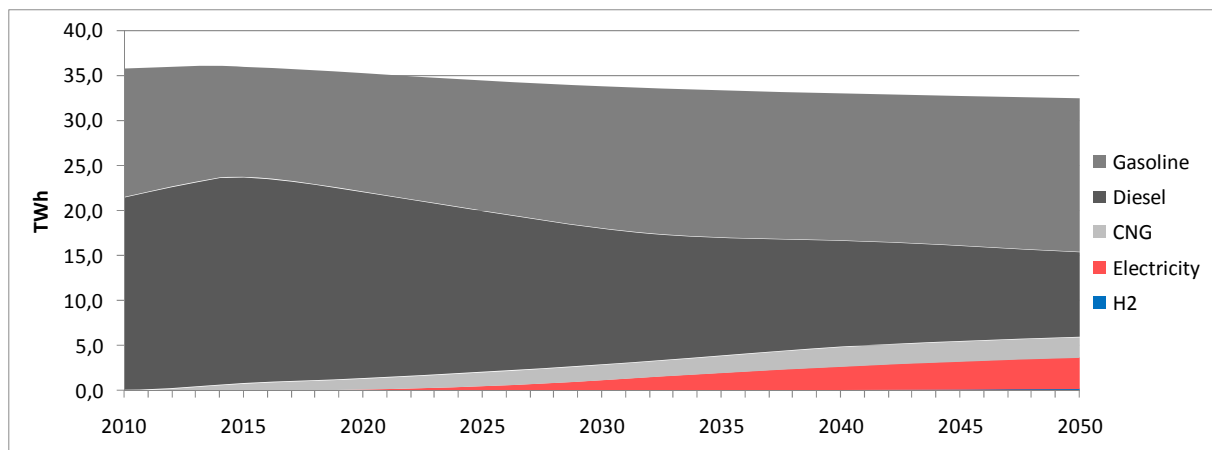
**Figure 10** shows the development of the vehicle stock in Scenario A. In this scenario the taxation level remains the same in the entire period 2010-2050. In the same time the improving vehicle efficiency compensates the light increase of fossil fuel prices. Therefore the costs of passenger stay at a low level or even decrease causing the demand for transportation to increase and the vehicle stock to grow. In the case of Austria that means that the vehicle stock grows from 4,2mio vehicles to about 5,8mio.



**Figure 10: Development of the Vehicles Stock – Scenario A**

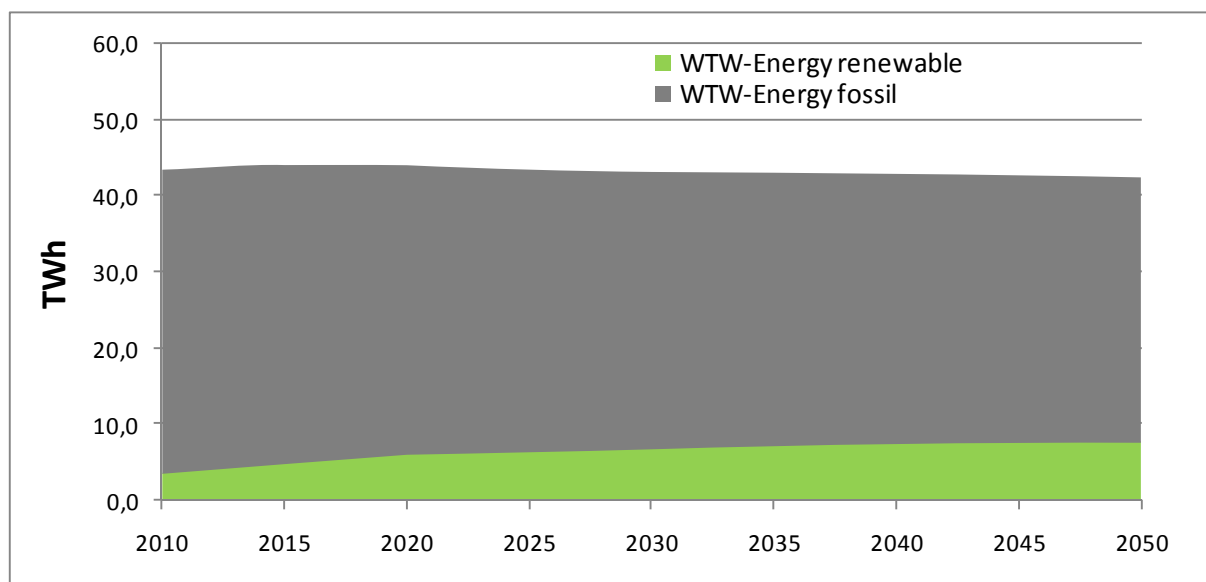
Taking a look at the powertrain systems within this stock it shows that conventional drive systems get replaced by Hybrid options which become the standard technology in the mid to long term. In this scenario Plug-In-Hybrids and Electric Vehicles don't achieve big shares not even in the long term. In Scenario A the final energy consumption of the passenger sector decreases slightly (see **Figure 11**). Although the vehicle fleet increases the higher vehicle efficiency causes a slight reduction of overall consumption.

Regarding the energy carriers one can see that liquid hydrocarbons remain the most important energy carriers even in a long term even though there is a considerable share of compressed natural gas and some electricity.



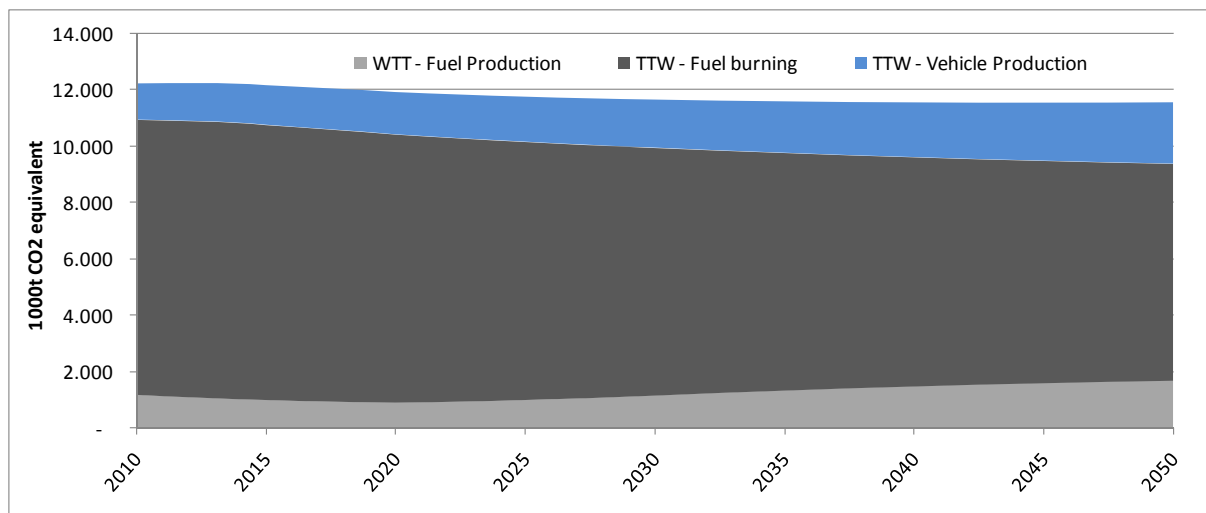
**Figure 11: Final Energy Consumption and Energy Carriers - Scenario A**

Final energy consumption might be a bit misleading when analysing the energy demand of the vehicle fleet especially when the electricity share increases. For a more detailed view one has to look at the well-to-wheel energy balance which also includes the electricity production. For scenario A the WTW-energy balance shows no considerable reduction of energy demand by the fleet up to 2050.



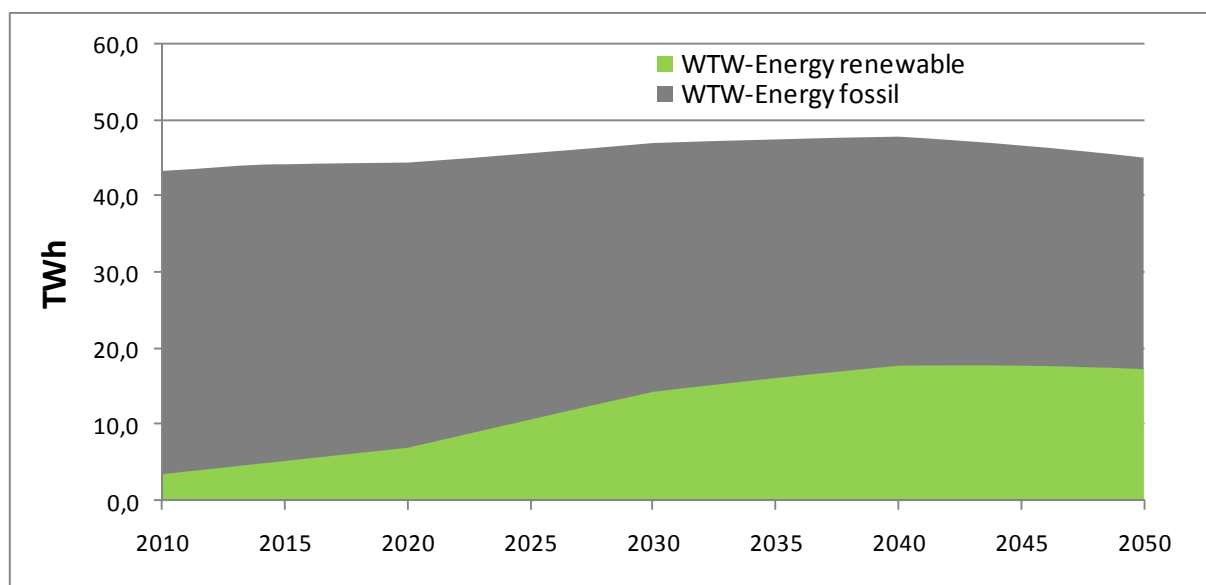
**Figure 12: Well-to-wheel energy demand - Scenario A**

In **Figure 13** the well-to-wheel (WTW) greenhouse gas emissions of the entire vehicle fleet are depicted. It shows only a slight decrease in emissions stabilising at a level of about 11 500t per year. In this chart one can also see the shares of emissions that come from the vehicle production and that ones that come from fuel production. Up to 2050 as propulsion technologies become more and more complex the emissions from vehicle production increase continuously. From the year 2030 on there is also a slight increase of GHG- emissions that come from the electricity production.



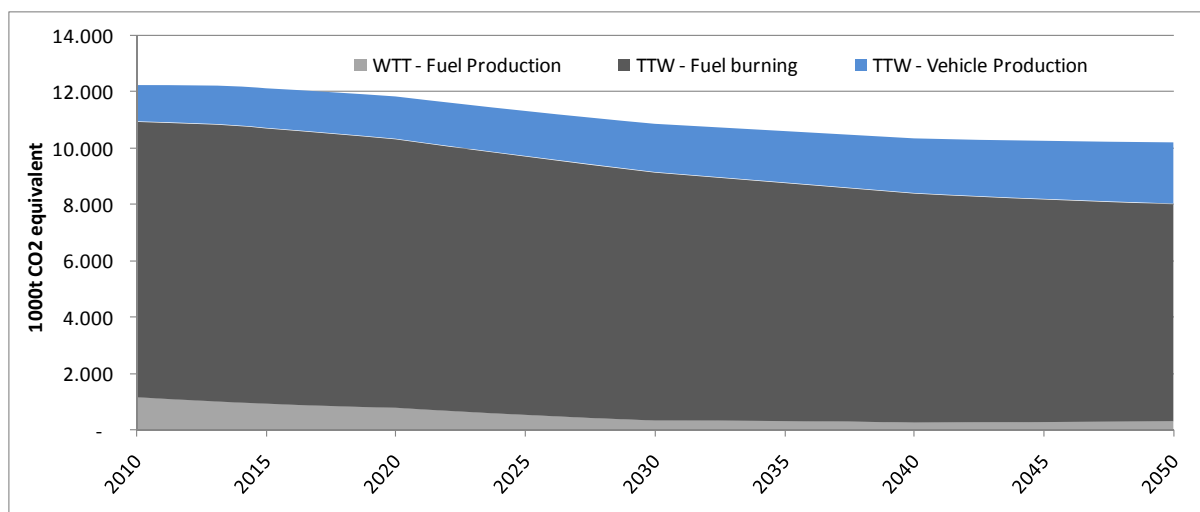
**Figure 13: Well-to-Wheel (WTW) greenhouse gas emissions – Scenario A**

**Figure 14** shows the energy demand in scenario A when a high biofuel blending rate of 30% was assumed. It shows that there is a shift from fossil to renewable energy sources when biofuels are used in a large scale. However the overall energy consumption increases when higher biofuel blending is assumed.



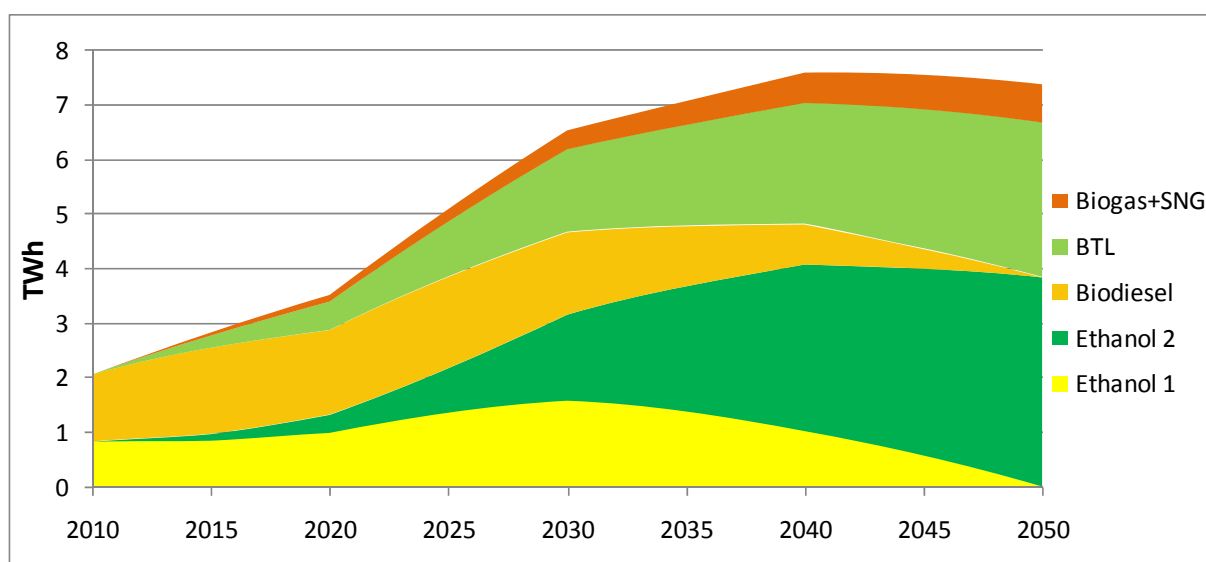
**Figure 14: Well-to-wheel energy demand - Scenario A - Biofuels active**

**Figure 15** shows the WTW greenhouse gas emissions in the 30% biofuel scenario. One can see that due to the almost emission neutral GHG balances of the applied biofuels the emissions from fuel production are almost reduced to zero and the overall GHG emissions are reduced by around 25%.



**Figure 15: Well-to-Wheel (WTW) greenhouse gas emissions - Scenario A - Biofuels active**

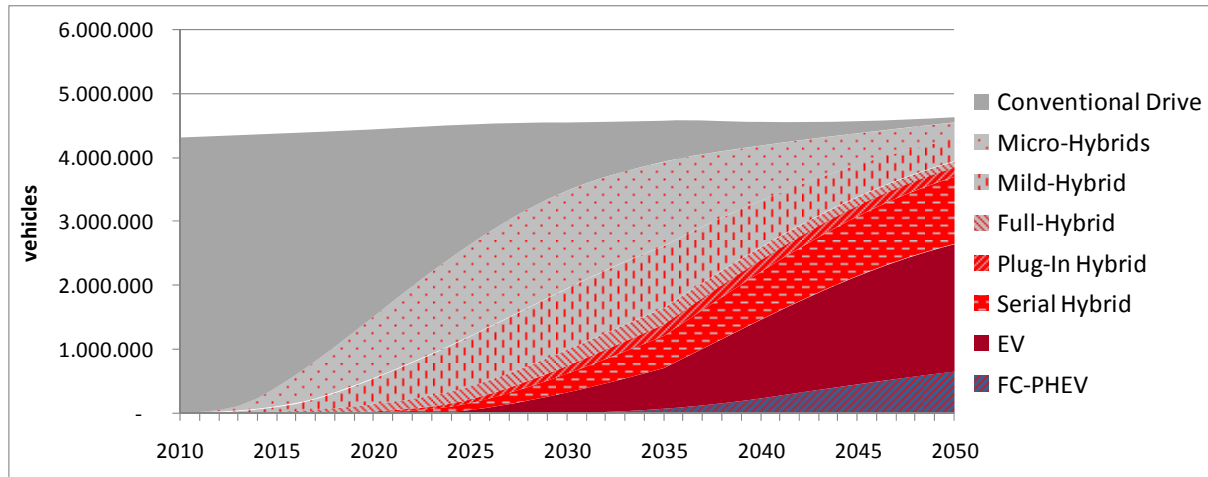
**Figure 16** shows the amounts of biofuels that are required to cover the demand of a 30% biofuel blending in this scenario. Up to 2050 a shift from 1<sup>st</sup> to 2<sup>nd</sup> generation biofuels within the fuels was assumed.



**Figure 16: Biofuel demand with active biofuel policy**

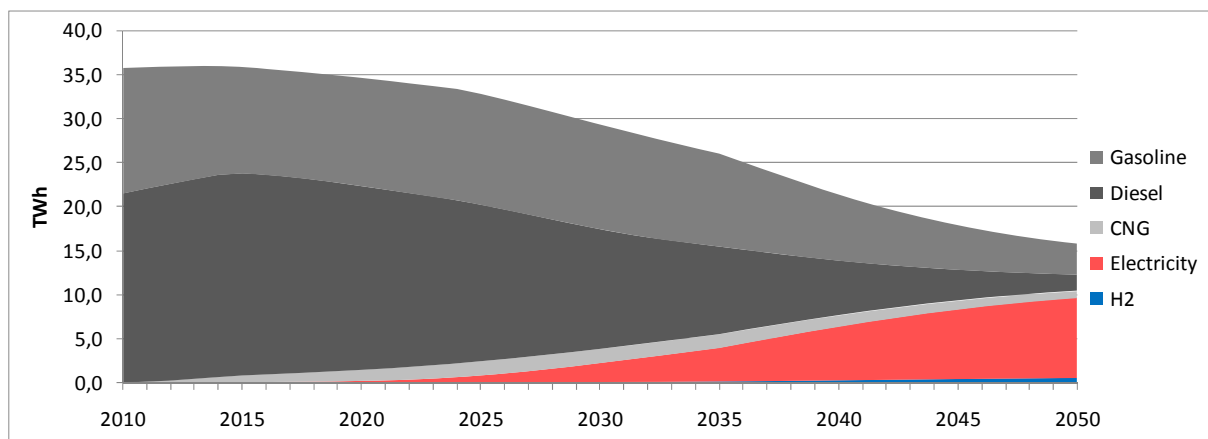
### 3.2 Scenario D

In Scenario D 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. Regarding the vehicle technologies within the stock it shows that conventional drive systems get replaced by hybrid systems in a short- to mid term. In a long term highly electrified vehicles such as Serial Hybrids, Plug-In Hybrids and Battery Electric Vehicles considerably gain share in the overall vehicle stock. Together they reach almost two thirds of the vehicles stock in 2050 (**Figure 17**).



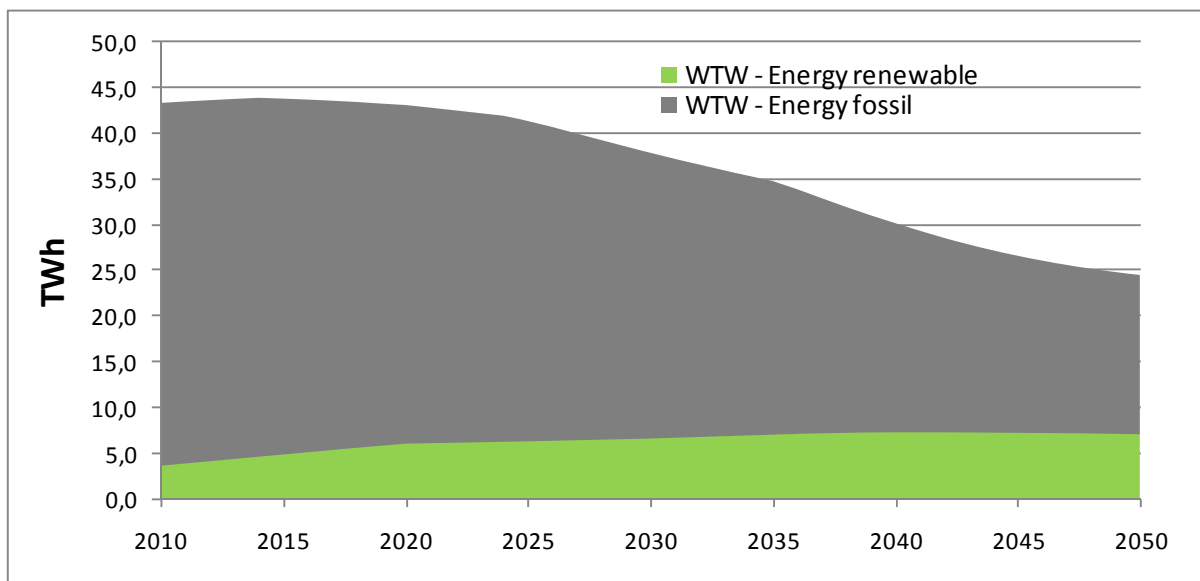
**Figure 17: Development of the Vehicles Stock – Scenario D**

The final energy consumption in scenario D is decreasing by about 50% up to 2050 caused by two developments: firstly there is a general switch to more efficient vehicles while the fleet size stays about the same. Secondly the deployment of electricity as final energy carriers causes a strong reduction in final energy consumption in a long term. Nevertheless it also has to be considered that in this chart primary energy consumption for the production of the electricity is not depicted. In an overall energy balance the reduction would not be that broad (**Figure 18**).



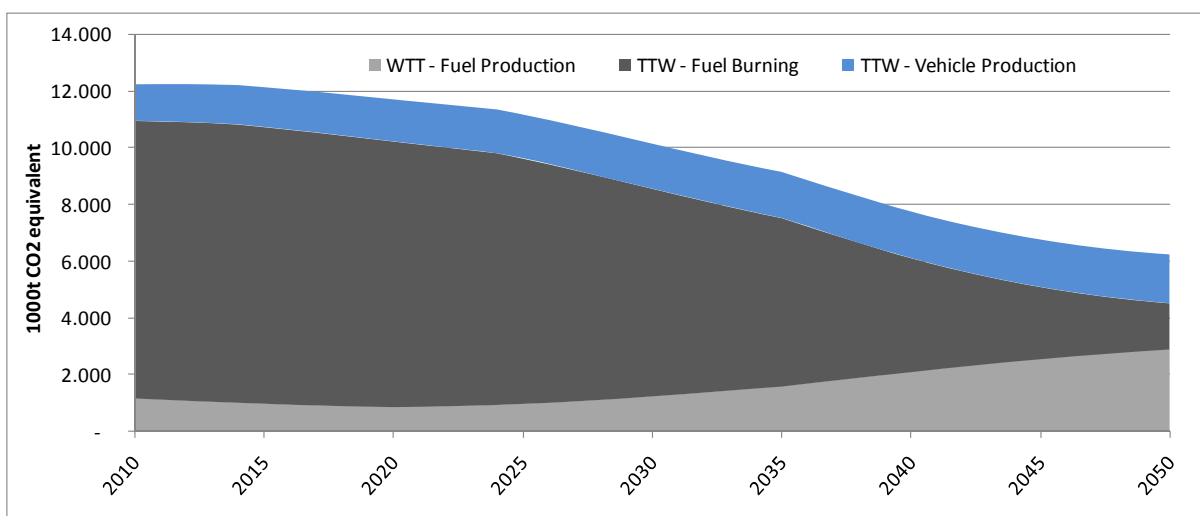
**Figure 18: Final Energy Consumption and Energy Carriers - Scenario D**





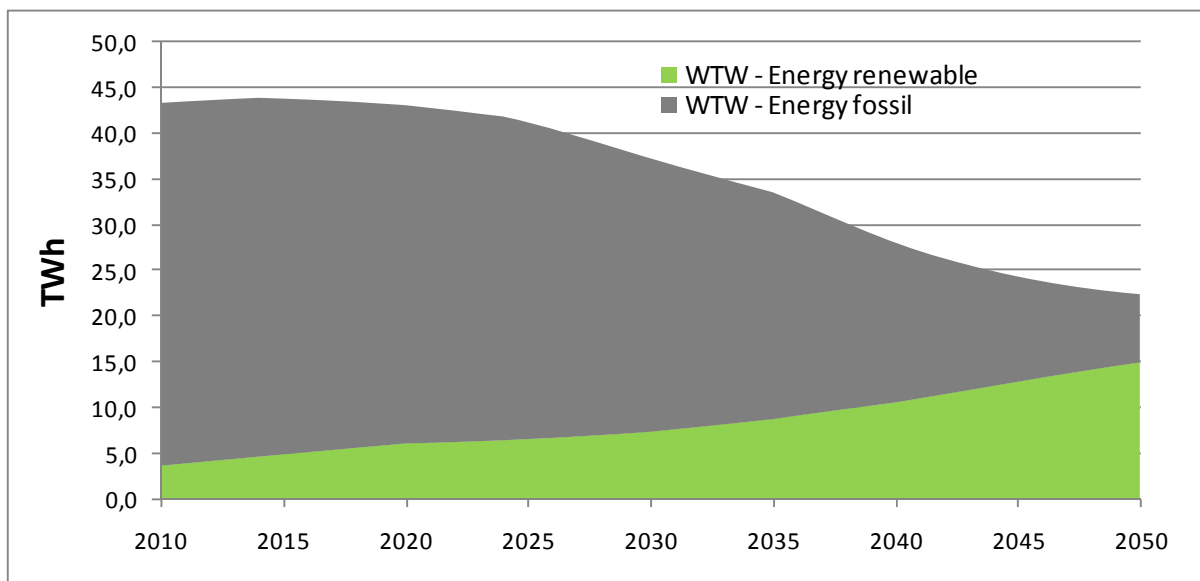
**Figure 19: Well-to-wheel energy demand - Scenario D**

In **Figure 20** the WTW greenhouse gas (GHG) emissions of the sector are depicted for scenario D. One can see that similar to the energy consumption there is also a strong decrease of GHG emissions. In this chart one can see that the emissions that come from electricity production increase steadily towards the end of the period. In this chart a fossil pathway of electricity production (gas & steam plants) was assumed. Even in und this assumption the GHG emissions can be reduced considerably.



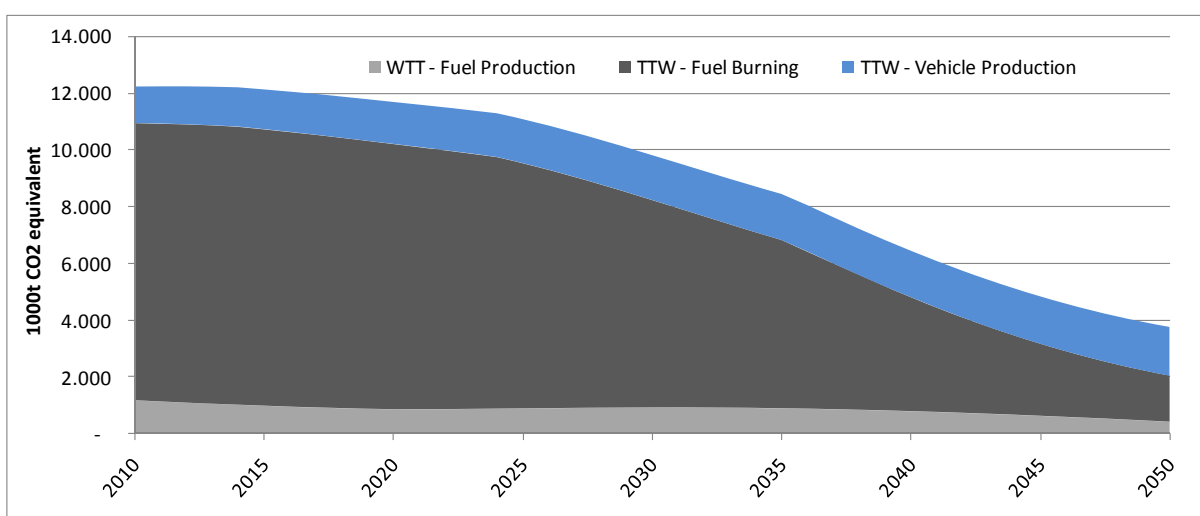
**Figure 20: Well-to-Wheel (WTW) greenhouse gas emissions – Scenario D**

Assuming that the electricity supply for electric vehicles would be shifted from fossil to renewable sources up to 2050 the fossil share of the energy supply can be reduced by more than 80% (**Figure 21**).



**Figure 21: Well-to-wheel energy demand - Scenario D - Renewable Electricity**

The WTW- greenhouse gas emissions of Scenario D with renewable energy supply are depicted in **Figure 22**. Through the almost emission neutral renewable electricity production the GHG emissions can be reduced by almost 70% up to 2050.



**Figure 22: Well-to-Wheel (WTW) greenhouse gas emissions – Scenario D – Renewable Electricity**

The Results indicate that generally the diffusion of electrified vehicles is quite robust. Taking a closer look it can be noticed that diffusion of vehicles with higher degrees of electrification (e.g. serial hybrids or pure electric vehicles) vary strongly in different scenarios. In particular political framework conditions can have significant effects on the diffusion of electric vehicles. Due to the high investment cost of such types of vehicles they can only compete under favourable framework conditions especially in the short run.

On a long term electrification of the passenger vehicle fleet can cause a major shift in energy demand of the entire sector. On short to medium term liquid hydrocarbons remain the main energy carriers for the sector.

## 4. Conclusions

The main conclusions of this analysis are:

- Electrification of vehicles is about to considerably gain market share within the next years in all Scenarios. Especially micro and mild hybrid configurations become a standard technology in the near- to medium-term. They can be seen as a logical step in automotive development to increase overall vehicles efficiency while keeping the internal combustion engine as the main propulsion component and liquid fossil fuel the standard energy carrier. Their potential of reducing the energy demand and the greenhouse gas emissions of the vehicle fleet however are limited.
- In order to reduce energy demand and emissions more considerably, vehicles with higher degrees of electrification such as Plug-In Hybrids and Electric Vehicles are required. To promote the diffusion of those types of vehicles in a short term strong political measures are necessary. Their long term performance will highly depend on the technological development and the costs of batteries, representing the key component of those vehicles. This technological progress of battery technology will be strongly affected by the short term performance of electrified vehicles due to technology learning effects. Furthermore higher taxation of individual motorised transport effects a stabilisation of the vehicle stock on the level of 2010 facilitating reductions in overall energy consumption and greenhouse gas emissions through the employment of efficient propulsion technologies.
- Regarding the potential electricity consumption of the vehicle fleet in different scenarios it turns out that the increase in overall demand is practically negligible in the short term. In the medium to long term they only cause a slow rise of overall electricity consumption over a long period leaving electricity producers enough time to adapt their capacities.
- When having high shares of electricity in the supply mix for the vehicle fleet the source of electricity becomes more and more important. Even with natural based fossil pathways the (Gas & steam plants) the greenhouse gas (GHG) emissions can be reduced considerably. With a 100% renewable electricity supply the GHG emissions of the vehicle sector can be reduced by almost 70%.

## References

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