The prospects of alternative automotive systems and fuels in Austria till 2050

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Abstract

The objective of this paper is to analyse the prospects of alternative automotive systems and fuels (AMF) in Austria in a dynamic framework up to 2050. In detail the cost development of AMF, environmental aspects and promotion or other policy strategies necessary for a wider use of alternative automotive concepts and alternative fuels in individual passenger transport will be analysed.

The core objective is to analyse if and under which policy and/or market conditions, to what extent and when AMF will become economically attractive in Austria in the long run and may contribute significantly to providing the service individual mobility. To meet this objective different scenarios are derived.

The method of approach is based on a dynamic energy economic analysis of AMF in comparison with conventional technologies and fuels.

The major results are: The first-generation biofuels could be competitive with conventional fuels only with policy support. Biodiesel and bioethanol should be replaced by more efficient and more environmentally benign second-generation biofuels starting from 2025. Other conceivable alternative fuels in the long term are biogas and hydrogen. Regarding automotive systems conventional vehicles will be almost completely replaced by hybrid and E-cars by 2050. Hydrogen vehicles may not achieve significant market penetration until 2040. In order to achieve long-term transition toward sustainable transport system, it is necessary to promote a combination of new, lower-emissions fuels, alternative vehicles with better system efficiency and a comprehensive package of regulatory standards and fiscal policies as soon as possible.

Introduction

The problems, which are currently accompanying the use of energy for providing individual automotive mobility such as growing consumption of fossil fuels and straightforward increasing greenhouse gas emissions, growing import dependency especially from politically unstable countries and a low energy conversion efficiency of cars could be solved or at least reduced using alternative automotive concepts and alternative fuels (AMF).

The most important alternative motive concepts discussed are: fuel cell vehicles, electric vehicles, hybrid systems and systems based on natural gas or biogas. The most important discussed new energy carriers are: bioethanol, biogas, biodiesel, hydrogen from renewable energy sources, synthetic fuels and electricity. If and to what extent these alternative concepts will become relevant in the future is still under discussion and subject to comprehensive research.

This paper focuses on analysis of prospects of alternative automotive systems and alternative fuels in a dynamic framework. Cost development of AMF, environmental aspects and promotion or other policy strategies necessary for a wider use of alternative automotive concepts and alternative fuels in individual passenger transport will be analysed in detail.

The core objective is to analyse if and under which policy and/or market conditions, to what extent and when alternative automotive technologies and fuels will become economically attractive in Austria in the long run (up to 2050) and may con-

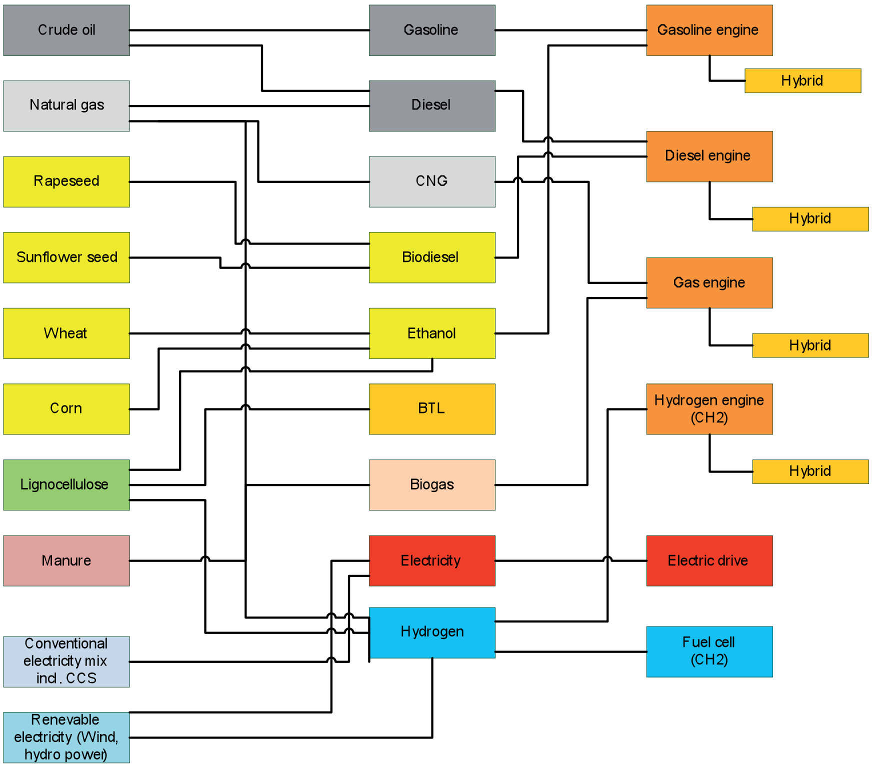

Figure 1: Well to wheel energy conversion chains

tribute significantly to providing the service individual mobility. To meet this objective two different scenarios are proposed.

Method

In this paper different energy conversion chains from well to wheel (WTW) are analysed from economic point of view. Figure **1** shows all analysed chains of automotive systems and fuels. The most important currently discussed alternatives for conventional fossil fuels are biofuels first and second generation, hydrogen from renewable energy sources (RES) and electricity. With respect to electricity, two types are considered: A conventional electricity mix and an electricity mix from RES – wind and hydro power. In the future price of the conventional electricity mix carbon capture and storage (CCS) is included. Besides alternative fuels some new, more efficient alternative automotive concepts are also required such as fuel cell vehicles, electric vehicles, hybrid systems and systems based on natural gas or biogas.

To make different automotive systems comparable it was necessary to define a reference vehicle with determined service parameters such as power and operating range. The reference vehicle's power and weight data are comparable to a European compact class car (power – 75 kW, weight – 1470 kg). It was assumed that all analysed vehicles offer the same service to user[1].

The method is based on a dynamic energy economic analysis of the AMF in comparison with conventional technologies and fuels. The economics is influenced in various scenarios by different type of policy measures.

The most important parameters that are considered in this analysis are: historical and current energy demand in transport sector in Austria, historical yearly new car registration for describing the car stock, fossil fuel price, specific fuel consumption, tax incentives for more efficient and alternative vehicles and alternative fuels, other current transport-related policies and measures and the goals of the Austrian Government.

To assess the long term perspectives of AMF in the individual transport sector it is important to consider the following impact parameter:

- possible developments of the energy price level (scenarios of the oil price);
- changes in demand for mobility;
- the international developments of different technologies with respect to "learning" (technical efficiency improvements and cost reductions) are considered;
- possible changes of environmental, energy and transport policy conditions (taxes, subsidies…).

The most important energy policy instruments investigated in scenarios are:

- Tax on gasoline and diesel and tax (exemptions) on biofuels and hydrogen;
- Motor vehicle tax;

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[1] In this work non-equal service level per car is included at least indirectly by using a quota for Zero-emission vehicles in cities. That is to say vehicles with lower travelling distances are squeezed into the market! E.g. it could be the case that 35% of the buyers would need a car with a radius of action of at least 150 km.

- NOVA (The tax on acquisition in Austria – named NOVA – is depending on the fuel consumption and the CO2 emission of the vehicle and offers an extra bonus for alternative vehicles);
- Quota (rate of sales).

Dynamic economic analysis

The method is based on a dynamic energy economic analysis (incl. fuel costs and investment costs) of the AMF in comparison with conventional technologies and fuels (Ajanovic, 2008a). In the future it is expected that the investment costs of all new technologies could be reduced through the learning effects. Future costs are generally based on the assumption that critical technology development programs will be successful. Some possible cost reductions of alternative automotive systems are described in this paper.

Technological learning can be illustrated by so-called experience or learning curves, and the usual formula to express an experience curve is using an exponential regression:

$$IC(x(t)) = a \cdot x(t)^{-b} \qquad (1)$$

Where:

IC(x(t)): Investment cost per unit car
x: Cumulative capacity
b: Learning index
a: Specific cost of the first unit

The analysed alternative automotive systems are in a different stage of development, so that total vehicle costs can be divided in two parts. One part is conventional part of vehicle which is very similar by all cars, e.g. chassis, seats, tires. All these parts are very mature so that no further significant learning effects can not be expected.

It is assumed that the basic structure of cars, except the power-train components, is similar for all technologies (JRC, 2007). On the one hand, in the future better and lighter materials for cars will be used, which can reduce the required rated power and consequently the costs of cars. On the other hand, due to the increasing amount of services in cars (e.g. air condition and electronic devices) cost increases occur, so that all in all the cost of basic car parts could be the same in the future.

Another part of the total investment costs consists of innovative parts, e.g. fuel cell, hydrogen storage tank, and battery. In this case considerable learning effects are possible.

$$IC(x(t)) = IC_{CON}(x(t)) + IC_{INNOV}(x(t)) \qquad (2)$$

Where:

IC_{CON}: Investment costs for the conventional part of vehicle (no learning effect)
IC_{INNOV}: Investment costs for the innovative part of vehicle (learning rate 20%).

The starting point is the fact that consumers do not demand energy (fuel) per se but energy services (mobility). The total transport costs are dependent on the fuel cost and investments costs for vehicles:

$$TC = FC + IC_{sp} \qquad (3)$$

Where:

TC: Transport cost (Euro/km)
FC: Fuel cost (Euro/km)
IC_{sp}: Specific investment costs for vehicle (Euro/km)

For the calculation of the fuel costs (Euro/km) two factors are relevant: the energy efficiency of the vehicle and fuel price. The current efficiency of motor vehicles for passenger transport is relatively low. The efficiency of the state-of-the-art gasoline vehicle in the test cycle (NEDC) is between 20% and 22% (Haas et al, 2008). Diesel vehicles have a slightly higher efficiency, about 25%. This low efficiency can be significantly improved by applying alternative power train technology, see Figure 2.

For conventional technologies the future efficiency improvements are assumed: For diesel cars 7% and for gasoline cars 13%. Fuel cell vehicles have already high efficiency about 55%, which could increase to 70% until 2050.

The fuel cost per passenger kilometre is calculated as follows:

$$FC = EC \cdot FP \qquad (4)$$

Where:

EC: Energy consumption (kWh/km)
FP: Fuel price at the refuelling station (EUR/kWh)

The total annual specific investment costs for vehicles are calculated as follows:

$$IC_{sp} = (\alpha \cdot (IC + NOVA) \cdot (1 + VAT)) / D_{km} \qquad (5)$$

Where:

α: Capital recovery factor (-)
IC_{sp}: Specific investment costs for vehicle (Euro/km)
NOVA: Tax on acquisition (Euro)
VAT : Value added tax
D_{km}: The annual number of kilometres driven per year (km)

The basic data for cost calculations are power (75 kW), annual kilometres driven (15.000 km), average vehicle life time (14 years) and interest rate (7%) (see Ajanovic,2008b; Haas, 2008; Jungmeier, 2006).

However, total transport costs in Euro per kilometres-driven are the crucial factor for the consumer decision. It is assumed that there are different levels of willingness-to-pay (WTP) among the consumers, see Figure ***3***. There are also consumers who are ready to pay for advanced vehicle technology, which is environmentally benign even if it is not the best economic option. That is why the best economic option never gains 100% market share.

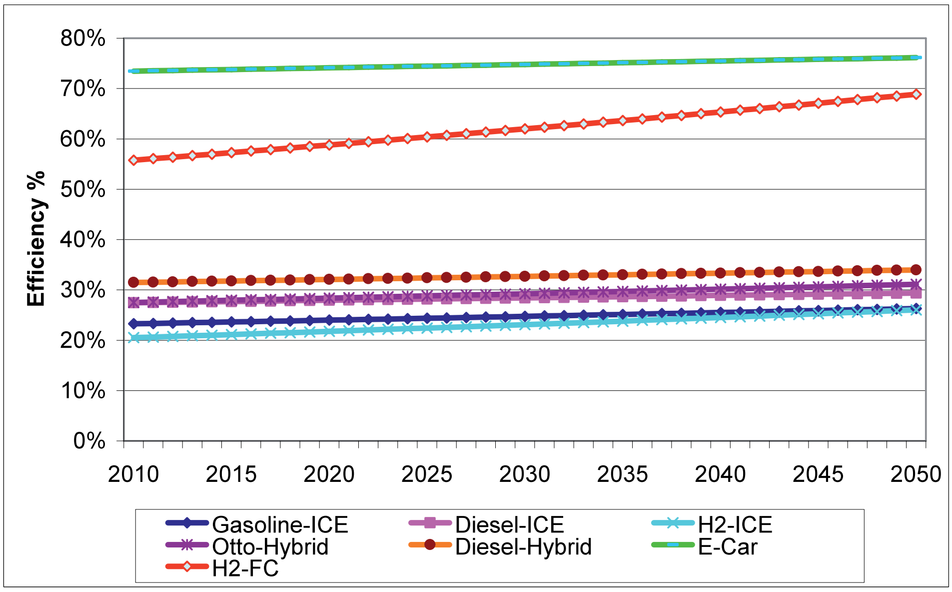


Figure 2: Assumptions on the development of efficiency of the analysed vehicles 2010-2050 (Source: AVL)

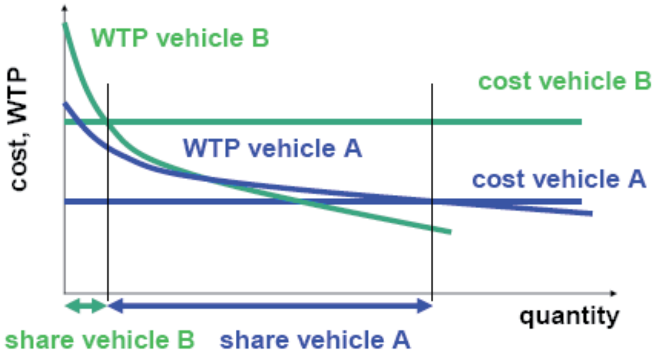


Figure 3: Different levels of willingness-to-pay (WTP)

Economic parameters

The yearly sale of new vehicles is modelled depending on the development of the fuel costs, investment costs and GDP. This development is linked to the annual vehicle demand by the elasticity of fuels price ε_{FP}, elasticity of vehicle price ε_{IC} and income elasticity ε_{y}. These elasticities have been derived from econometric time series analyses.

$$Z_{t+1} = Z_t \cdot \left(\frac{FP_{t+1}}{FP_t}\right)^{\varepsilon_{FP}} \left(\frac{IC_t}{IC_{t+1}}\right)^{\varepsilon_{IC}} \cdot \left(\frac{GDP_{t+1}}{GDP_t}\right)^{\varepsilon_{\gamma}} \qquad (6)$$

$\varepsilon_{FP} = -0.5$

$\varepsilon_{IC} = 1$

$\varepsilon_{\gamma} = 0.8$

Where:

Z: Vehicle sales per year
FP: Fuel price
IC : Investment cost
GDP: Gross domestic product

Modelling policy effects in scenarios

Depending on the applied policy measures and the future development of the oil price two scenarios are analysed in this paper:

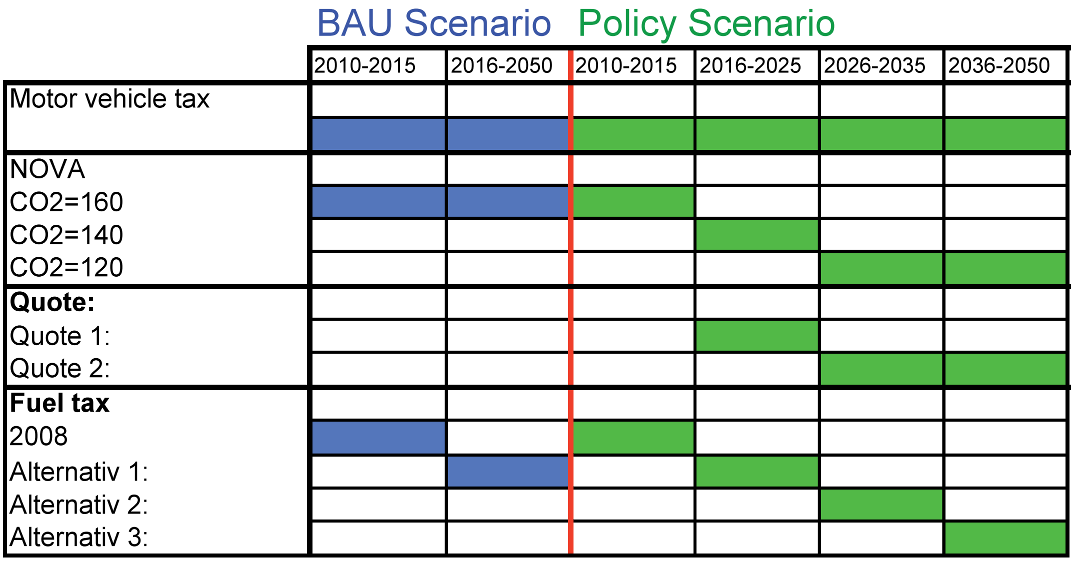
1. BAU-Scenario: Low oil price and business as usual policy
2. Policy-Scenario: High oil price and more active policy.

In the case of "Low oil price" moderate increase in oil price has been assumed. According to this scenario in 2050 the diesel price will be 0.05 Euro/kWh and the gasoline price 0.056 Euro/kWh. In a "High oil price" scenario oil prices are approximately 40% higher than in the "Low oil price" scenario.

With respect to energy policies the impact of different fiscal policy categories such as fuel taxes, vehicle taxes and new vehicle tax incentives have been analysed as well as efficiency and CO_2 consumption standards, see Table 1.

As shown in Table 1, it is modelled that fuel taxes are gradually increasing over time. In BAU scenario after 2015 all biofuels will be taxed, but relatively low comparing to conventional fossil fuels. It is assumed that the range of the biofuels-taxes lies between 0.03 Euro/kWh and 0.05 Euro/kWh. In this scenario,

Table 1: Transport policy instruments



	BAU Scenario		Policy Scenario			
	2010-2015	2016-2050	2010-2015	2016-2025	2026-2035	2036-2050
Motor vehicle tax						
	🟦	🟦	🟩	🟩	🟩	🟩
NOVA						
CO2=160	🟦	🟦	🟩			
CO2=140				🟩		
CO2=120					🟩	🟩
Quote:						
Quote 1:				🟩		
Quote 2:					🟩	🟩
Fuel tax						
2008	🟦		🟩			
Alternativ 1:		🟦		🟩		
Alternativ 2:					🟩	
Alternativ 3:						🟩

between 2016 and 2050, only hydrogen and electricity are assumed without fuel tax. In Policy scenario till 2050 all alternative fuels will be taxed. The range of the tax in 2050 in this case will be between 0.06 Euro/kWh and 0.08Euro/kWh.

In the Policy scenario it is also assumed that, starting from 2016, 25% of all new vehicles must have an alternative automotive system. In the first stage, from 2016 to 2025, all alternative vehicles are included in this quota. In the second stage, from 2026 to 2050, this quota includes only electro and hydrogen vehicles.

Results

BAU-SCENARIO: LOW OIL PRICE AND BUSINESS AS USUAL POLICY

Development of total transport costs in BAU scenario, with the moderate increase of oil price and business as usual policy, is shown in Figure 4. In this scenario it is assumed that alternative fuels will be exempted from taxes until 2015. The investment costs of the vehicles have a big influence on the overall transport costs per kilometre. Currently, fuel cells and hydrogen vehicles are new and very expensive technologies. Through learning, sharing of experience and reducing the risk of adoption of the new technology, costs can be decreased and technical characteristics can be improved in order to reach competitiveness. Due to higher efficiencies of the fuel cell vehicles and the reduction of the investment costs per vehicle due to technological learning, these vehicles could be an interesting option in the long term, starting from 2040.

The share of investment and fuel costs in the total transport costs for some analysed AMF are shown in Figure 5. It is obvious that investment cost for vehicle has the largest impact on the total transport costs.

In Figure 6 a clear shift from conventional drive systems to alternative ones is shown. In a short to medium term the hybrid vehicles will massively gain market share becoming the dominant technology, starting from about 2025. The number of electric vehicles will be rapidly increasing starting from 2030, while hydrogen vehicles may not achieve significant market penetration until 2050.

In this scenario total vehicle stock will increase to approximately 5.5 million vehicles till 2050.

Already in the BAU scenario, due to higher vehicle efficiency, the energy consumption in the individual road transport sector is decreasing. In the first decades fossil fuels remain the most important energy source of the sector. In the medium to long term the fuel mix experiences a strong diversification of fuel sources with biofuels and electricity attaining importance, see Figure 7.

Due to the increasing share of AMF in individual road transport total greenhouse gas emissions could be significantly reduced starting from 2025. In 2050 in BAU scenario WTW greenhouse gas emissions could be reduced for about 5 Mil ton CO_2-equivalent, Figure 8.

POLICY SCENARIO: HIGH OIL PRICE AND AMBITIOUS POLICY

Policy scenario is scenario with the high increase of oil price and more active transport policy with different instruments such as fuel and motor vehicle tax, the standard fuel consumption tax (NoVa) and transport quotas. In this scenario NOVA is higher comparing to the BAU scenario so that investment costs are also a little bit higher. Here it is assumed that all alternative fuels will be taxed till 2050.

Development of the total transport cost in the Policy scenario is shown in Figure 9. The range of travel costs in a long term in this scenario lies mostly between 0.27 Euro/km and 0.34 Euro/km. Only exceptions are travel costs of hydrogen vehicles with internal combustion engine (ICE). These vehicles have low efficiency comparing to fuel cell vehicles so that impact of the high fuel price – hydrogen price – is obvious. Starting from about 2040 fuel cell vehicles could be competitive with other automotive systems on the market. In a long term the best option considering total transport costs are Otto-motors powered by ethanol from ligno-cellulosic materials.

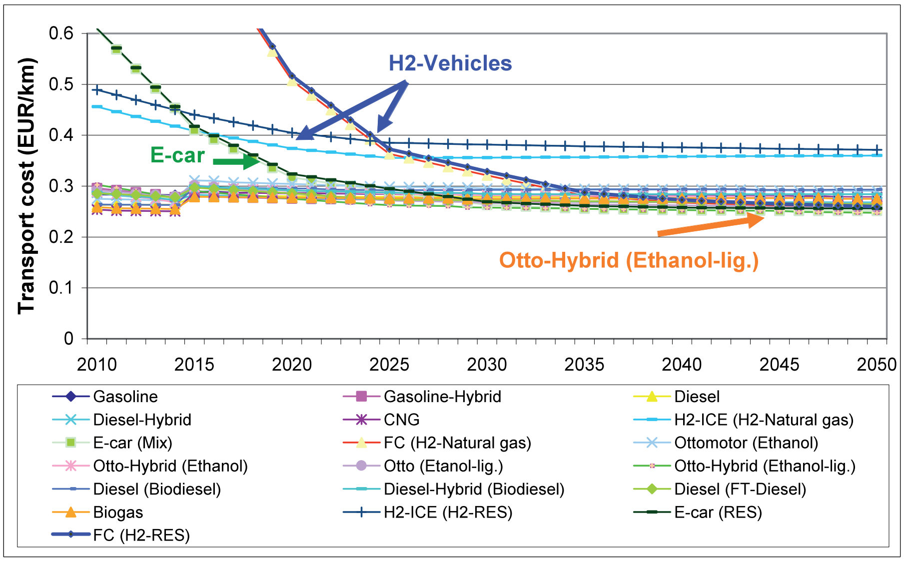


Figure 4: BAU-Scenario: Development of total transport cost (2010-2050)

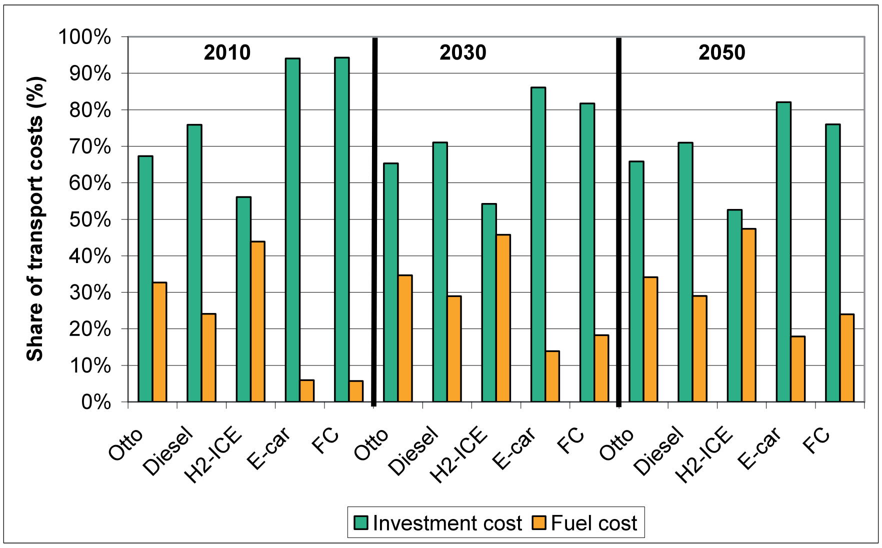


Figure 5: Share of investment and fuel cost on total transport costs in BAU-Scenario

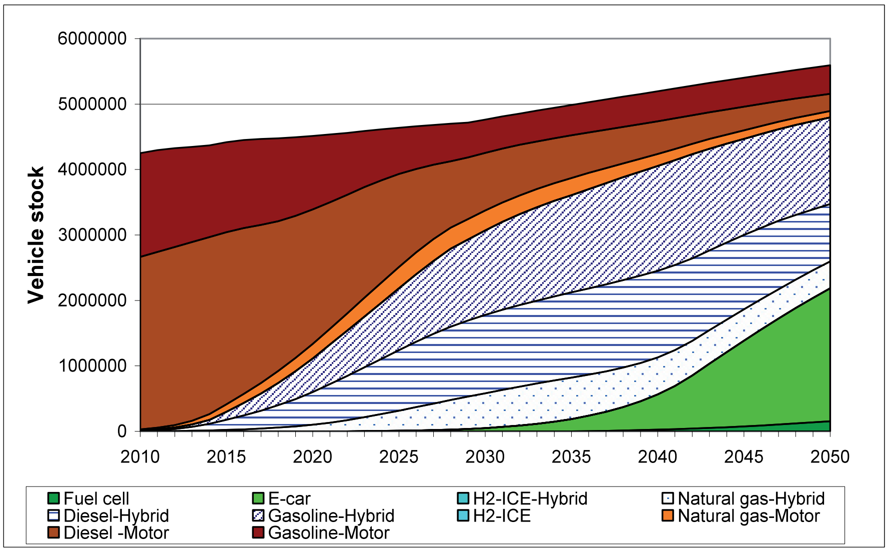


Figure 6: BAU-Scenario: Distribution of overall vehicle stock broken down by vehicle technologies

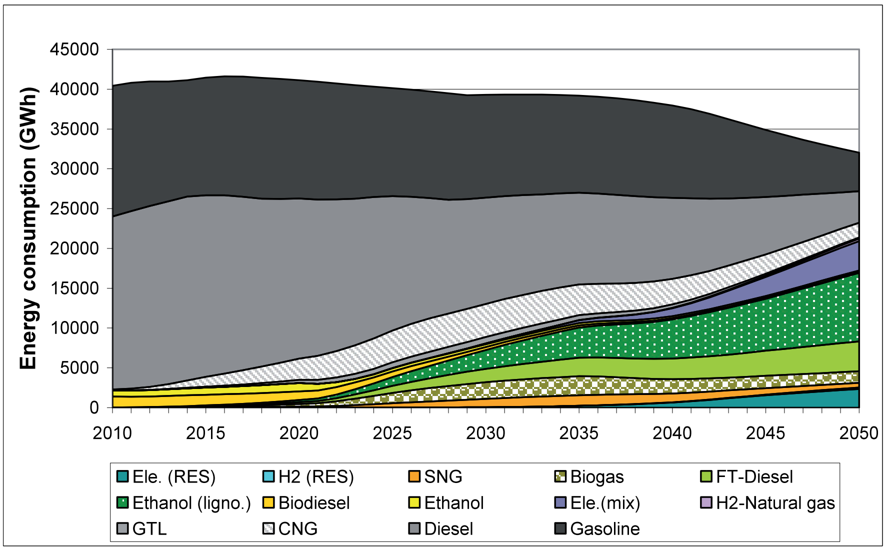


Figure 7: Scenario BAU – Energy consumption

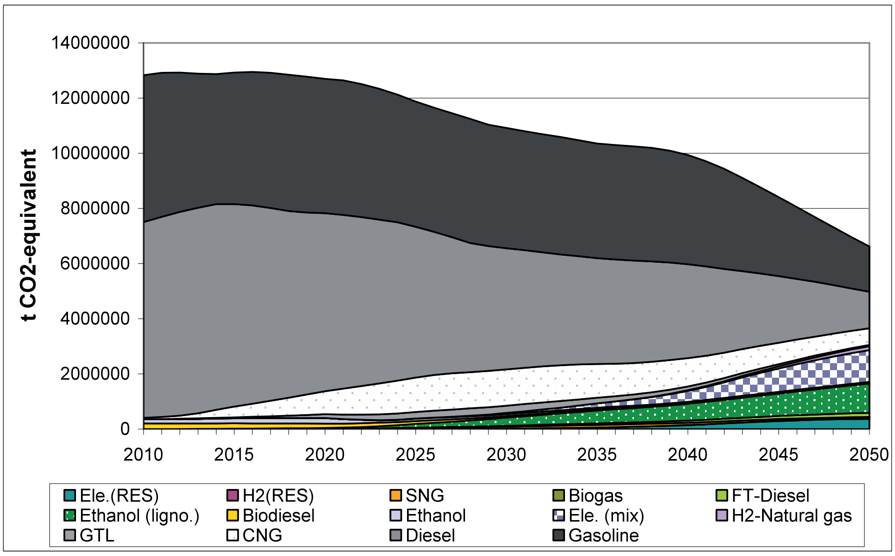


Figure 8: BAU-Scenario: WTW greenhouse gas emissions

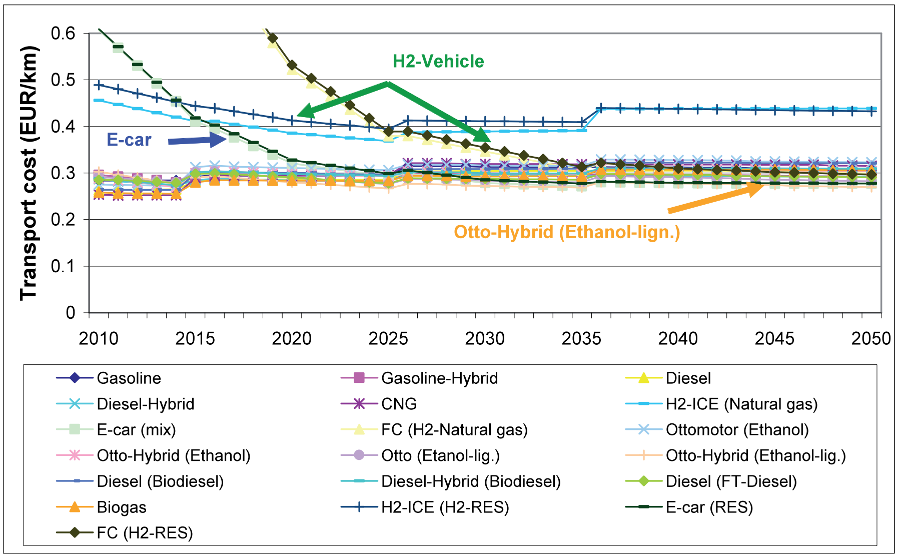


Figure 9: Policy Scenario: Development of total transport cost (2010-2050)

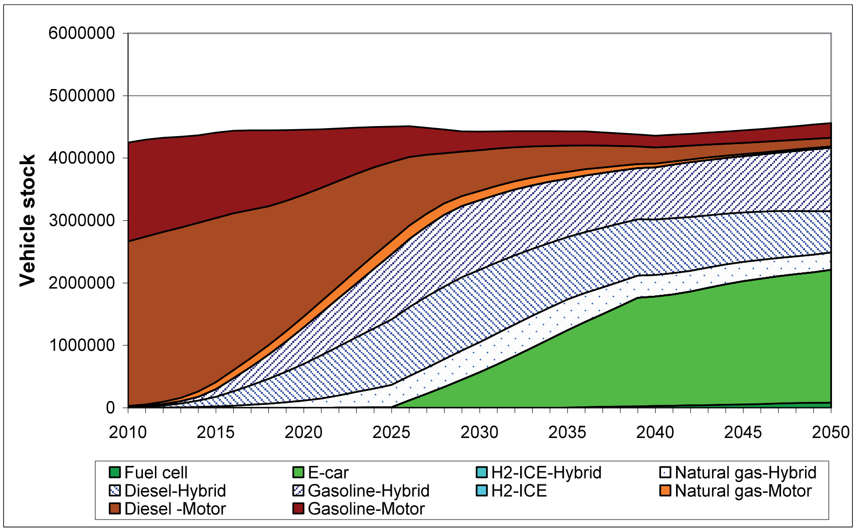


Figure 10: Policy Scenario: Distribution of overall vehicle stock broken down by vehicle technologies

Due to the additional tax on fuels and vehicles, in scenario with more active policy total transport costs are higher then in the scenario with business as usual politic. At the same time these additional policy measures have an impact on a total vehicle stock and share of different technologies. As shown in Figure **10**, in case of an active policy the vehicle stock in 2050 could count about 1 million vehicles less than in the BAU scenario.

The reduction in the total vehicle stock and increasing share of alternative more efficient automotive systems and fuels have also impact on the total energy consumption. With the more active transport policy total energy consumption in individual road transport can be reduced to 24 TWh until 2050, see Figure 11.

With the decreasing energy consumption in individual road transport WTW greenhouse gas emissions could be in 2050 for 70% lower than in 2010, see Figure 12.

Conclusions

The major conclusions of this analysis are:

- In a BAU-scenario with fuel prices increasing only moderately the stock of vehicles is increasing continuously and the major effect is a strong "hybridisation" of vehicles.
- In a scenario with high oil price and an ambitions introduction of "green" policies the total stock of vehicles stagnates or is even slightly decreasing and electric cars gain significant market shares already from 2030.
- Yet, a major characteristic of all investigated scenarios is that the manifold of propulsion systems as well as of fuels increases significantly.
- The higher decrease in energy consumption and a reduction of the vehicles stock can be achieved only if appropriate accompanying policies are implemented.

In order to achieve long-term transition to sustainable transport system, it is necessary to take certain actions as soon as possible. That can be possible with combination of new, lower -emissions fuels, alternative vehicles with better system efficiency and a comprehensive package of regulatory standards and fiscal policies.

In the scope of this work we have tried to provide evidence for policy makers which policy strategies in transport can bring fossil energy and CO_2 reduction at lowest costs and give recommendations for priority setting in technology R&D for heading towards a sustainable automotive transport system in Austria.

References

Haas, 2008: R. Haas, A. Ajanovic, M. Kloess, G. Jungmeir, K.Könighofer, P.Preninger, J.Rechberger:" Szenarien der (volks) wirtschaftlichen Machbarkeit alternativer Antriebssysteme und Kraftstoffe im Bereich des individuellen Verkehrs bis 2050 – ALTANKRA" Final Report, 2008

Ajanovic, 2008a: A. Ajanovic: "On the economics of hydrogen from renewable energy sources as an alternative fuel in transport sector in Austria", International Journal of Hydrogen Energy 33 (2008) 4223-4234, 2008

Jungmeir, 2006: G. Jungmeier, K.Könighofer, A. Ajanovic, R.Haas: „Wasserstoff aus erneuerbarer Energie in Österreich – Ein Energieträger der Zukunft?", Graz, 2006

JRC, 2007: "Well-to-wheel analysis of future automotive fuels and powertrains in the European context", JRC, EUCAR, CONCAWE ,2007

Ajanovic, 2008b: A. Ajanovic, R.Haas: "On modeling the impact of fuel prices and income on service and energy demand in individual transport in Austria – Evidence from the period 1970-2006", International Energy Workshop, IEA, Paris, 30 June – 2 July 2008

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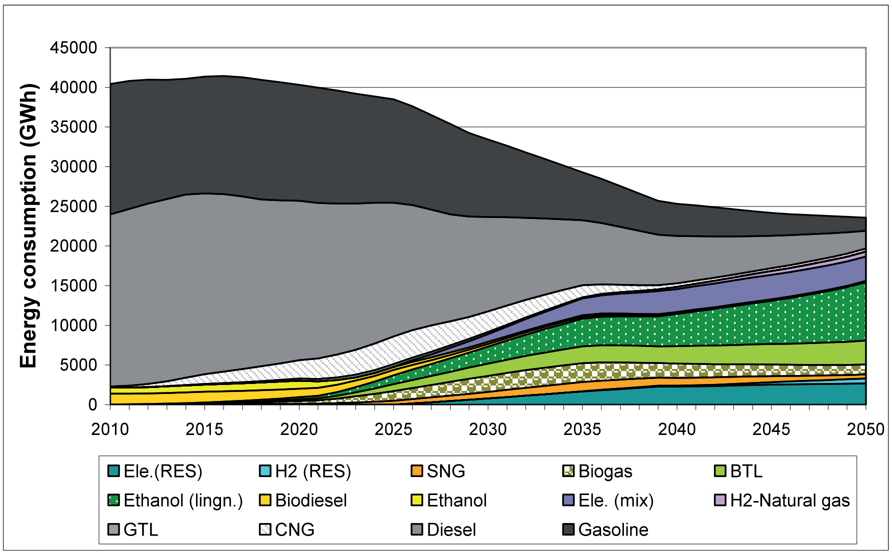

Figure 11: Policy Scenario: Energy consumption

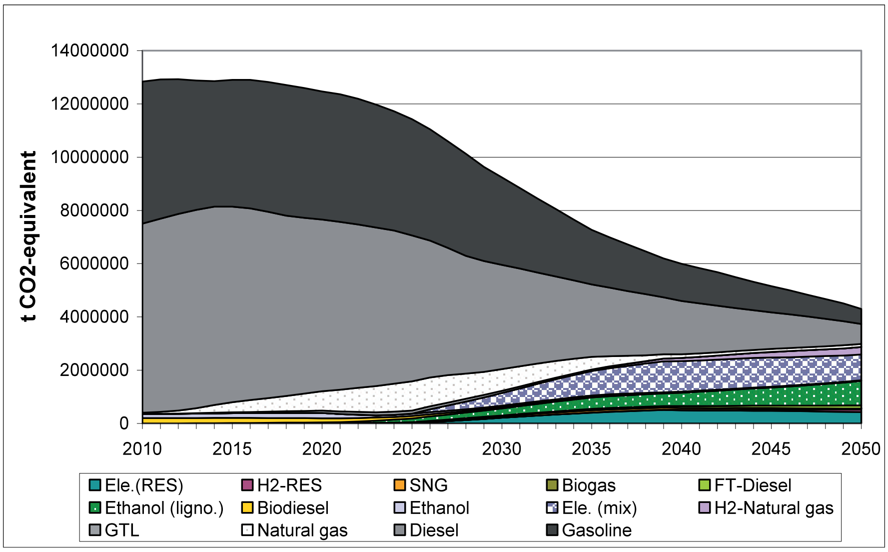

Figure 12: Policy Scenario: WTW Greenhouse gas emissions