Powertrain Scenarios for Cars in European Markets to the Year 2040

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Summary

Dramatic changes in the market for car powertrains seem possible in the near future. Triggered by the need of significant CO_2 reduction in the transport sector according to COP21 (Paris) or air quality problems in European cities, the introduction of more and more electrified powertrains appears necessary. In order to analyze ways to reduce CO_2-emissions from cars and especially the competition between various efficiency technologies, alternative powertrains, and fuels, the vehicle technologies scenario model VECTOR21 is used in different scenario simulations. Results for two recently modelled pathways for Germany show a continuous market penetration of electrified powertrains such as full hybrids and plug-in electric vehicles. A review of our recent VECTOR21 scenarios shows that in 2040, the final energy demand in liquid fuel products is reduced by 45% on average. Furthermore, we give insights in detailed analysis of the total cost of ownership in European countries like UK, NL, DE and ES for different type of car fleets. And we discuss consequences of different scenarios in terms of mobility costs, CO_2-reduction in vehicle stock, etc.

1. Introduction

Dramatic changes in the market for car powertrains seem possible in the near future. Triggered by the need of significant CO_2 reduction in the transport sector according to COP21 (Paris) or air quality problems in European cities, the introduction of more and more electrified powertrains appears necessary. There are also examples of statements to impose regulations which solely allow the registration of “zero emission” powertrains starting from 2030. In order to analyze ways to reduce CO_2-emissions from cars and especially the competition between various efficiency technologies, alternative powertrains, and fuels, the vehicle technologies scenario model VECTOR21 is used in different scenario simulations. The model is shortly introduced in the second section. In the third section, the results of two recent simulations of the German car market are shown. Additionally, a review of recent simulation results is discussed with a focus on the vehicle fleet’s final energy demand. The shown VECTOR21 modelling approach is cost driven. A comparison of the cost of ownership of electric vehicles across European markets, gives an insight in their current economic feasibility.

2. VECTOR21 - a technology-driven scenario model for vehicle markets

In order to analyse pathways to reduce CO_2-emissions from cars and the competition between various efficiency technologies, alternative powertrains and fuels, the vehicle technologies scenario model VECTOR21 has been developed [1], [2]. VECTOR21 is a hybrid of an agent-based and discrete choice market penetration model that assesses the competition between different powertrain alternatives. It is used to model the effects of changing political and technological conditions on the prospective market shares of powertrain technologies. Furthermore, the model covers aspects like manufacturer strategies to comply with CO_2 regulation and the regulation’s influence on the vehicle stock. It incorporates various drivetrain technologies in three size segments (small, medium, large). Detailed technical characteristics, i.e. energy consumption, and costs of current and future vehicles are provided. Customer agents chose their new vehicle (Figure 1) matching vehicle costs, CO_2 emissions and available refueling- or recharging infrastructure to their preferences.

In recent years, the model was extended to cover the European (EU28) [3] and U.S. market [4] with their specific conditions. Amongst others, the extension comprises specific costs, customer characteristics (mileage, preferences towards alternative powertrains),

emission regulation, taxation systems and supply restrictions. The modelling of the European vehicle stock is based on the simulation results of the new vehicle fleet. The future evolution of a vehicle fleet is modelled based on market and segment specific survival and mileage degression curves [5]. This allows for a differentiated analysis with regards to vehicle mileage, age, segment and powertrain.
Additionally, different approaches can be used to model the customer purchase decision. Besides the cost-driven analysis (relevant cost of ownership), a utility-based approach is featured to model the market uptake of alternative powertrains [6], [7].

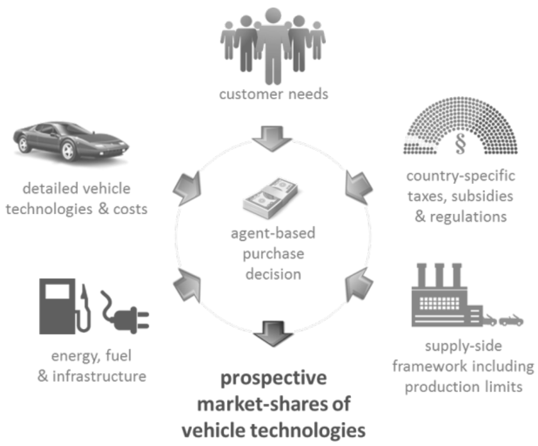

Figure 1: Model approach of vehicle technology scenario model VECTOR21[1]

3. VECTOR21 scenarios and lessons learned for fuel requirements

In the following we present recently updated scenarios for the German and the EU car market that illustrate possible pathways for the evolution of different powertrain market shares. We discuss the cost and utility development for electrified powertrains and how it varies across markets. Major drivers towards the electrification of the passenger car fleet are identified through a review of our scenario calculations. Additionally, implications for the energy sector regarding liquid fuels and electricity are shown.

3.1 Germany up to 2040 in two different scenario worlds

Embedded in a modelling framework to assess air quality and climate effects of transport[2], different scenarios for Germany up to the year 2040 were recently modelled with VECTOR21. To visualize model outcomes under different assumptions, two of them are presented in the following: A reference scenario and a scenario that depicts a “regulated shift”.

The reference scenario reflects an extrapolation of today’s situation. It considers a moderate development of existing technological, political and social trends. EU CO_2 targets for new passenger cars are moderately tightened to 75 g CO_2/km for the year 2030 and 65 g CO_2/km in 2040. The oil price increases moderately. Fuel, gas and electricity prices do not experience strong changes in their taxation schemes, resulting in moderate gasoline (1.70 EUR_{2010}/l in 2040) and diesel prices (1.60 EUR_{2010}/l in 2040). Charging and fueling infrastructure development is following foreseen quotas. Key components of alternative powertrains such as traction batteries are continuously improved concerning their technical characteristics and their production costs. Vehicle ownership rates per capita increase slightly so that the passenger car stock increases by about 8% in 2040 versus 2010.

In contrast to that, the “regulated shift” scenario is determined by policies aimed at a stringent climate protection and a strong mitigation of air pollution. Consequently, EU CO_2 limit values for new passenger cars are strongly decreased to 60 g CO_2/km in 2030 and 45 g CO_2/km in 2040. Taxes on conventional fuels are raised, resulting in gasoline and diesel prices greater than 2.40 EUR_{2010}/l in 2040. Charging infrastructure is built up to reach full coverage in 2040. Hydrogen fuel stations are made available countrywide. R&D funding is emphasized resulting in improved learning curves for key components of alternative powertrains. Vehicle ownership rates per capita see a decline, leading to a decrease in the total number of passenger cars of about 10% in 2040 versus 2010.

The resulting market development for new passenger cars following these two pathways is shown in Figure 2. In the reference scenario, conventional diesel (D) and gasoline (G) powertrains see a decrease in sales and are continuously substituted by full hybrid powertrains G-HEV, D-HEV). The latter make up for almost 70% of the sales in 2040, conventional diesel and gasoline powertrains play a negligible role. Around a third of all powertrains sold is electrified with an external plug, the majority (90%) being plug-in hybrids (PHEV).

Due to more ambitious CO_2 targets and high prices for fossil fuels, amongst others, new vehicle sales of conventional hybrid gasoline and diesel powertrains see a strong decline to a market share of 17% in 2040 in the “regulated shift” scenario. Here, more than 80% of the sales are electrified powertrains (of which 60% are PHEV, 33% are battery electric vehicles (BEV) and 7% are fuel-cell electric vehicles (FCEV)).

[1] www.vector21.de
[2] www.dlr.de/veu

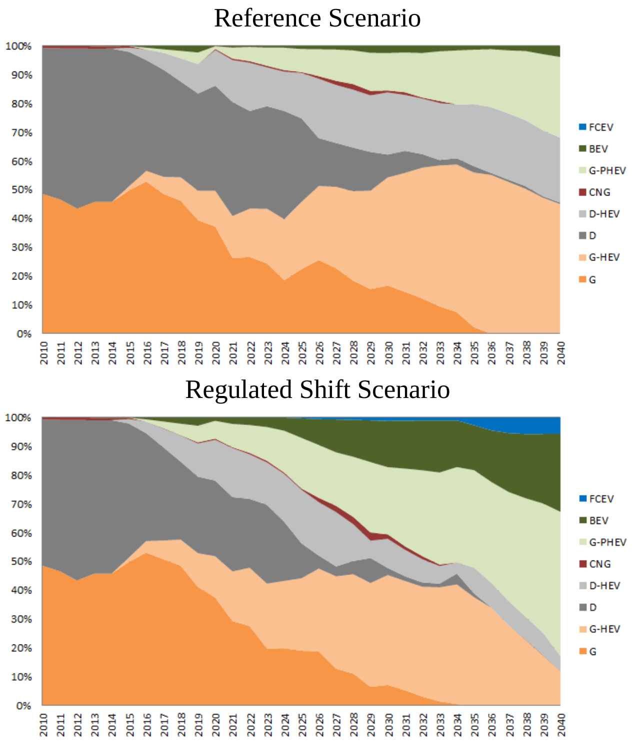

Figure 2: Results for the market development of new passenger cars in Germany in Reference (top) vs. “Regulated Shift” scenario (bottom) (own illustration)

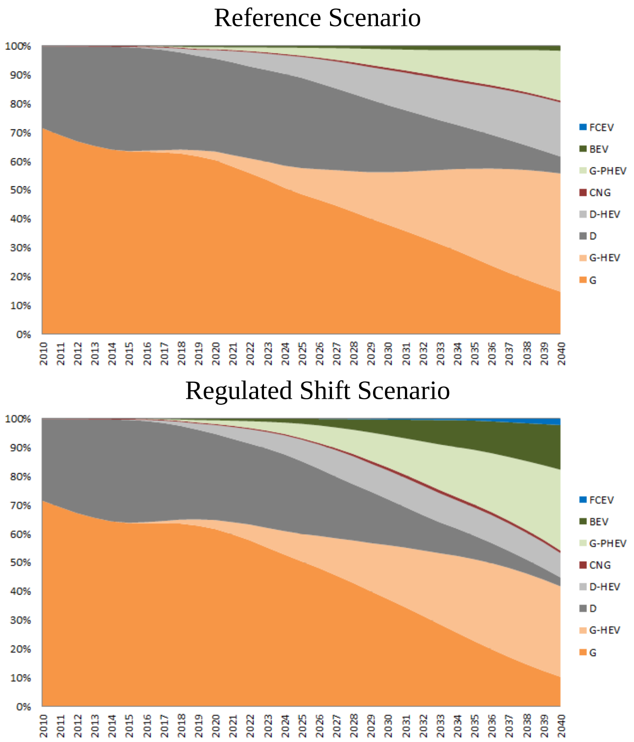

Figure 3: Results for passenger car stock in Reference (top) vs. “Regulated Shift” scenario (bottom) (own illustration)

Subsequently, these market developments change the vehicle stock (Figure 3), as older vehicles drop out and new technologies enter the fleet. In 2040 under the reference scenario, over 80% of the vehicle stock is gasoline and diesel driven, the majority being fully hybridized powertrains. Around 20% of the stock is made up of electrified powertrains, the vast majority being plug-in hybrids. Natural gas vehicles (CNG) sum up to around 1% of the stock.

In contrast to that, in 2040 under the “regulated shift” scenario, conventional powertrains make up for around 55% of the stock in Germany (Figure 3, bottom). The rest of the stock consists of PHEV (around 30%), BEV (15%), FCEV (2%) and CNG vehicles (<1%).

Following the stock turnover, the specific (Figure 4) and absolute energy consumption is decreasing. This is mainly due to the improvement of conventional powertrains. The specific energy consumption of gasoline cars decreases by 42% from 2010 to 2040 in the Reference scenario. That of diesel cars decreases by 30%. In the “Regulated Shift” scenario the fuel efficiency of conventional powertrains does not improve as much, due to the greater market shares of alternative powertrains. This effect is caused by the fleet CO_2 emission regulation. Higher sales of low emission vehicles like PHEV or BEV impose less pressure on the efficiency improvement of conventional powertrains.

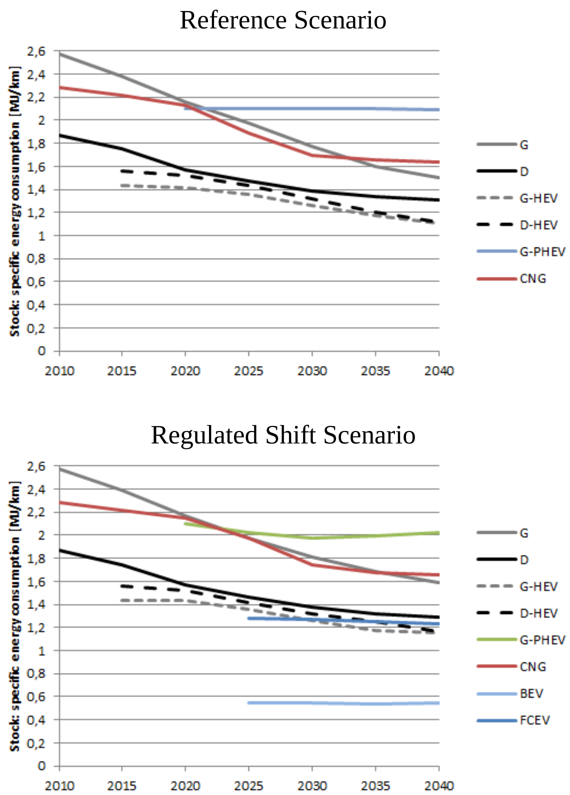

Figure 4: Average specific energy consumption in the vehicle stock in Reference (top) vs. “Regulated Shift” scenario (bottom) (own illustration)

Yet, the total energy demand (in liquid fuel products) decreases more in the "Regulated Shift" scenario. The difference amounts to 320 PJ for the year 2040.

3.2 European market scenario up to 2040

Simultaneously to Germany, market developments in the major European markets United Kingdom, France and Italy were simulated with VECTOR21 following a baseline pathway. For more methodological details on input parameters and model algorithm, refer to[3] and [5].

The share of powertrains for new passenger over time is depicted in Figure 5 as a sum over the four major EU markets Germany (32% share), United Kingdom (25%), France (22%) and Italy (21%). The share of conventional gasoline and diesel powertrains in 2010 over all major EU markets is similar to the shares in Germany in the same year. Due to moderately tightened EU CO_2 targets for new passenger cars towards 65 gCO_2/km in 2040, moderately increasing energy prices and charging/fueling infrastructure development and an ongoing techno-economic improvement of key EV components, the bonus-malus CO_2 emission-based system in France, conventional diesel (D) and gasoline (G) powertrains see a decrease in sales and are continuously substituted by full hybrid powertrains (G-HEV, D-HEV). The latter make up for more than 75% of the sales in 2040. 20% of all powertrains are electrified with an external plug, a third of them being battery electric vehicles (BEV). CNG powertrains are mainly sold in Italy, as CNG infrastructure is well developed and prices are comparatively low.

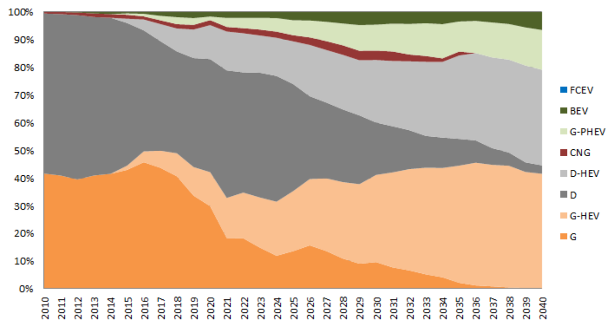

Figure 5: EU market development of new passenger cars in the "Reference scenario"

3.3 VECTOR21 results: A scenario review

Within the last years, several scenarios have been simulated with the VECTOR21 model depicting a variety of pathways for the market development of passenger cars. Each pathway results in a different vehicle stock composition, resulting in turn in a bandwidth of final energy consumption with regards to liquid fuels (Figure 6).

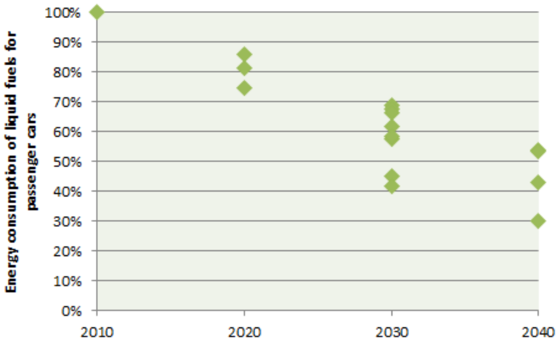

Figure 6: Review of different VECTOR21 scenarios: Final energy consumption of liquid fuels in the German stock in 2010-2040 ([3], [8], [9])

While in 2010, practically all passenger car powertrains were fossil fuel based, this share decreases over the years. VECTOR21 results show that in 2030, 40-70% of the final energy consumption for passenger cars will still be based on liquid fuels, depending on scenario assumptions. In 2040, the share of liquid fuels amounts to 30-55%- note that fewer scenarios have been simulated. Here, the gasoline price is assumed to reach 1.60 – 2.40 EUR_{2010}/l and the diesel price 1.50 – 2.50 EUR_{2010}/l). The total energy consumption of passenger cars amounted to 1,500 PJ in 2010 [10]. All scenarios show that the annual demand in gasoline and diesel from passenger cars in Germany decreases, even when a growth in transport performance is assumed. The average demand across scenarios is 740 PJ in 2030 and 608 PJ in 2040.

When assuming that a complete transition to a fully electrified car fleet is achieved by the year 2040, the final energy demand decreases significantly. This is due to the higher efficiency of electric powertrains. Thus, local pollution and noise caused by combustion engines is eliminated. Yet, the efficiency gain only has a positive impact on the CO_2 emission reduction, when the electricity production is based on renewable energy sources. Based on the average consumption of today's vehicles the tank-to-wheel efficiency can increase by 60%[3]. In the following it is assumed that today's final energy demand could be cut in half. The final energy demand of passenger cars in 2015 cumulated to 1,525 PJ [11]. Following the aforementioned assumptions, the final energy demand can be decreased to 763 PJ in 2040. In 2015, the share of renewable (gross) electricity production reached 29%, equaling 675 PJ [12]. Assuming that all other basic conditions remain the same, a complete transition in the energy sector towards renewable energy sources concludes in an annual energy production of 2,326 PJ per year. The addition of the vehicle fleet's electricity demand amounts to an annual renewable production of 3,089 PJ. Therefore, today's renewable electricity pro-

[3] Gasoline: 4.8 l/100km (NEDC), plus 30% markup for real-world consumption. BEV: 15.4 kWh/100km (NEDC), plus 40% markup.

duction has to be increased by the factor 2.4 in order to achieve a nearly zero-emission passenger car fleet.

4. Total costs of ownership for European markets

Within the project "Incentives for Cleaner Vehicles in Urban Europe" (I-CVUE)[4], an advanced model to calculate total costs of ownership (TCO) and vehicle utility was developed and made publicly accessible via a web-tool[5]. For the TCO calculations, purchase cost and resale values, profit tax reliefs, maintenance and repair cost, fuel and energy cost, motor vehicle taxes as well as purchase taxes and monetary incentives are considered. Additionally, cost due to range limitations are included for BEV, as well as all relevant national taxation and incentive schemes for Austria, Germany, Spain, the Netherlands and the United Kingdom. Furthermore, different vehicle segments and customer types, e.g. private customers or commercial fleet operators are taken into account. For more details on the methodology of the tool, refer to [7].

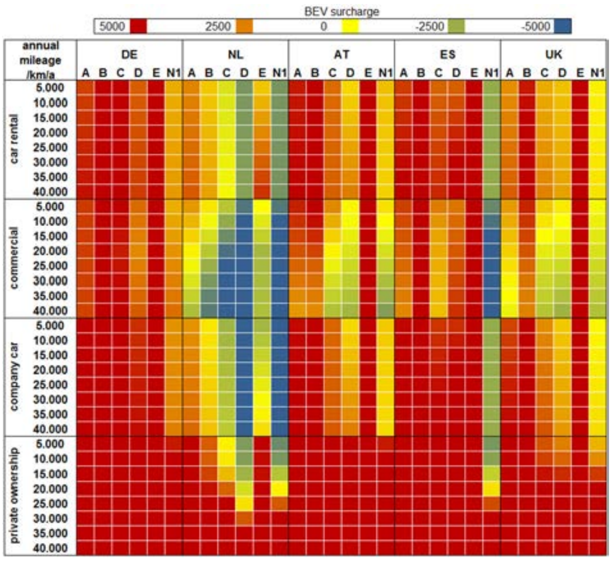

Figure 7: BEV surcharge in EUR$_{2016}$ compared to conventional vehicles (lowest TCO) [7]

The TCO analysis is based on 2016 market data and shows that in every country, with the exception of Germany, there is savings potential by replacing a conventional vehicle with a BEV (Figure 7). Here, blue to green fields indicate lower TCO for BEV, whereas red and orange fields mark lower TCO for conventional vehicles. Currently, the most favorable conditions for BEV can be found for commercial fleets in the Netherlands. There, electric vehicles profit from significant savings regarding registration tax and motor tax plus an above standard depreciation. It is clearly illustrated that the private ownership of a BEV is only economically viable for some segments in the Netherlands.

4 http://icvue.eu
5 http://dsm.icvue.eu

5. Conclusion

Our scenarios depict the variety of possible pathways of the powertrain market for passenger cars. Applying ambitious regulatory measures leads to a turnover of today's powertrain market. A reduction in a bandwidth of 46-70% in the use of fossil fuels can be achieved in Germany from 2010 to 2040. The current economic feasibility of electric vehicles does not seem to support an ambitious development. Across European markets, vehicle segments and usage types there is a substantial cost gap between conventional and electric powertrains. Exceptions from this situation can already be observed for commercial and company cars in the Netherlands and commercial light duty vehicles in Austria and Spain.

A transition towards a fully electrified passenger car fleet has a proximate effect on the demand in renewable electricity production. In order to reach greenhouse gas neutrality in Germany, as suggested by the Paris Climate Agreement, today's renewable energy production has to be increased by the factor 2.4. This offers an opportunity for alternative energy sources like synthetic fuels, given that they are less emission intensive than fossil fuels.

5. References

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