Report

Development of the car fleet in EU28+2 to achieve the Paris Agreement target to limit global warming to 1.5°C

20. September 2018

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Institute of Vehicle Concepts

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Institut für Fahrzeugkonzepte
Pfaffenwaldring 38-40
D-70569 Stuttgart

Head of Institute
Prof. H. E. Friedrich
Tel.: +49 (0)711/6862-256

Project leader
Bent van den Adel, M.Sc.
Tel.: +49 (0)711/6862-8287

Title	Development of the car fleet in EU28+2 to achieve the Paris Agreement target to limit global warming to 1.5°C		
Authors	Bent van den Adel (Bent.vandenAdel@dlr.de) Ulrike Kugler Stephan Schmid		
Project	GP-EU-CAR		
Commissioned by	Greenpeace Belgium Haachtsesteenweg 159, 1030 Brussel, Belgium		
File Name	20180907_GP_EUCarFleet_1.5.docx		
File Path	G:\41313-TBS\03-Projekte\3019795_GP-EU-CAR\Report		
Version No.	**Changes**	**No. of pages**	**Date**
1		23	12. September 2018

Written by (Date, Signature)	Checked (Date, Signature)	Approved (Date, Signature)
06.08.18	6.9.2018	08.08.18

DLR-FK-QM-VD-02-0-02

Contents

Figures

Tables

Glossary

a	Year
BEV	Battery Electric Vehicle
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CV	Conventional Vehicles
EU28	European Union (28 member states)
EU28+2	European Union (28 member states), Switzerland and Norway
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gas
Gt	Giga tons (10^9 Tons)
HEV	Hybrid Electric Vehicle
H_2	Hydrogen
ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
Mt	Mega Tons (10^6 Tons)
PHEV	Plug-in Hybrid electric Vehicle
Pkm	Passenger Kilometres
T	Ton
TtW	Tank-to-Wheel
UNFCCC	United Nations Framework Convention on Climate Change
Vkm	Vehicle Kilometres
TTW	Tank-to-Wheel
WTT	Well-to-Tank
ZEV	Zero emission vehicle

1. Introduction

This study explores how the passenger car market and stock in the EU28 plus Switzerland and Norway (EU28+2) has to develop, to ensure that the cumulated CO_2 emissions of the private mobility sector stay below the corresponding CO_2 budget to fulfil the Paris Treaty. Therefore, it is differentiated between a scenario to keep the mean global temperature increase to 1.5°C with a likelihood of 50% and of 66%. Over the last decade, the emissions from the EU28+2 car segment have changed little. If this trend continues in the next decade the passenger car CO_2 budget for EU28+2 would be completely depleted in the 50% scenario within 10 years. In the 66% scenario the carbon budget would be depleted within 5 years.

For the scenarios, only the market developments of CO_2 emitting vehicles are taken into account. Therefore, it is assumed for this particular study that zero emission vehicles (e. g. battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV)) will fill up the new car sales. Therefore, the Vehicle Technology Scenario Model VECTOR21[1] only considers six different drivetrains such as diesel- and petrol-hybrids (HEV) and petrol plug-in hybrids (PHEV), as well as more efficient modern diesel and petrol drivetrains. Within the simulation runs, the new vehicle sales are calculated. Furthermore, the sales numbers are used to calculate the vehicle stock using the VECTOR21 stock model, which also gives the amount of the TTW (Tank-to-Wheel) CO_2 emissions on a yearly basis.

Beside the measures targeting the technical composition of the new vehicle market and the car stock, other paths to reduce the CO_2 emissions from the private transport sector also exist. Synthetic fuels, as well as a change in behaviour, such as a model shift, are examples. Those options are not part of this study but should be taken into account by drawing potential paths to reduce the CO_2 emissions and, thus, limit global warming.

[1] www.vector21.de

2. Carbon Budgeting

In the Paris Treaty, the members of the United Nations Framework Convention on Climate Change (UNFCCC) set the target to keep global warming well below 2°C and to pursue efforts to limit the increase in mean global temperature to 1.5°C above pre-industrial levels (UNFCCC 2016).

When modelling net anthropogenic warming due to CO_2 emissions, the concept of a global carbon budget (i.e. (UNEP 2015),(Le Quéré et al. 2017)) in combination with likelihoods to stay below a certain mean global temperature increase is often used. This concept illustrates that, to be able to limit global warming to a certain rise in temperature (i.e. 1.5°C), there is only a limited amount of greenhouse gases left that can be emitted. Starting in 2011, the global CO_2 budget (=cumulative CO_2 emissions) amounted up to 400 Gt CO_2 emissions for a 66% likelihood and 550 Gt CO_2 emissions for a 50% likelihood to stay below 1.5°C increase in global mean temperature increase (Pachauri, Mayer, and Intergovernmental Panel on Climate Change 2015). The Global Carbon Project[2] publishes a yearly update of global carbon emissions. From 2011 to 2016, global CO_2 emissions from fossil fuels and industry summed up to 214.3 Gt, with an annual average of 35.7 Gt (Boden, Marland, and Andres 2017).

Following the regional figures given in (Friedlingstein et al. 2014), EU28[3] had a share in global anthropogenic emissions (fossil fuel combustion and cement production) of 9.7% in 2013 and 9.2% in 2014 (2013: 3.5 Gt CO_2, 2014: 3.4 Gt CO_2). These figures are in line with the data submitted under the United Nations Framework Convention on Climate Change UNFCCC (Table 2-1). Including Norway and Switzerland, EU28+2 had an average share in global CO_2 emissions between 2011 and 2015 of 10.4%. This share is applied to the global carbon budget and amounted for the EU28+2 at the end of 2010: 57 Gt CO_2 (50% likelihood) and 42 Gt CO_2 (66% likelihood). Over the period of 2011-2015, EU28+2 have emitted 18.08 Gt of CO_2 emissions. Subtracting these CO_2 emissions, the remaining carbon budgets for the EU28+2 are 38.7 Gt of CO_2 emissions at the end of 2015 (50% likelihood) or 23.1 Gt CO_2 (66% likelihood) (Table 2-2).

If emission levels as of today were to continue over the next years, the CO_2 budgets for EU28+2 would be depleted in 9 years (50% likelihood) or even 5 years (66% likelihood) from 2018 on.

[2] http://www.globalcarbonproject.org/carbonbudget/17/data.htm
[3] EU28 member states: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Table 2-1: Annual anthropogenic CO_2 emissions of EU28+2[4]

CO_2 emissions [Gt]	**2011**	**2012**	**2013**	**2014**	**2015**
EU28	3.78	3.72	3.63	3.46	3.49
Norway	0.04	0.04	0.04	0.04	0.04
Switzerland	0.04	0.04	0.04	0.04	0.04
Sum (EU28+2)	**3.86**	**3.80**	**3.71**	**3.54**	**3.57**
Share of global CO_2 emissions[5]	***11%***	***11%***	***10%***	***10%***	***10%***

(UNFCCC 2017)

Table 2-2: Remaining CO_2 budgets for EU28+2 to stay below 1.5°C increase of global mean temperature

CO_2 budgets for EU28, Norway and Switzerland [Gt] at the end of…	**2010**	**2015**
66% likelihood	41.6	23.1
50% likelihood	57.2	38.7

For the last decade, passenger cars in EU28+2 have had a share of 13-15% of total CO_2 emissions in that region (Figure 2-1) and 57-58% of CO_2 emissions from transport (road transportation, domestic aviation, domestic navigation and railways[6]). Total anthropogenic CO_2 emissions (without agriculture and LULUCF[7]) in EU28, Switzerland and Norway have decreased by 18% (2015 vs. 2005).

However, CO_2 emission reductions in transport in the same period of time have been significantly smaller and decreased by 6%. While CO_2 emissions of other transport modes (light and heavy duty trucks, motorcycles, domestic aviation, domestic navigation and railways) have decreased by 8%, CO_2 emissions of passenger cars have been reduced slightly less: -5%. In 2015, CO_2 emissions from passenger cars in the EU28+2 amounted to 536 Mt (of 2,648 Mt CO_2 in total).

Following the top-down methodology, carbon budgets for passenger cars in EU28+2 are deducted (Table 2-3):

- The CO_2 emission share of passenger cars in 2015 (15% of total CO_2 emissions) was used to calculate the starting budget at the end of 2010: 8.6 Gt CO_2 (50% likelihood) and 6.3 Gt CO_2 (66% likelihood).

[4] without Agriculture and Land Use, Land Use Change and Forestry (LULUCF)
[5] From fossil fuel combustion and industrial processes as given in (Boden, Marland, and Andres 2017)
[6] Fuel-driven only; electric traction is reported within the energy sector
[7] Land Use, Land Use Change and Forestry

- From these CO_2 budgets, annual CO_2 emissions from passenger cars until the end of 2015 were subtracted: 2.6 Gt CO_2 in sum for 2011-2015 based on statistical data from (UNFCCC 2017)

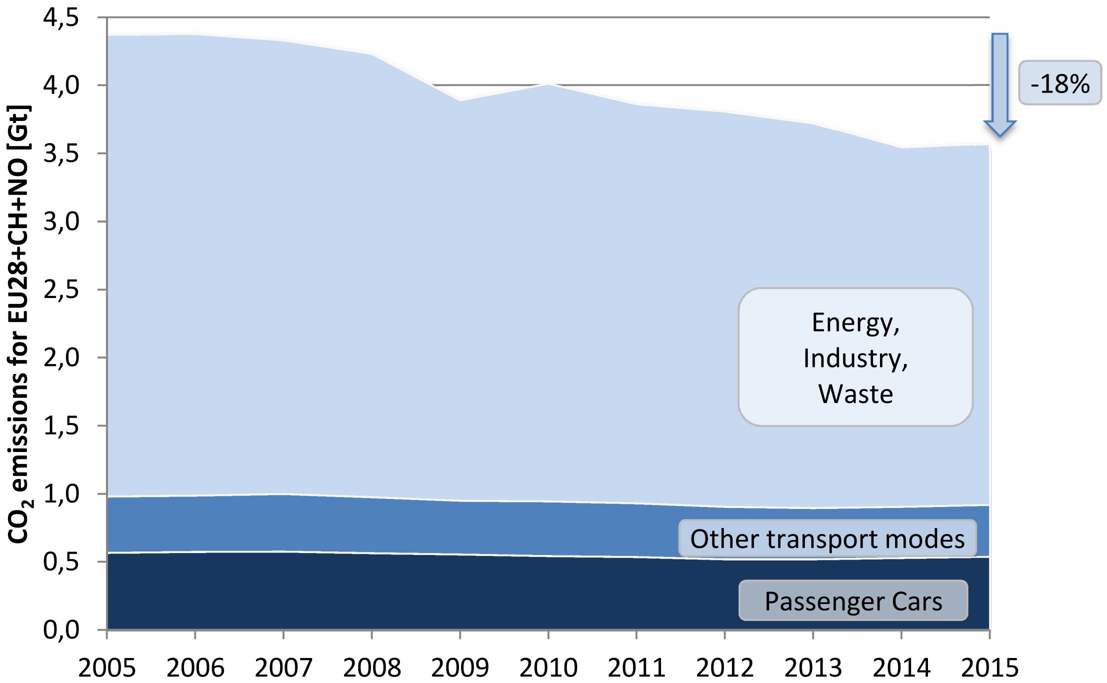

Figure 2-1: Direct CO_2 emissions from passenger cars, other transport modes and other sectors in EU28+2 between 2005 and 2015 (UNFCCC 2017)

From 2016 on, the remaining CO_2 budgets for passenger cars in EU28+2 are 6.0 Gt (50% likelihood) and 3.6 Gt (66% likelihood). If the current annual CO_2 emissions from passenger cars continue, the carbon budget would be completely depleted in the 50% scenario within 10 years and in the 66% scenario within 5 years. The top-down analysis of the remaining carbon budgets for passenger cars in EU28+2 shows that quick and stringent CO_2 emission reductions are necessary to stay below a 1.5°C increase in global mean temperatures. Either CO_2 savings from other areas need to be identified or stringent CO_2 emissions reductions are necessary from passenger cars.

Table 2-3: Remaining CO_2 budgets for Passenger Cars in EU28+2 to stay below 1.5°C increase of global mean temperature

CO_2 budgets for EU28, Norway and Switzerland [Gt] at the end of…	**2010**	**2015**
66% likelihood	6.3	3.6
50% likelihood	8.6	6.0

3. Passenger Car Sector in EU28+2

3.1. New Vehicle Sales

Sales of new passenger cars in EU28+2 amounted to around 16 million vehicles per year before the economic crisis. Sales experienced a decline up to 2013, and have been rising since then (Figure 3-1). In 2017, 15.6 million new passenger cars were sold in that region, reaching pre-economic-crisis levels. The main sales markets are: Germany (23% of sales in 2017), the United Kingdom (17%), France (14%), Italy (13%) and Spain (8%). Although Poland has the 6th biggest passenger car fleet in the EU (see chapter 3.2), sales of new vehicles are small and amounted to 3% of total EU28 sales in 2017 (Switzerland: 2% of EU28+2; Norway: 1%).

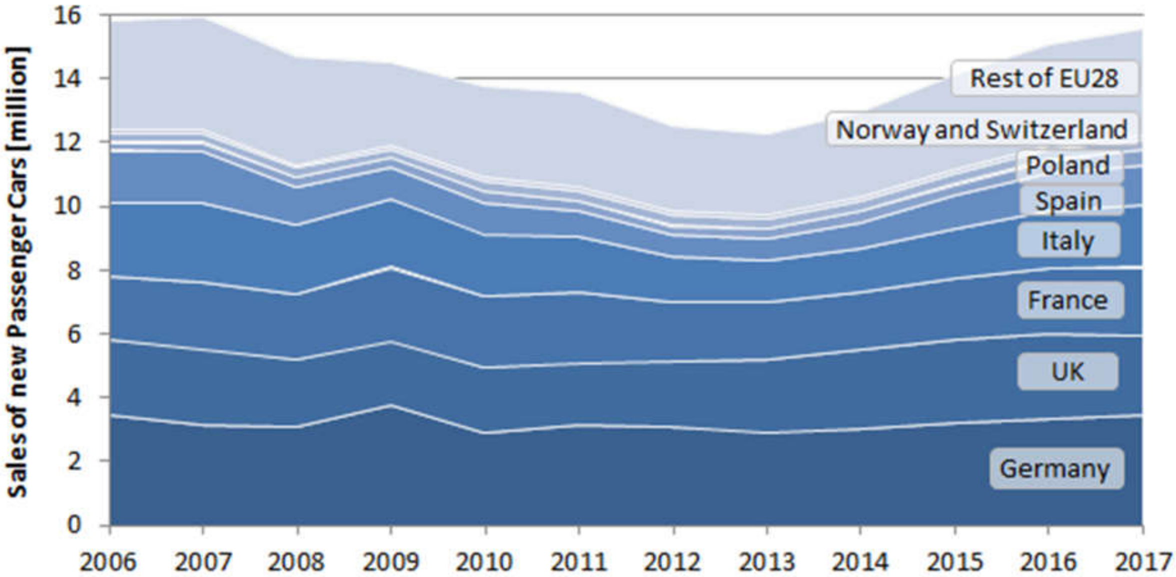

Figure 3-1: Sales of new passenger cars in EU28+2 between 2006 and 2017 (ACEA 2018)

The distribution of vehicle sizes give another insight into the market: in 2015, 30% of the new cars sold within EU28 belonged to the small vehicle segment (e.g. Fiat Panda, VW Polo), another 40% to the medium segment (e.g. VW Golf, Audi A4) and 30% to the vehicles of larger size (e.g. Audi A6, BMW 7-series, Mercedes Benz SLK, Ford S-Max, Nissan Navara, VW Transporter-T5) (ICCT 2016).

3.2. Passenger Cars in Use

In EU28+2 in 2015, there were 259 million passenger cars in use (ACEA 2017). Their number has been increasing by 4% over 4 years (2011-2015). The highest amount of passenger cars is to be found in Germany with 45 million in 2015 (18% of the total EU28+2 fleet), followed by Italy (37 million, 15%), the United Kingdom (34 million, 13%), France (32 million, 13%), Spain (22 million, 9%) and Poland (21 million, 8%).

Passenger cars in the EU are predominantly driven by liquid fuels. In 2015, more than 97% of all passenger cars were using petrol or diesel, 2% were using liquefied petroleum gas (LPG) and natural gas (NG) and 0.5% were electrified (of which 80% were hybrid vehicles and 20% BEV as well as plug-in hybrid electric vehicles (PHEV)) (ACEA 2017).

The share of petrol and diesel driven cars varies from member state to member state. In 2015, Germany showed a slightly higher share of petrol driven cars (66%), while France had a slightly higher share of diesel driven cars (64%). Of the EU28 member states, the Netherlands had the highest share of (hybrid) electric vehicles in its fleet in 2015 (2.7%, of which 15% are PHEV and BEV). Of the markets with the highest amount of (hybrid) electric vehicles within the EU, the United Kingdom had the highest share in 2015 (1.1%, of which 36% are PHEV and BEV). (ACEA 2017)

The passenger car fleet in Switzerland is likewise predominantly petrol and diesel fuelled. In 2017, electric vehicles had a share of 1.8% of the total fleet (Bundesamt für Statistik 2018). Norway has adopted various policies to enhance the market penetration of EV. Consequently, sales of new BEV have reached a share of nearly 40% in Norway in 2017 (EAFO 2018). This in turn leads to a comparatively high share of electrically driven passenger cars in the Norwegian fleet: 3% in 2015 and 4% in 2016 (Statistics Norway 2017).

3.3. Scenarios for New Vehicles Sales and Car Stock to stay within the CO_2 Budget

There are two main pathways for decarbonising passenger car fleets:

- targeting the market penetration of alternative powertrains via new vehicle sales and
- targeting the existing vehicle fleets, see e.g. (Öko-Institut et al. 2016).

An ambitious, explorative scenario up to 2050 is set up to analyse technological options for new passenger cars using the Vehicle Technology Scenario Model VECTOR21 (see Annex 7). This new vehicle sales scenario is then used as an input to model vehicle stock scenarios. The analysis encompasses the four major EU passenger car markets Germany, France, United Kingdom and Italy, as well as the major eastern European market Poland.

Within this study, three base powertrain concepts are modelled (Figure 3-2): conventional vehicle (CV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV)[8]. In total, six different drivetrains are taken into account (petrol, petrol HEV, petrol PHEV, diesel, diesel HEV and compressed natural gas (CNG)).

[8] Including range extended electric vehicles (REEV)

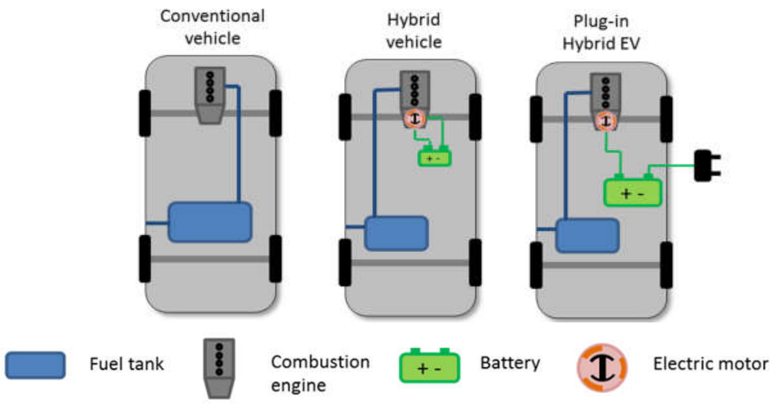

Figure 3-2: Powertrain concepts used for the scenarios; adapted from (Klötzke et al. 2015)

3.3.1. Boundary conditions

For the upcoming simulations, a set of boundary conditions is considered, modelling a continuation of current trends. Therefore, for this study, the total number of sales and stock are kept on a steady level for all scenarios with around 15 million cars (sales) and 260 million cars (stock) per year. In addition, the following scenarios show only the market development of CO_2 emitting vehicles. Therefore, it is assumed that zero emission vehicles (e.g. BEV and FCEV) will fill up the new car sales, to remain on a steady sales level. Furthermore, the scenarios do not consider any behavioural changes, modal shift or disruptive changes.

In the European Union, automobile manufacturers have to fulfil CO_2 Tank-to-Wheel (TTW) emission standards for their new light duty vehicles (European Union 2009). Up to now, these standards are set at 95 g CO_2/km (fleet average) until 2021. For the purpose of this study, ambitious CO_2 emission target pathways are modelled, assuming tighten standards.

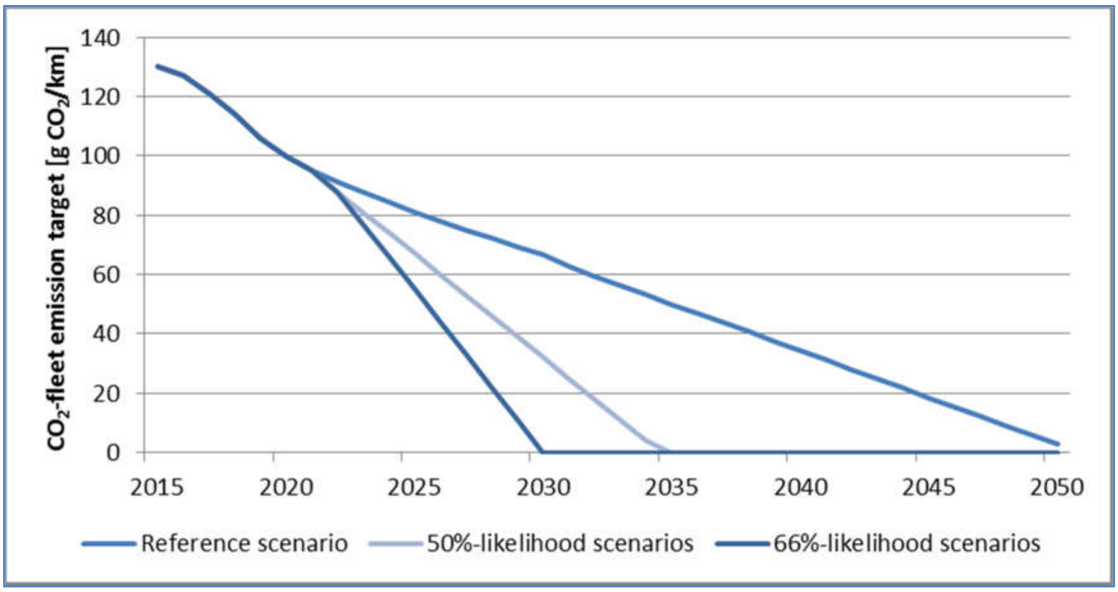

Figure 3-3: Assumption on development of CO_2-fleet emission target for new passenger cars in EU28

Vehicle Taxes according to current legislation, purchase premiums (e. g. United Kingdom's Plug-In Grant or Germany's "Umweltbonus") and other incentives for passenger cars with lower CO_2 emissions (e. g. France's bonus-malus system) are part of the modelling framework and are extrapolated.

The scenarios (50% and 66% likelihood) consist of copious modelled measures, which lead to a reduction of CO_2 emissions from the car stock. Examples include increasing fuel prices or strengthened CO_2-regulations (see Figure 3-3). Prices for conventional fuels (diesel and petrol) almost double compared to today's level due to increasing raw oil prices (>130 €$_{2010}$/bbl in 2050) and stringently fuel taxation (assumption based on IEA 2016).

3.3.2. Reference Scenario

To be able to classify the scenario results, a reference scenario is modelled which shows a moderate evolution of the new vehicle market, as well as of the car market and the related CO_2 emissions. It can be seen that the share of conventional petrol and diesel vehicles decreases slowly (see Figure 3-4). Diesel cars are sold until 2030 and petrol cars until the mid-2030s. The hybrid versions of diesel and petrol cars play a secondary role, but PHEV gains a significant market share. The phased-out diesel vehicles are replaced by petrol cars including PHEV. PHEV maintain their market share until the early 2040's. CNG plays a minor role but can be found almost until 2050. The gap between the number of diesel and petrol powered vehicles and the total number of vehicles required to keep both sales and stock steady, needs to be filled by zero emission vehicles like BEV and FCEV.

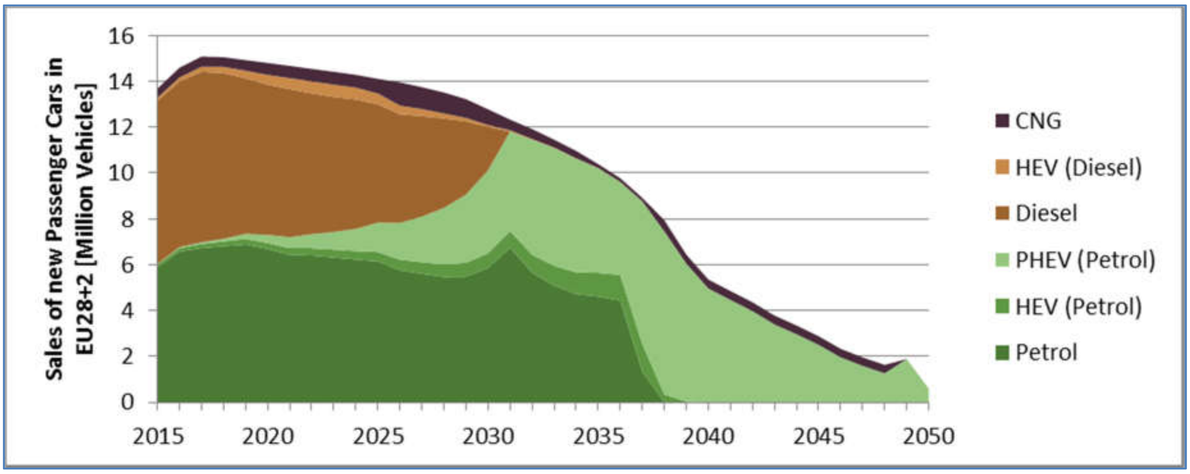

Figure 3-4: Scenario results from VECTOR21 for the new vehicle sales in EU28+2 in the reference scenario.

The development of the car stock, which is also modelled with VECTOR21, shows a long period in which diesel and petrol vehicles are present (see Figure 3-5). Until 2030 there is only a slow decrease in the number of diesel vehicles and from 2030 on it takes another 20 years until the last diesel vehicle disappears. A significant decline of petrol vehicles starts around 2035 and even in 2050 there are around 10 million petrol cars in the stock. The number of PHEV increases slowly until 2040 and is maintained until 2050.

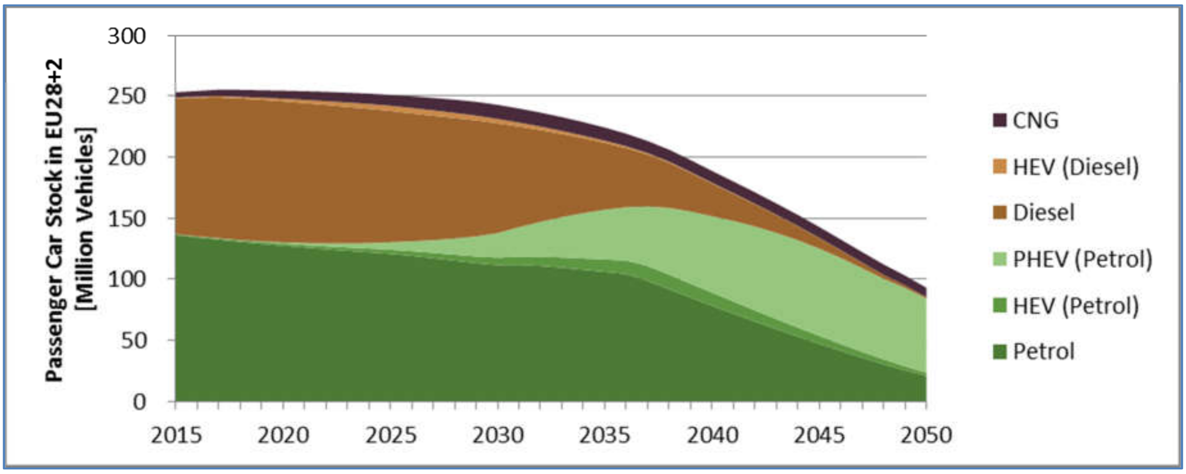

Figure 3-5: Scenario result from VECTOR21 for the development of the car stock in EU28+2 in the reference scenario.

Due to the technological developments, annual CO_2 emissions are decreased significantly. By 2035 the TTW CO_2 emissions from the car stock and thus private transport are halved (see Figure 3-6). By 2050 they are reduced by 80%. The cumulated CO_2 emissions, which are relevant for global warming, amount to 8.3 Gt by 2050.

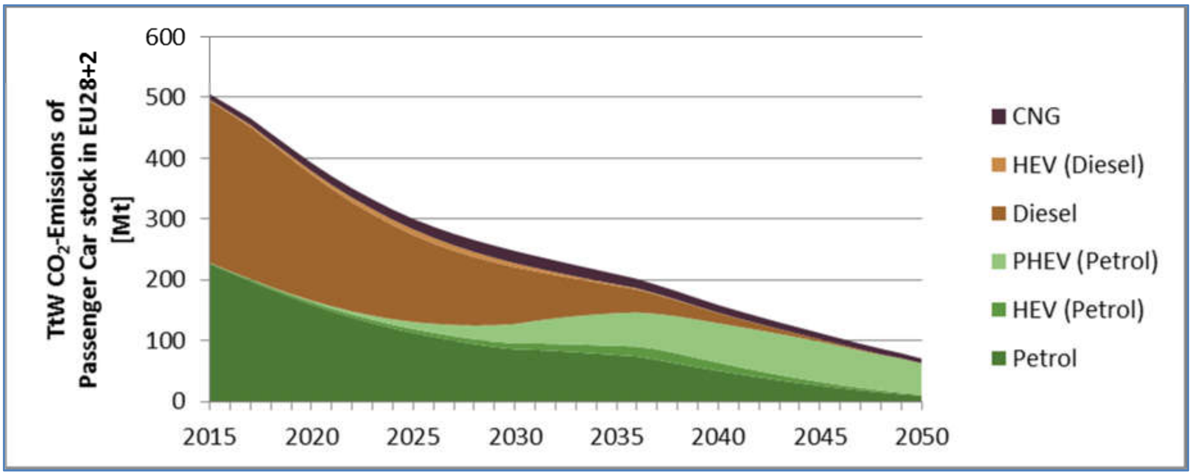

Figure 3-6: Scenario results from VECTOR21 for the development of the TTW CO2-emissions from the car stock in EU28+2 in the reference scenario.

3.3.3. 50%-likelihood scenario

The stringent emission reduction requirements of the 1.5°C carbon budget (6.0 Gt CO_2 with 50%-likelihood and 3.6 Gt CO_2 with 66% likelihood, see Table 2-3) mean that in addition to an ambitious market development of new vehicles, today's energy consumption and CO_2 emissions of existing passenger car fleets in EU28+2 (see chapter 2) will have to decrease. The vehicle stock module of VECTOR21 was used to model effects on energy consumption and CO_2 emissions of the EU28+2 car fleet. The assumed rates of change in the passenger car fleet thus follow the climate imperative of the 1.5°C target to illustrate a potential path.

The measures in the 50%-likelihood scenario lead to a vehicle market with a slight decrease in sales of diesel and petrol vehicles from 2018 and 2019 with an increasing decline in the following years as can be seen in Figure 3-7. While for 2018 conventional diesel and petrol sales reach 7 million cars each, in 2025 the diesel cars sales fall below 500,000 new vehicles and in 2027 the same happens to petrol cars. Even the hybrid models cannot help to keep the market share of diesel and petrol cars much longer. Only the PHEV, which is also equipped with a petrol driven engine but can recharge the battery externally, has a significant market share until 2035. CNG can maintain its market share until 2030 but does not gain higher proportions. The gap between the number of diesel and petrol powered vehicles and the required number of new vehicles needs to be filled by zero emission vehicles. In 2038, only zero emission vehicles like BEV and FCEV are sold in EU28+2 referring to the scenario results of VECTOR21.

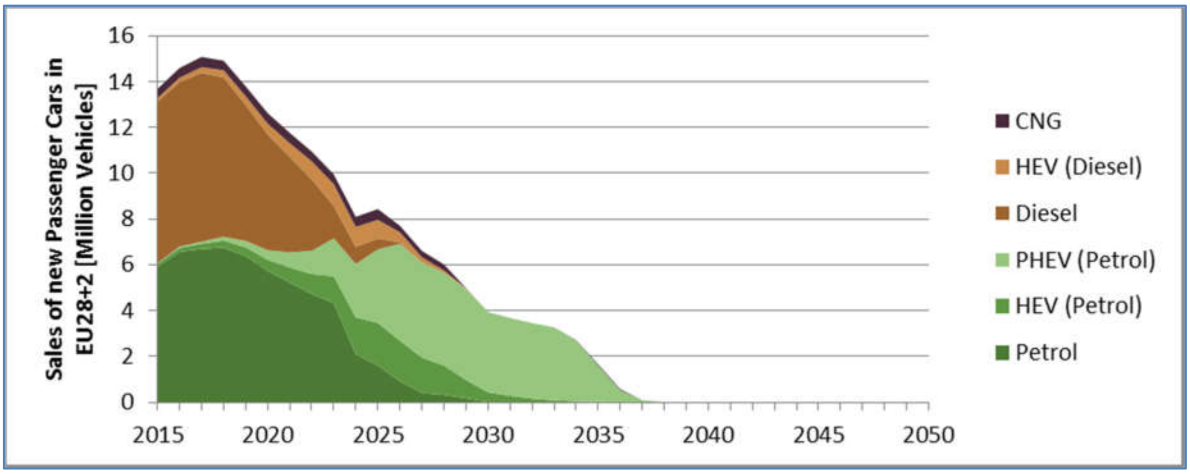

Figure 3-7: Scenario results from VECTOR21 for the new vehicle sales in EU28+2 in the 50%-likelihood scenario.

Due to the current discussions about diesel and petrol cars (e.g. city bans, air quality, CO_2) we assume that conventional vehicles will not stay in the stock as long as they did in the past. Therefore conventional vehicles disappear gradually from the vehicle stock. Thus, the number of diesel and petrol cars is reduced by almost 50% by 2025 in the scenario. But due to the survival rates, it takes a long time until the last of these cars vanish. Conventional diesel cars remain in the vehicle stock until the early forties, whilst conventional petrol cars can still be found a few years later. As for new vehicle sales, the hybrid diesel and petrol cars cannot compensate the decrease in sales of conventional diesel and petrol cars. Only the petrol PHEV will be found in larger numbers in the vehicle stock of EU28+2, especially between 2030 und 2045.

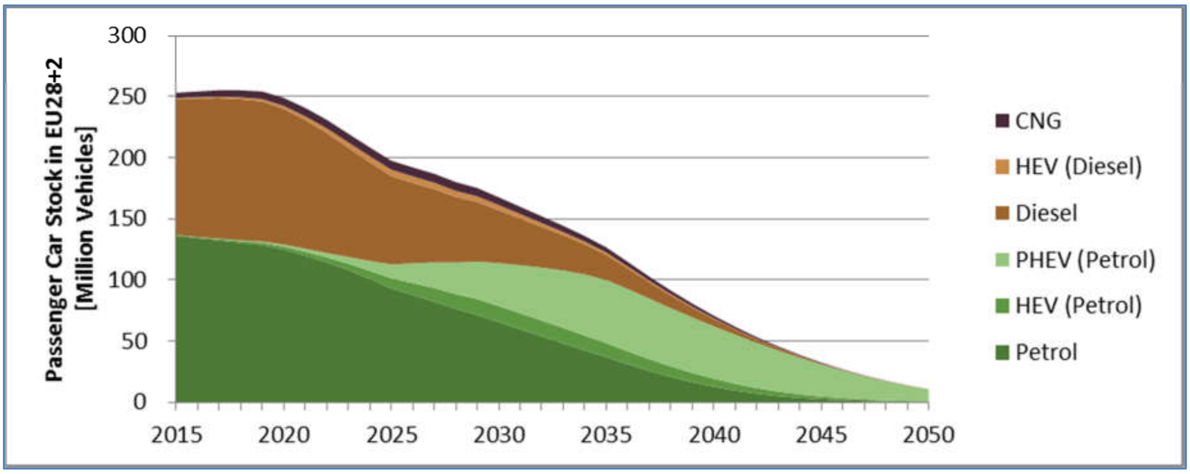

Figure 3-8: Scenario result from VECTOR21 for the development of the car stock in EU28+2 in the 50%-likelihood scenario.

Along with the replacement of older diesel and petrol cars with new, more efficient models, the TTW CO_2 emissions decrease significantly, dropping to less than 50% by 2030. With this reduction cumulated, CO_2 emissions of slightly below 6 Gt can be achieved. As can be seen, the CO_2 emissions from the car stock goes down to almost zero in 2050, so within this sales and stock scenario, under the anticipated boundary conditions, it is not expected that the given budget for the 50%-likelihood scenario will be exceeded.

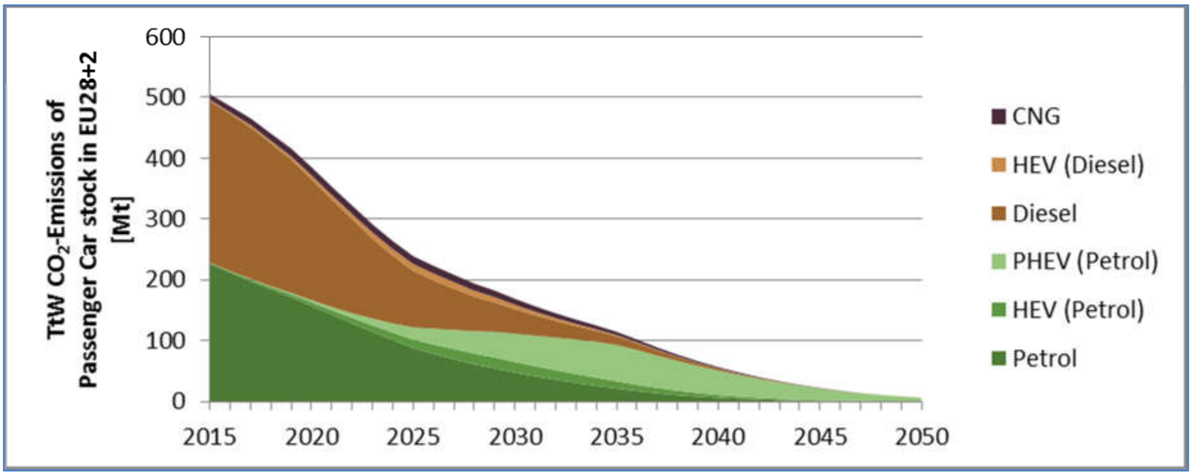

Figure 3-9: Scenario results from VECTOR21 for the development of the TTW CO2-emissions from the car stock in EU28+2 in the 50%-likelihood scenario.

3.3.1. 66%-likelihood scenario

To achieve the goal of the 66%-likelihood scenario, a budget of 3.6 Gt CO_2 must not be exceeded (see chapter 2). Within the modeling, stark measures are taken to revolutionize the new vehicle market towards electric mobility and to transform the car stock in order to decrease the TTW CO_2 emissions drastically. Therefore the number of diesel and petrol sales drops significantly, from around 15 million in 2018 to around 5 million from 2025 ongoing. Thus, the share of diesel and petrol, conventional, as well as hybrid, decreases rapidly. The last vehicle with an internal combustion engine is sold in 2028, while the market declines by 50% until 2022. Even the PHEV cannot achieve high market shares. The gap between the number of diesel and petrol powered vehicles and the required number of new vehicles needs to be filled by zero emission vehicles. In 2030, only zero emission vehicles like BEV and FCEV are sold in EU28+2 referring to the scenario results of VECTOR21.

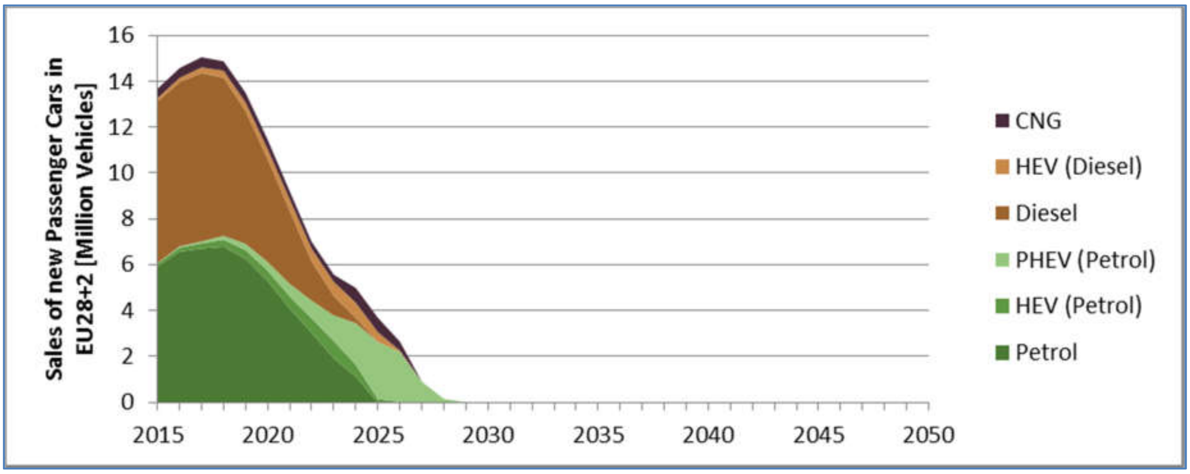

Figure 3-10: Scenario result from VECTOR21 for the new vehicle sales in EU28+2 in the 66%-likelihood scenario.

Furthermore, hard measures are taken for the car stock. To reduce the number of vehicles, which are not locally emission free, the lifetime of these vehicles in the stock is cut. The phase out of diesel and petrol cars is fast, so that in 2030 the number of diesel and petrol cars in the stock are reduced by two thirds and in the mid-forties, no diesel or petrol powered cars can be found in the car stock.

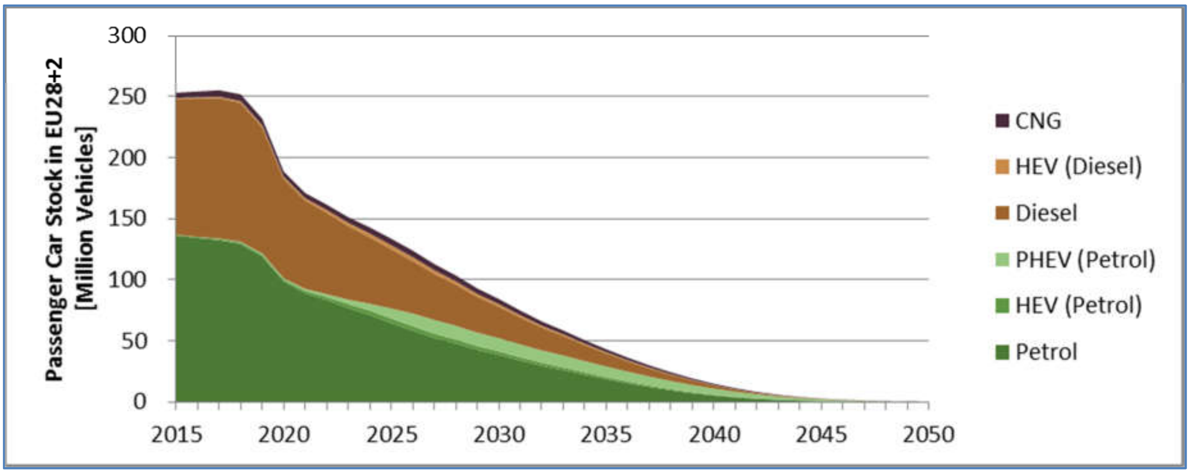

Figure 3-11: Scenario result from VECTOR21 for the development of the car stock in EU28+2 in the 66%-likelihood scenario.

This leads to a significant reduction in CO_2 emissions, by 50% by 2022 and 90% by 2035. However, even the strict measures do not lead to a scenario, where the goal of 3.6 Gt cumulated CO_2 emissions from the private transport sector is met. In total, the cumulated CO_2 emissions amount to 3.9 Gt in this scenario.

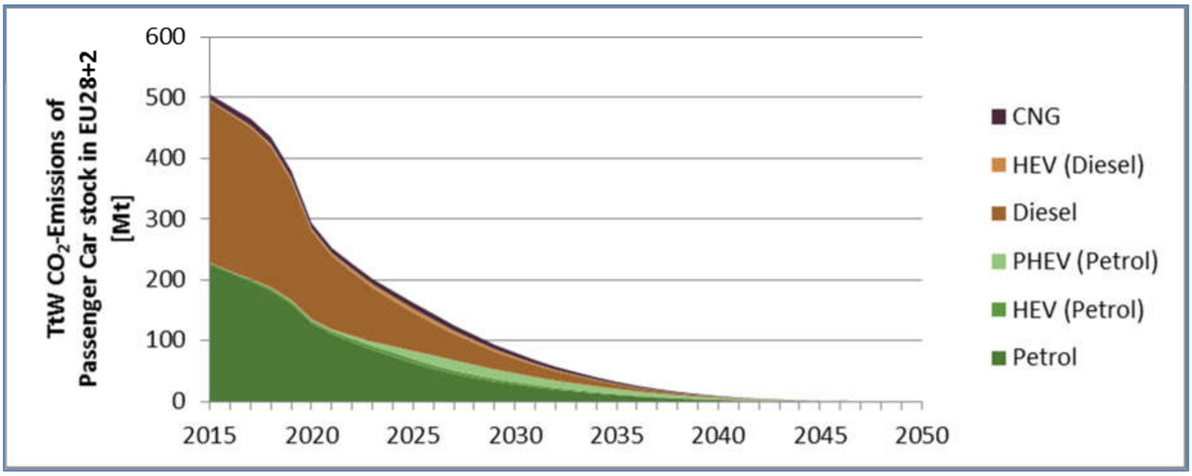

Figure 3-12: Scenario results from VECTOR21 for the development of the TTW CO2-emissions from the car stock in EU28+2 in the 66%-likelihood scenario.

It can be concluded, that further measures are needed to reduce the direct TTW CO_2 emissions from the car stock in EU28+2 to stay within the anticipated budget of 3.6 Gt from the private transport sector. Such measures can be technological (e.g. fast breakthrough of ZEV, further improvements in efficiency or synthetic fuels) and social (e.g. change in behavior or modal shift).

4. Outlook on Implications on other Sectors

It is to be anticipated that a number of consequences will follow from the scenarios. The energy and the automotive sector will be influenced considerably, with other areas also affected. As can be seen in the scenario results, the number of diesel and petrol vehicles decreases significantly. It can be supposed that the demand for cars in the EU28+2 will not abate in the same extent. Thus, under the assumption that the car will play a role in private mobility in the future, comparable to today, the gap has to be filled by zero emission vehicles. That requires a tremendous change in the automotive sector with a sharp growth in production and development capacities of BEV and FCEV. Associated therewith, negative effects on employment in the automotive sector can be expected. On the other hand, new business models enable job opportunities. Furthermore, FCEV and particularly BEV are resource-consuming products. Huge amounts of rare earth and other materials like lithium are required.

Since this study aims to show paths to reduce the TTW emission of CO_2, the model result in significant reductions in fossil fuels. Hence, hydrogen and electricity need to be available in the required amounts. Moreover, they need to be produced and distributed. Particularly for hydrogen, this is a huge challenge. Last but not least, to reduce not only the TTW but also the WTT (well-to-tank) CO_2 emissions, the production of hydrogen and electricity needs to be based on renewable resources. In this context, some experts are discussing the introduction of synthetic fuels, which could be another option to reduce the overall CO_2 emissions from the car stock. Beside CO_2 free energy sources, behavioural changes can have positive effects on the greenhouse gas emissions from private transport, e.g. a growth in bicycle use or public transport to reduce the amount of passenger cars.

5. Summary

The primary objective of the study was to show how the European new car market and the corresponding stock could develop to meet a certain greenhouse gas budget for private transport in EU28+2 (EU28 plus Norway and Switzerland). The budget was derived by taking the current share of emissions from private transport in relation to the total emissions of CO_2 in EU28+2 and, thus, calculating the remaining budget based on the global remaining CO_2 budget to keep the mean global warming under 1.5 °C, with a likelihood of 50% (and 66% respectively).

The composition of new vehicle sales and the car stock was determined with the Vehicle Technology Scenario Model VECTOR21. Hence, it was possible to assume boundary conditions that entail an alteration of the composition towards more efficient and vehicles with less CO_2 emissions. It could be shown that, under the presumption that the private car will play a role similar to that of today, the shift towards CO_2-free technologies needs to happen very fast. This comes in part from the fact that cars have a certain lifetime in the car stock, which means that their emissions will be there for several years.

In the 50% likelihood scenario, conventional diesel and petrol cars are phased out by the end of the next decade. Hybrid diesel and petrol cars - particularly plug-in hybrids - are sold until the middle of the 2030s. Due to the survival-rates of the cars in the stock, conventional diesel and petrol cars can be found on the streets until the mid-2040s. Plug-in hybrids in this scenario will outlast 2050. The share of diesel and petrol powered cars in this scenario leads to cumulated CO_2 emissions which will stay within the given budget for the private transport sector.

Further measures in the scenario parameters show further decline of diesel and petrol cars in the second scenario. This scenario aims to keep the budget under tightened constraints which will lead to a 66%-likelihood to limit mean global warning to 1.5°C. Although conventional diesel and petrol cars disappear from the new car market by 2025, and PHEV by 2028, they stay in the car stock until the early-2040's. The number of diesel and petrol cars in the stock is almost halved by 2025, as are CO_2 emissions. The CO_2 budget is exceeded by 10%. Therefore, further measures, especially a behavioral change towards other transport modes like walking, cycling or public transport, are necessary to be able to limit the cumulated CO_2 emissions to the given budget.

Since this study only investigated the TTW emissions, a closer look has to be taken at the upstream chain of the energy supply of electricity and hydrogen to be able to give a definitive conclusion to the question. The same also applies for synthetic and renewable fuels if they are taken into consideration.

6. References

ACEA. 2017. "Vehicles in Use - Europe 2017." Brussels: European Automobile Manufacturers Association. http://www.acea.be/statistics/article/Report-Vehicles-in-Use.

ACEA. 2018. "Consolidated Registrations - by Country." European Automobile Manufacturers Association (ACEA). G:41313-TBS03-Projekte3019795_GP-EU-CARWP2_Passenger_Car_SectorStatistikdatenPC_90-17_by_country_Enlarged_Europe.xlsx. http://www.acea.be/statistics/article/consolidated-figures-by-country.

Boden, T.A., G. Marland, and R.J. Andres. 2017. "Global, Regional, and National Fossil-Fuel CO2 Emissions." Emission inventory. Oak Ridge, USA: Carbon Dioxide Information Analysis Center, US DOE. http://cdiac.ess-dive.lbl.gov/trends/emis/tre_glob_2014.html.

Brokate, Jens, Christoph Schimeczek, and Horst E. Friedrich. 2017. "A Disaggregated Approach to Model International Passenger Car Markets and Their Interdependencies." In . Genf.

Bundesamt für Statistik. 2018. "Strassenfahrzeuge – Bestand, Motorisierungsgrad (Vehicles - Stock, Engine Type)." Neuchâtel, Schweiz. G:41313-TBS03-Projekte3019795_GP-EU-CARWP2_Passenger_Car_SectorStatistikdaten20180307_Strassenmotorfzge_Schweiz.xlsx. https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/verkehrsinfrastruktur-fahrzeuge/fahrzeuge/strassenfahrzeuge-bestand-motorisierungsgrad.html.

EAFO. 2018. "EV Market Share in 2017." 2018. http://www.eafo.eu/.

European Union. 2009. Regulation (ec) No 443/2009 of the European Parliament and of the Council. EC 443/2009. http://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX:32009R0443.

Friedlingstein, P., R. M. Andrew, J. Rogelj, G. P. Peters, J. G. Canadell, R. Knutti, G. Luderer, et al. 2014. "Persistent Growth of CO2 Emissions and Implications for Reaching Climate Targets." Nature Geoscience 7 (10): 709–15. https://doi.org/10.1038/ngeo2248.

ICCT. 2016. "European Vehicle Market Statistics - Pocketbook 2016/17." Berlin: International Council on Clean Transportation (ICCT) Europe. https://www.theicct.org/sites/default/files/publications/ICCT_Pocketbook_2016.pdf.

IEA. 2016. "World Energy Outlook 2016." Paris: Internation Energy Agency. G:\41313-TBS\10-Referenzdaten\IEA_WEO.

Klötzke, Matthias, Benjamin Frieske, Ole Soukup, Thorsten Koska, Hanna Hüging, Katrin Bienge, Michael Ritthoff, et al. 2015. “Begleitforschung zu Technologien, Perspektiven und Ökobilanzen der Elektromobilität.”

Kugler, Ulrike, Matthias Klötzke, Stephan Schmid, Wojciech Gis, Tuuli Järvi, Heidi Auvinen, and Christoph Schimeczek. 2015. “Scenario Report, with an in-Depth Description of the Scenarios’ Background.” Project deliverable D6.2. eMAP. Stuttgart: DLR Institut für Fahrzeugkonzepte.

Le Quéré, Corinne, Robbie M. Andrew, Pierre Friedlingstein, Stephen Sitch, Julia Pongratz, Andrew C. Manning, Jan Ivar Korsbakken, et al. 2017. “Global Carbon Budget 2017.” Earth System Science Data Discussions, November, 1–79. https://doi.org/10.5194/essd-2017-123.

Mock, Peter. 2010. “Entwicklung Eines Szenariomodells Zur Simulation Der Zukünftigen Marktanteile Und CO2-Emissionen von Kraftfahrzeugen (VECTOR21).” Stuttgart: Universität Stuttgart.

Öko-Institut, DLR, IFEU, and Infras AG. 2016. “Endbericht Renewbility III - Optionen Einer Dekarbonisiserung Des Verkehrssektors.” Berlin.

Pachauri, R. K., Leo Mayer, and Intergovernmental Panel on Climate Change, eds. 2015. Climate Change 2014: Synthesis Report. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Propfe, Bernd. 2016. “Marktpotentiale Elektrifizierter Fahrzeugkonzepte Unter Berücksichtigung von Technischen, Politischen Und ökonomischen Randbedingungen.” Universität Stuttgart.

Schimeczek, Christoph, Matthias Klötzke, Ulrike Kugler, and Stephan Schmid. 2015. “Report on Enhanced Model Algorithm and Model Calibration.” EMAP Project deliverable D6.1. Stuttgart: DLR Institut für Fahrzeugkonzepte.

Statistics Norway. 2017. “Registered Vehicles.” Ssb.no. March 28, 2017. http://www.ssb.no/en/transport-og-reiseliv/statistikker/bilreg/aar/2017-03-28.

UNEP. 2015. “The Emissions Gap Report 2015.” Synthesis Report. Nairobi: United Nations Environment Programme (UNEP). http://www.unep.org/emissionsgapreport2015/.

UNFCCC. 2016. “Report of the Conference of the Parties on Its Twenty-First Session, Held in Paris from 30 November to 11 December 2015.” January 29, 2016. https://unfccc.int/resource/docs/2015/cop21/eng/10.pdf.

UNFCCC. 2017. “National Inventory Submissions.” United Nations Framework Convention on Climate Change. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php#fn1.

7. Annex – VECTOR21 – Vehicle Scenario Technology Model

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 (Mock 2010; Propfe 2016). 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 their 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 7-1) matching vehicle costs, CO_2 emissions and available refueling- or recharging infrastructure to their preferences.

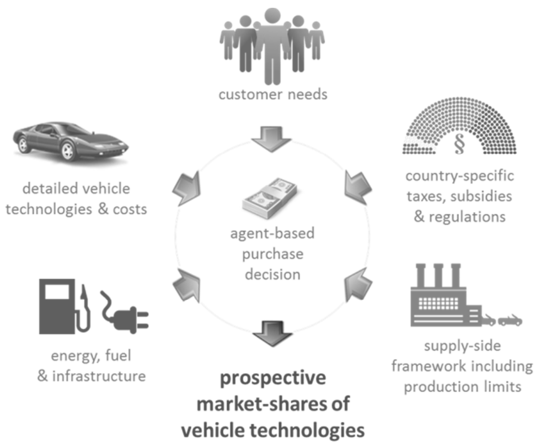

Figure 7-1. Model approach of vehicle technology scenario model VECTOR21[9]

In recent years, the model was extended to cover the European (EU28) (Kugler et al. 2015) and U.S. market (Brokate, Schimeczek, and Friedrich 2017) 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 segment specific survival and mileage degression curves (Schimeczek et al. 2015). The EU28+2 market is calculated based on upscaling the 5 single markets (France, Germany, Italy, Poland, UK) according to sales-weighted alikeness.

[9] www.vector21.de