Electromobility+

eMAP

# D6.2 Scenario Report

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# 1 Introduction

Within the collaborative project eMAP, feasible deployment paths of electrified vehicles (EV) are analysed up to 2030. The scope of the study covers electromobility diffusion in passenger car markets, i.e. take-up of plug-in hybrid vehicles (PHEV), battery electric vehicles (BEV), range extended electric vehicles (REEV) and fuel cell electric vehicles (FCEV). For the analysis, the vehicle market model VECTOR21 (Vehicle Technologies Scenario Model) is used specifying consumer demand and market supply of electromobility in Finland, France, Germany, Italy, Poland, the United Kingdom and the EU28. VECTOR21 is simulating the competition between conventional and alternative powertrains for the new vehicle market. Using relevant costs of ownership, the least cost- and $CO_2$-intensive car is chosen by the customer. A description of the technical details is given in Schimeczek et al. (2015). For more background information on the supply side of the electromobility market, refer to Frieske et al. (2015) and Kleiner et al. (2015).

Starting from VECTOR21 for Germany, an extended version of VECTOR21 is developed within eMAP to cover European markets (EU28). In addition to Germany, the markets Finland, France, the United Kingdom, Italy and Poland are modelled interdependently, thus representing about three quarters of the EU28 new passenger car sales.

In eMAP, three scenarios towards an electrified fleet are modelled: Business as Usual (BaU) as a reference up to 2030, Technology Driven (TeD) with higher efficiencies of electrified vehicles and Policy Driven (PoD) with a stricter EU-wide $CO_2$ regulation for passenger cars and a more pronounced promotion of electrified vehicles (the latter with individual measures per country).

This report encompasses

- An overview on the key elements of each scenario (Chapter 2)
- An in-depth description of the technology and economy framework for each scenario including e.g. fuel and electricity prices, battery cost developments and the national and EU-wide regulatory framework including e.g. $CO_2$ targets and taxes (Chapters 3-5)
- Results for each scenario, e.g. market shares of electric and conventional powertrains and $CO_2$ emissions of the fleet (Chapters 3-5)
- A summary of the results (Chapter 6)
- A discussion of the lessons learned (Chapter 7)

# 2 Scenario storylines

Three scenario storylines are developed to analyse potential future deployment paths for electrified vehicles: Business as Usual (BaU) as a reference up to 2030, Technology Driven (TeD) with higher efficiencies of electrified vehicles and Policy Driven (PoD) with a stricter EU-wide $CO_2$ regulation for passenger cars and a more pronounced promotion of electrified vehicles (the latter with individual measures per country). The underlying questions are:

- BaU: What will the market penetration of electrified vehicles be with current policies and technologies?
- TeD: Which additional impact can a better or faster development of technologies have to enhance electric components (and thus increase the amount of electric vehicles in the fleets)?
- PoD: Which impact do alternative policies at national and at EU-level have to enable a faster and more pronounced market penetration of electrified vehicles?

The BaU scenario incorporates current policies and technologies as of 2014. This means, however, that the current status concerning $CO_2$ targets, taxation schemes, energy system, infrastructure, powertrain efficiencies and others is not frozen but does develop over time.

The TeD scenario assumes the same political and economic framework as in the BaU scenario. However, electric powertrain technologies become more efficient and traction battery costs decrease faster compared to the BaU scenario.

The EU-level PoD scenario models the effects of a stronger European climate protection policy by setting the EU $CO_2$ target for passenger cars to 60 g $CO_2$/km in 2030. Furthermore, in the national PoD scenarios (concentrating on the eMAP partner countries Finland, Germany and Poland), individual measures to promote electrified vehicles are modelled per country:

Finland (from 2018 on):

- Tax exemption for the powertrain-based part of the annual tax for electrified vehicles (PHEV, REEV, BEV, FCEV),
- 25% increased annual tax ($CO_2$ and powertrain based) for all vehicles[1].

[1] To maintain the tax revenue from cars in a manner in favour of EV, the tax being $CO_2$ based and thus lowest for EV

Germany (from 2016 on):

- Lowering purchase costs by 1,500 € for electrified vehicles (PHEV, REEV, BEV, FCEV) by tax exemptions or purchase premiums for a period of 5 years (2016-2020),
- Exemption from the renewable energy levy[2] for public charging stations,
- Increasing investments (and thus coverage) in charging infrastructure by 10%[3] per year,
- Raising awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects (and thus increasing the customers' willingness-to-pay by 10%[3]).

Poland (from 2016 on):

- Lowering purchase costs by 1,050 € for electrified vehicles (PHEV, REEV, BEV, FCEV) by tax exemptions or purchase premiums ,
- Raising awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects (and thus increasing the customers' willingness-to-pay by 10%[3]).

In Table 1, key characteristics for each scenario storyline are given.

[2] So-called "EEG-Umlage", part of the electricity price, in 2015 6,17 €ct/kwh

[3] In relative terms compared to the BaU scenario

**Table 1. Scenario definition – key characteristics**

| Scenario | BaU | TeD | PoD |
|---|---|---|---|
| **Vehicle design** | 6 powertrain concepts (5 electrified); 3 sizes; 9%-30% increase in vehicle energy efficiency[4] up to 2025 | Higher EV energy efficiency | As in BaU |
| **Traction battery costs[5]** | 2010-2015: 450 €/kWh; floor costs reached in 2029 (230 €/kWh) | 2010-2012: 450 €/kWh; floor costs reached in 2019 (230 €/kWh) | As in BaU |
| **Charging infrastructure coverage** | *Finland*:<br>2020[6]: 30%; 2030: 55%<br>*Germany*:<br>2020[6]: 25%; 2030: 50%<br>*Poland*:<br>2020[6]: 3%; 2030: 28% | As in BaU | *Germany:*<br>increasing coverage by 10%[3] p.a.<br>*Finland & Poland:*<br>as in BaU |
| **$CO_2$ targets** | 2015: 130 g/km;<br>2020: 95 g/km;<br>2030: 75 g/km,<br>considering phase-in & super credits | As in BaU | 2015: 130 g/km;<br>2020: 95 g/km;<br>2030: 60 g/km |
| **Taxation scheme & subsidies** | As current legislation | As in BaU | *Finland:*<br>EV tax exemption; 25% higher annual taxes for all vehicles<br>*Germany:*<br>1,500 €/EV (2016-2020); exemption from renewable energy levy<br>*Poland:*<br>1,050 €/EV |
| **Willingness-to-Pay** | Adapted per country according to PPP[7] | As in BaU | *Germany & Poland:*<br>increasing WTP by 10%[3]<br>*Finland*:<br>as in BaU |

A detailed description of the national and EU-wide scenario parameters can be found in chapters 4 - 6.

[4] engine-based measures, lightweight construction, improvements in aerodynamic drag
[5] based on sold units using learning curves
[6] According to EC proposal COM(2013) 18 final
[7] Purchasing Power Parity (Eurostat 2014)

# 3 Business as Usual scenario (BaU)

The BaU scenario models the effect of current policies and of the current development of EV technologies. The BaU scenario is used as a reference up to 2030 versus the other two scenarios to see the effects of

- Enhanced technological development of EV and EV components (Technology Driven scenario),
- Stronger climate protection goals in the EU and national policies promoting EV (Policy Driven scenario).

The BaU scenario framework is defined by EU-wide scenario and country specific parameters.

## 3.1 EU-wide scenario framework

### 3.1.1 Economic and political framework

**$CO_2$ targets**

The storyline of the BaU scenario is underlined by the basic concept that current policies and technologies are not frozen to the status of today but do show an evolution over time. Consequently, the eMAP consortium decided to incorporate a tightening of the EU $CO_2$ targets for passenger cars beyond 2020 as it is already discussed today. The $CO_2$ target curve as assumed in the BaU scenario is thus the following: 130 g $CO_2$/km in 2010, 95 g $CO_2$/km in 2021[8] and 75 g $CO_2$/km in 2030.

**Other EU-wide parameters**

The evolution of oil and hydrogen prices in the EU as used in the BaU scenario is given in Table 2.

Table 2. BaU scenario: Oil and hydrogen prices

| | Unit | 2010 | 2020 | 2030 | Source |
|---|---|---|---|---|---|
| Oil price | [$\$_{2011}$/bbl] | 108 | 120 | 124 | IEA (2012) |
| $H_2$ price | [$€_{2010}$/kg] | 20 | 8 | 6 | McKinsey (2011) |

[8] While the EU $CO_2$ target for passenger cars is 95 g/km already in 2020, only 95% of each manufacturer's new passenger cars have to comply to that target; from 2021 on, this percentage is raised to 100% (Regulation (EU) No 333/2014)

Diesel and gasoline prices are depending on the evolution of the oil price. However, national taxes are major price components. Diesel and gasoline prices are thus calculated per country (see chapter 3.2).

Electricity markets, although deregulated, are still widely nationally based and are thus also modelled individually per country (see chapter 3.2).

### 3.1.2 Techno-economic framework

The EU-wide techno-economic framework of the BaU scenario is defined by $CO_2$ emission intensities, powertrain concepts, energy consumption, EV technologies and vehicle costs amongst others.

EU-wide well-to-tank $CO_2$ emission intensities cover upstream $CO_2$ emissions of fuels (CNG, diesel, gasoline and hydrogen). $CO_2$ emissions caused by the production of electricity are depending on the national energy mix and are thus calculated per country (chapter 3.2).

**Table 3. BaU scenario: Upstream $CO_2$ emissions of fuels**

| | | 2010 | 2020 | 2030 | Source |
|---|---|---|---|---|---|
| Well-to-tank $CO_2$ emission intensity [g/MJ] | Hydrogen | 100 | 73 | 21 | McKinsey (2011) |
| | Compressed Natural Gas | 9 | 9 | 9 | JEC (2013) |
| | Diesel | 18 | 17 | 16 | |
| | Gasoline | 16 | 15 | 15 | |

Six base powertrain concepts are modelled (Figure 1), among them five electrified powertrains: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), range extended electric vehicles (REEV), battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV). In total, 10 different drivetrains are taken into account (gasoline, gasoline HEV, gasoline PHEV, gasoline REEV, diesel, diesel HEV, compressed natural gas (CNG), CNG HEV, BEV and FCEV).

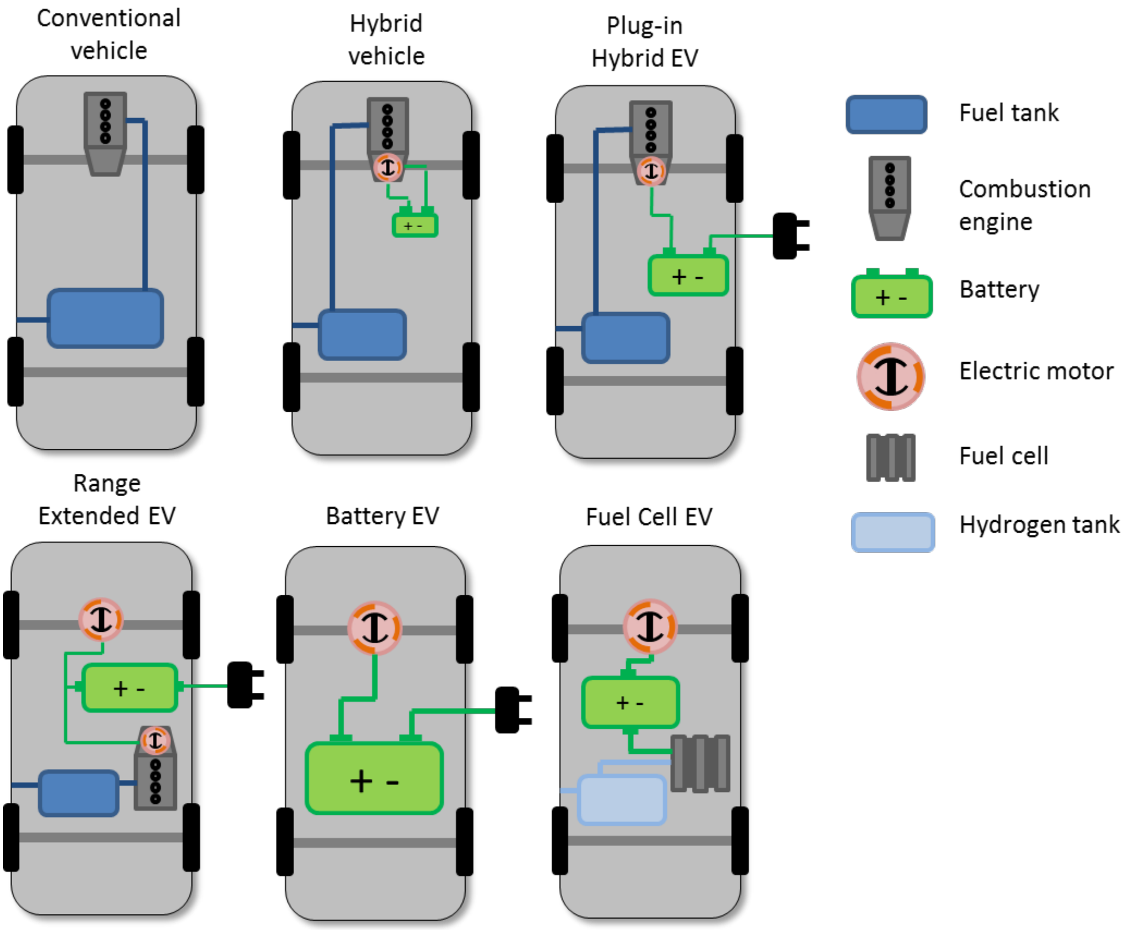


Figure 1. Powertrain concepts used for the scenarios; adapted from DLR & Wuppertal Institut (2015)

For the plug-in electrified powertrains PHEV and REEV that are able to drive certain distances purely electrically, the share of electric energy in total energy consumption is needed. It is calculated according to the type approval standards (NEDC[9]) as described in (UN/ECE R 101) and varies between powertrain concept and vehicle size (as the battery size varies). The range in the share driven in charge depletion mode is 58%-67% for PHEV and 72%-78% for REEV[10]. The share of electric energy in total energy consumption in [MJ/km] is ranging from 30%-33% for PHEV and 44%-48% for REEV.

Three segment sizes (small, medium and large) are modelled in VECTOR21. Their respective assignment of vehicle sizes according to the European Commissions' classification scheme is shown in Table 4.

[9] New European Driving Cycle
[10] referring to the distance driven

Table 4. Segment sizes in VECTOR21

| Segment size | EU classification | Model Examples |
|---|---|---|
| Small | A, B | Renault Zoe, Citroen C1, VW Polo, Smart fortwo, Ford Fiesta, Opel Corsa, Mini, Fiat 500, Skoda Fabia |
| Medium | C, D, S, M | Nissan Leaf, VW Golf, Audi A3, Skoda Octavia, Mercedes Benz C-Class, BMW 3, VW Passat, Porsche 911, Opel Meriva, Renault Scenic |
| Large | E, F, J | BMW i8, Mercedes Benz E-Class, Audi A6, Mercedes Benz S-Class, Audi A8, Nissan Qashqai, Ford Kuga, Porsche Cayenne, Tesla Model S, Audi Q3, VW Tiguan |

In VECTOR21, the above mentioned powertrain concepts are offered for all segment sizes (small, medium, large) with varying layout for the EV technologies traction battery, electric motor and power electronics (Table 5).

Table 5. Technical parameters for key EV technologies

| | Small | | | Medium | | |
|---|---|---|---|---|---|---|
| | Electric motor [kW] | Traction battery [kWh] | Power electronics [kW] | Electric motor [kW] | Traction battery [kWh] | Power electronics [kW] |
| HEV | 15 | 1 | 15 | 25 | 2 | 25 |
| REEV | 65 | 10 | 65 | 100 | 15 | 100 |
| PHEV | 40 | 8 | 40 | 60 | 12 | 60 |
| FCEV | 65 | 2 | 65 | 100 | 3 | 100 |
| BEV | 65 | 20 | 65 | 100 | 25 | 100 |

| | Large | | |
|---|---|---|---|
| | Electric motor [kW] | Traction battery [kWh] | Power electronics [kW] |
| HEV | 40 | 3 | 40 |
| REEV | 160 | 20 | 160 |
| PHEV | 90 | 16 | 90 |
| FCEV | 160 | 4 | 160 |
| BEV | 160 | 40 | 160 |

For an in-depth description of key EV components, refer to (Frieske et. al, 2015).

Prices for EV components (production costs plus margin) are calculated based on the number of sold units using learning curves (see Schimeczek et al. (2015) for a detailed methodological description).

Initial prices for traction battery systems in 2010 are assumed to be 450 €/kWh. Initial prices for power electronics and the electric motor start at 25 €/kWh in 2010, respectively. The resulting price curves until 2030 are given in chapter 3.3.5.

Energy consumption over time of the most efficient powertrain versions in the medium segment is shown in Figure 2. For each powertrain, an increase in energy efficiency is accounted for until 2025, varying from 9% for BEV to 30% for gasoline driven vehicles[11]. Generally, gasoline and CNG vehicles have higher efficiency potentials than diesel vehicles. Next to engine-based measures, lightweight construction and improvements in aerodynamic drag are taken into account. As energy consumption is decreasing over time, costs of powertrains are increasing accordingly.

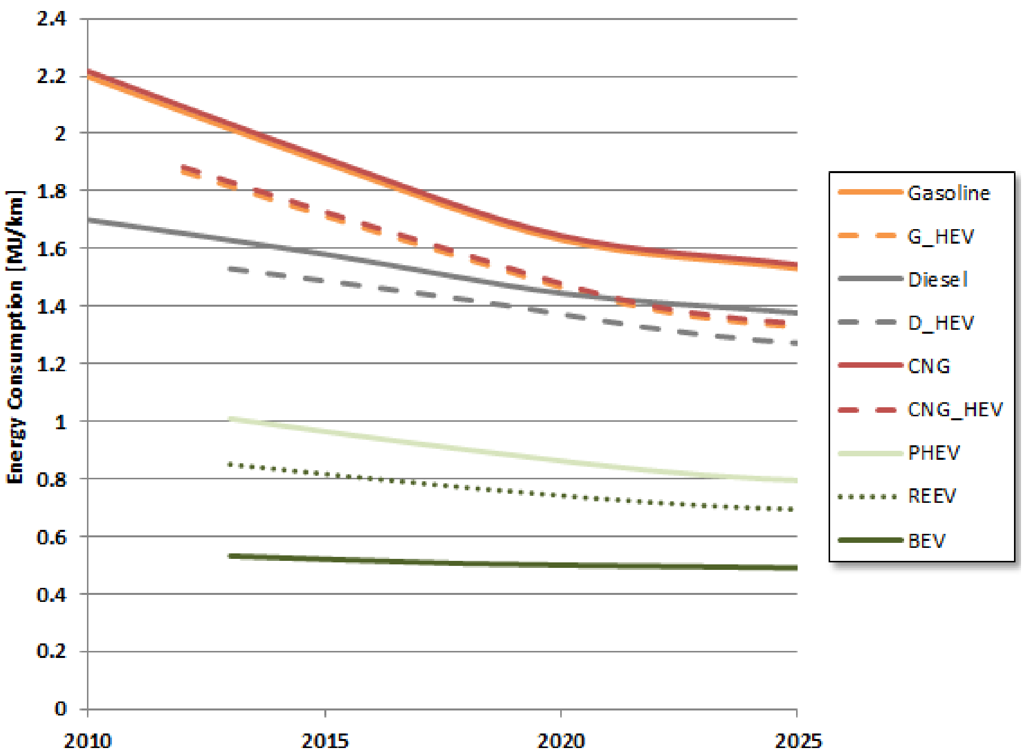


Figure 2. Energy consumption over time of VECTOR21 powertrains (most energy efficient version, medium segment)

[11] The underlying development is assumed based on know-how gained in other DLR projects for industrial clients.

## 3.2 National scenario framework

### 3.2.1 Finland

**Taxation scheme**

The Finnish automobile taxation scheme consists of taxes on acquisition (VAT, purchase tax), taxes on ownership and fuel taxes (VAT applied). The Finnish VAT is 23% up to 2012 and 24% from 2013 on.

**Taxes on acquisition**:

The Finnish purchase tax is based on $CO_2$ emissions (g per kilometre) and is calculated using Equation 1 and Equation 2 (ACEA, 2012).

Purchase tax [%] = 4.88 + 0.122*$CO_2$ [g/km] (valid up to 2011) **Equation 1**

Purchase tax [%] = 52.15 – 51.95/(1+$e^{0.015*(CO2[g/km]-152)}$) (valid from 2012 on) **Equation 2**

Minimum tax rates are 12.2% until 2012 and 5% since 2012, and maximum tax rates 48.8% and 50%, respectively (Figure 3). Battery electric vehicles are taxed based on the minimum rate. VAT is added on top.

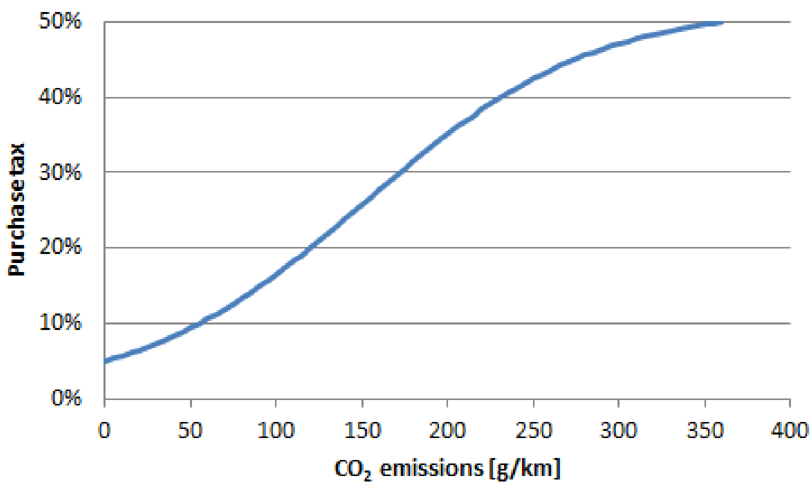


**Figure 3. Purchase tax rates over $CO_2$ emissions in Finland**

**Ownership tax**:

The annual ownership vehicle tax consists of a base tax based on $CO_2$ emissions and a tax on powertrain based on the gross vehicle weight. The base tax varies from € 20 per year for zero emitting cars to € 600 per year for cars with emissions of 400 g/km or higher (until end 2012), from 43.07 € per year to 606.26 € per year (between 2013 and 2015) and from 69.71 € per year to 617.94 € per year (from 2016 on) (ACEA, 2012 and Trafi, 2015).

The tax on driving power is imposed on vehicles that are powered by some other force or fuel than solely gasoline. Until the end of 2011, the tax was € 24.45 per year for every 100 kg of gross vehicle weight. It was reduced to € 20.07 per year for the year 2012 and since 2013 it has been differentiated according to the powertrain as shown in Table 6 (ACEA, 2012 and Trafi, 2015).

**Table 6. Powertrain part of the annual ownership tax – valid from 1.1.2013**

| Driving power | Euro/year/100kg gross weight |
|---|---|
| Gasoline (also G-HEV) | no tax |
| Diesel (also D-HEV) | 20.08 |
| Electricity | 5.48 |
| Electricity and gasoline (REEV)* | 3.65 |
| Electricity and gasoline (PHEV) | 1.83 |
| Electricity and diesel (PHEV) | 17.89 |
| Alternative fuels (CNG, LPG etc.) | 11.32 |

* estimated in between BEV and PHEV

**Fuel and electricity tax**

Taxes on fuel and electricity are a sum of excise duties and VAT. Excise duties on fuels are 0.65 €/l gasoline (2010-2014) and 0.38 €/l diesel in 2010, increasing to 0.50 €/l diesel in 2014 (ACEA, 2012). In the BaU scenario, it is assumed that fuel taxes are not raised any further and remain constant from 2014 on up to 2030.

Taxes on electricity are the same as for private households (ACEA, 2012).

**Infrastructure**

The assumption for fuel and charging infrastructure coverage until 2030 is given in Table 7.

**Table 7. Infrastructure coverage in Finland**

| Infrastructure coverage | 2010 | 2020 | 2030 |
|---|---|---|---|
| Gasoline/Diesel | 100% | 100% | 100% |
| Electricity | 5% | 30% | 55% |
| Hydrogen | 0% | 3% | 20% |
| CNG | marginal | | |

On the one hand, the number of slow and fast electric charging stations is moderate (Kleiner et al., 2015), but on the other hand, there are private outlets installed at most private residential and work place car parks or places for preheating of both the engine (around 1.5 million cars, 60% of the stock, with block heaters installed) and the interior of the car in winter time (IA-HEV, 2015). Because of that, it is assumed that Finland has moderately better infrastructure coverage for electricity than the other VECTOR21 markets. CNG vehicles and CNG fuel stations are marginal at the moment in Finland and are expected to remain so in the future.

Infrastructure coverage for hybrid powertrains like PHEV and REEV is calculated according to their share driven in charge depleting mode (share of electric energy) and their share driven in charge sustaining mode (share of gasoline). In Finland in 2030, this sums up to infrastructure coverage of 86% for PHEV and 80% for REEV. This in turn means that the VECTOR21 customer groups “Laggards” and “Late Majority” are not inclined to buy electrified vehicles until 2030 as their infrastructure requirements are higher.

**Vehicle sales and segment size shares**

Almost three quarter of the Finnish new vehicle sales in 2010 are cars of medium size (Table 8), followed by the small segment with 18% and the large segment with 9%. Compared to EU15 countries (IHS, 2014), where half of the newly manufactured cars are sold in the medium segment, medium sized cars are highly popular in Finland as many companies offer company cars for private use as part of the salary.

Table 8. New vehicle segment size shares in Finland and EU-15 (2010)

| | Share Finland | *Share EU15* |
|---|---|---|
| **Small** | 17.7% | *39.8%* |
| **Medium** | 73.6% | *51.9%* |
| **Large** | 8.7% | *8.3%* |

New vehicle sales as shown in Figure 4 are based on (ACEA, 2014) from 2010-2014 and a scenario of the Finnish national road emission model Aliisa for 2015-2030 (Mäkelä, 2014) which has its basis on a total road mileage scenario for Finland for 2030 (Ristikartano et al., 2014).

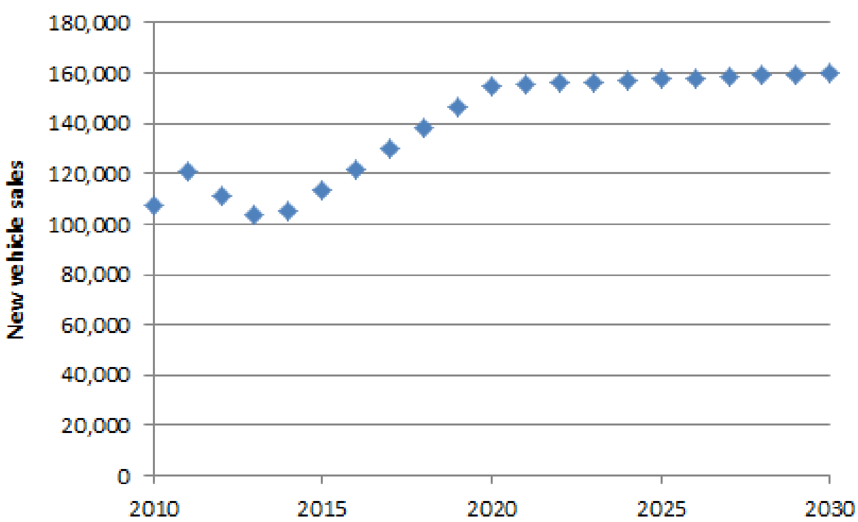


Figure 4. New vehicle sales in Finland 2010-2030 (ACEA, 2014; Mäkelä, 2014; Ristikartano et al., 2014)

### Yearly mileage distribution

As VECTOR21 is a cost-based market model, the yearly mileage per respective customer is needed. Finnish mileage distribution curves per vehicle segment are shown in Figure 5 and were calculated based on odometer readings of ca 30% of cars over 3 years in 2010 (Järvi, 2013) using a cross-sectional method. The annual mileage of small vehicles is smaller than the annual mileage of large vehicles. It is assumed that the minimum mileage is 1,000 km per year.

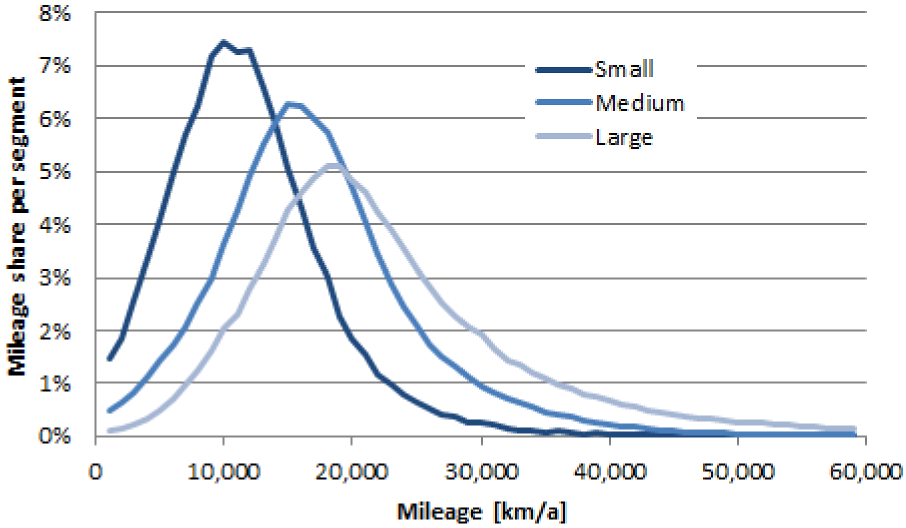


Figure 5. Yearly mileage distribution per vehicle segment in Finland; own calculation based on (Järvi, 2013)

### Electricity prices

Electricity prices in Finland today are relatively low, amongst others due to a 30% share of electricity produced by nuclear energy. There are approved plans in Finland to construct two more nuclear power plants, so that the share of electricity produced by nuclear could reach up to 60% in 2025. At the same time, Finland has a target of 38% renewables for electricity production by 2020 using its vast amounts of wooden biomass (IEA, 2013).

Finnish electricity prices as used in VECTOR21 for 2010 until 2030 were taken from the Finnish Energy Authority for households as an average of monthly prices for four different user groups of households (Figure 6). These prices show a very moderate increase from 11 € ct. per kWh in 2010 to 13 € ct. per kWh in 2030.

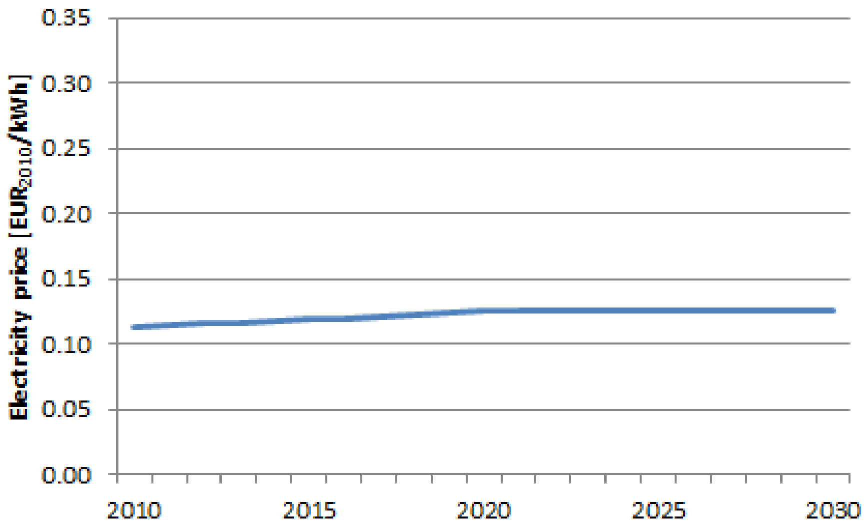


Figure 6. Electricity prices used for Finland 2010-2030 (taxes included)

**Fuel Prices**

Gasoline and diesel fuel prices are calculated using a regression analysis of historical oil prices and Finnish historical fuel prices following the methodology of (Mock, 2010). Figure 7 shows the resulting graphs.

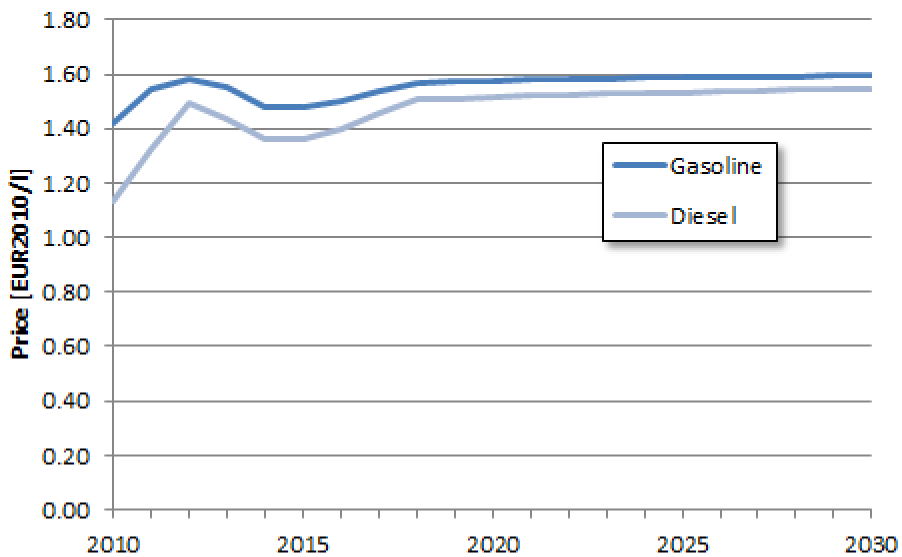


Figure 7. Gasoline and diesel prices used for Finland 2010-2030 (VAT and fuel taxes included)

Figures are real prices up to 2014 taken from the Oil Bulletin of the European Commission (European Commission, 2014) and then estimated to 2030 using the oil price scenario as described in chapter 3.1. In 2014, the fuel tax on diesel was increased from 38 € ct. per litre to 50 € ct. per litre; it is assumed that fuel taxes remain constant from 2014 on.

### 3.2.2 Germany

**Taxation scheme**

The German automobile taxation scheme includes VAT, taxes on ownership and fuel taxes. VAT is at 19%.

**Ownership tax**:

Since 2009, the annual vehicle ownership tax in Germany consists of a tax on displacement size and a tax for $CO_2$ emission exceedances: above 120 g $CO_2$/km until 2011, above 110 g/km until 2013 and above 95 g/km from 2014 on. Owners of diesel cars have to pay higher rates (Equation 3 and Equation 4).

Gasoline: Ownership tax [€] = 2*displacement size [l] *10 + 2*[$CO_2$-95] [g/km] (if >95 g/km from 2014 on) **Equation 3**

Diesel: Ownership tax [€] = 9.5*displacement size [l] *10 + 2*[$CO_2$-95] [g/km] (if >95 g/km from 2014 on) **Equation 4**

**Fuel and electricity tax:**

Taxes on fuel are a sum of excise duties and VAT. Excise duties on fuels are 0.6545 € per litre gasoline and 0.4704 € per litre diesel. For CNG in transport, there is a reduction in excise duties until the end of 2018 to 13.90 € per MWh (ca. 0.19 €/kg). From 2019 on, excise duties on CNG are 31.80 €/MWh (ca. 0.44 €/kg).

Taxes and levies on electricity are a sum of charges for renewables, network maintenance and concession, combined heat and power as well as taxes on energy and VAT.

**Infrastructure**

The assumption for fuel/charging infrastructure coverage until 2030 is given in Table 9. While there is always a sufficient number of gasoline and diesel fuel stations within easy reach, the electricity, CNG and hydrogen network has to be built up first. The European Commission has set a target of 1.5 million electric charging points in Germany in 2020, of which 10% should be available in public. For further details, see (Kleiner et al., 2015).

The installation of public charging points in Germany started after 2010, thus an initial coverage of 0% was assumed for 2010. The underlying assumption is that potential EV buyers will require at least one charging station within their periphery. Once that charging station is available EV are bought. In addition, EV drivers will use private charging points (e.g. in their garages or by installing wall boxes). The figures given in Table 9 therefore represent the sum of private and public charging points.

Table 9. Hydrogen, CNG and electricity infrastructure coverage in Germany

| Infrastructure coverage | 2010 | 2020 | 2030 |
|---|---|---|---|
| Gasoline/Diesel | 100% | 100% | 100% |
| Electricity | 0% | 25% | 50% |
| CNG | 7% | 10% | 17% |
| Hydrogen | 0% | 1% | 4% |

Infrastructure coverage for hybrid powertrains like PHEV and REEV is calculated according to their share driven in charge depletion mode and their share driven in charge sustaining mode. In Germany in 2030, this sums up to infrastructure coverage of 85% for PHEV and 78% for REEV. This in turn means that the VECTOR21 customer groups “Laggards” and “Late Majority” are not inclined to buy electrified vehicles until 2030 as their infrastructure requirements are higher.

**Vehicle sales and shares**

In 2010, 59% of the German cars that were newly sold were of medium size (Table 10), followed by the small segment with 28% and the large segment with 13%. This roughly follows EU-15 segment size shares (IHS, 2014), although in Germany medium and large cars are more popular.

Table 10. Vehicle segment shares in Germany and EU-15 (2010)

| | Share | *Share EU15* |
|---|---|---|
| Small | 28.0% | *39.8%* |
| Medium | 59.3% | *51.9%* |
| Large | 12.6% | *8.3%* |

New vehicle sales in Germany are based on (ACEA, 2014) from 2010-2014 and then extrapolated to reach the level of vehicle sales prior to the economic crisis at 3.2 million annually (Figure 8).

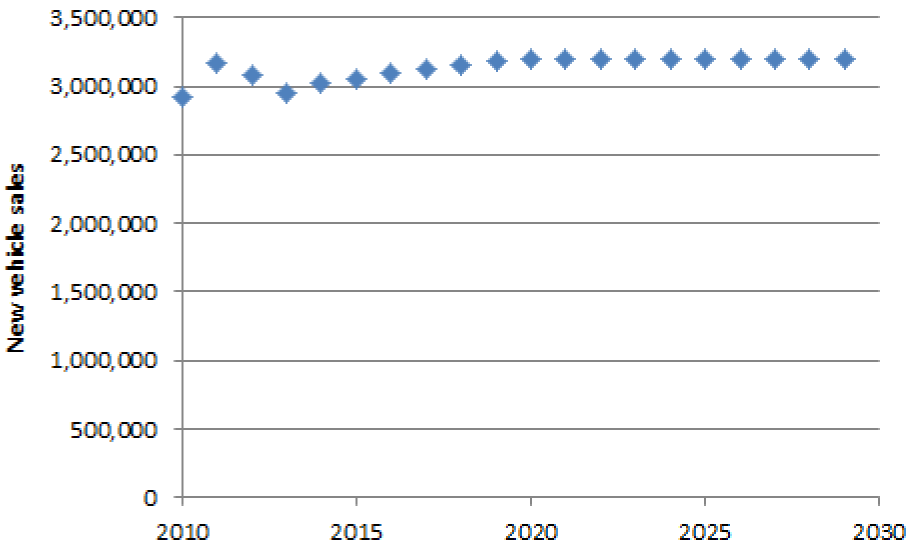


Figure 8. New vehicle sales in Germany 2010-2030

**Yearly mileage distribution**

German mileage distribution curves per new vehicle segment are shown in Figure 9. Small vehicles will be driven less annually than large vehicles. It is assumed that the minimum mileage is 1,000 km per year and the maximum mileage is 60,000 km per year.

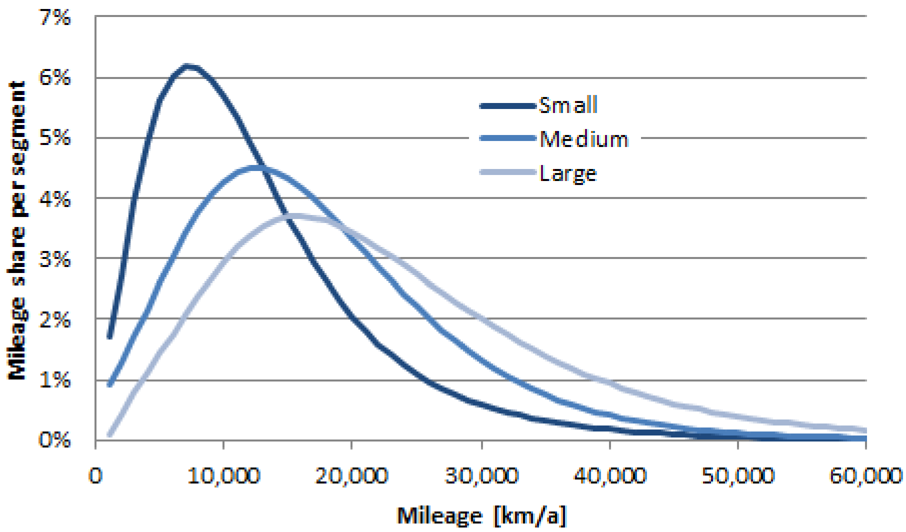


Figure 9. Yearly mileage distribution per new vehicle segment in Germany (Mock, 2010)

**Electricity prices**

German electricity today (2014) is mainly produced by non-renewable sources summing up to around 70% of the electricity mix, of which 16% are nuclear (Destatis, 2015). Germany adopted a phase-out-plan for nuclear energy by 2022 and has a target of 35% by 2020 for renewables used for electricity production.

Figure 10 shows the electricity prices as used for the BaU scenario in Germany from 2010 up to 2030. The underlying scenario for the electricity production costs was taken from (Nitsch et al., 2012) scenario C, following the targets given in the so-called “energy concept” of the German federal government (Bundesregierung, 2010). In addition to the production costs, network charges, concession fees, fees for the integration of renewables and cogeneration, electricity taxes and VAT sum up to form the final electricity prices. The development of those additional electricity price components was estimated using own calculations. Electricity prices in the BaU scenario in Germany thus increase from 24 ct. per kWh in 2010 to 32 ct. per kWh in 2030.

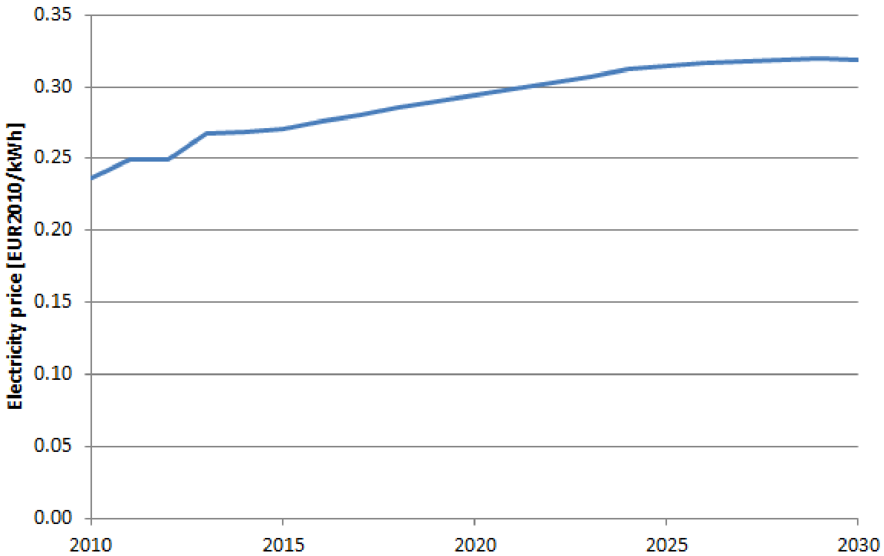


Figure 10. Electricity prices used for Germany 2010-2030; electricity production costs taken from Scenario C (Nitsch et al., 2012)

**Fuel prices**

Gasoline and diesel fuel prices are calculated using a regression analysis of historical oil prices and German historical fuel prices following the methodology of (Mock, 2010). Figure 11 shows the resulting graphs. Figures are real prices up to 2014 taken from the Oil Bulletin of the European Commission (European Commission, 2014) and then estimated to 2030 using the oil price scenario as described in chapter 3.1.

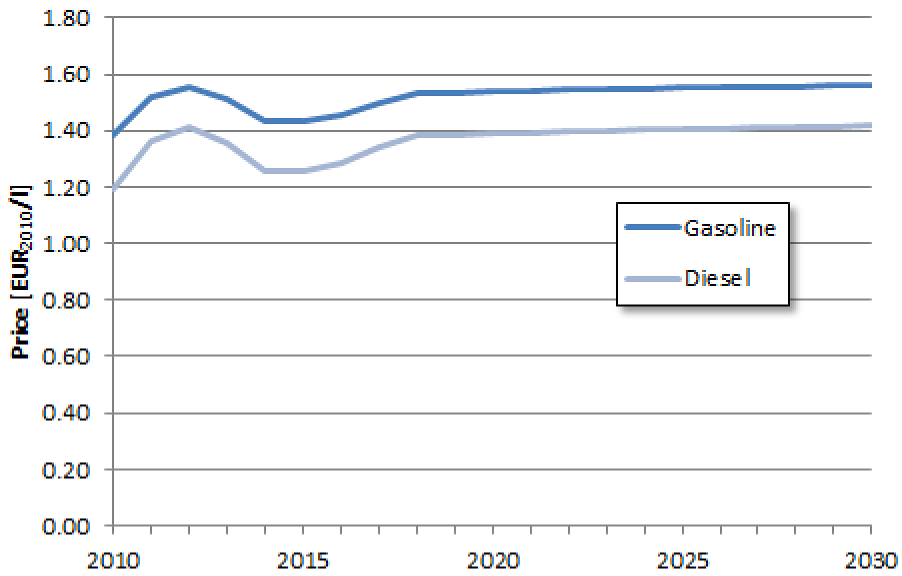


Figure 11. Gasoline and Diesel prices used for Germany 2010-2030 (VAT and fuel taxes included)

### 3.2.3 Poland

**Taxation scheme**

The Polish automobile taxation scheme consists of taxes on acquisition (VAT, purchase tax) and fuel taxes. There is no ownership tax in Poland.

**Purchase tax:**

VAT in Poland is 23%. Purchase tax in Poland is 3.1% for vehicles up to 2.0 litre displacement and 18.3% for vehicles with more than 2.0 litres. Therefore in Poland passenger cars, also in the large segment, are usually offered with a displacement of 2.0 litres or less. It is assumed that customers will not buy vehicles with a higher displacement as this would be unwise in economic terms.

**Fuel and electricity tax:**

Fuel taxes for gasoline amount to 54% and to 48% for diesel. In 2011, taxes included in end user electricity prices totalled 22.2% (3 € ct./kWh).

**Vehicle sales and shares**

In 2010, over 60% of the newly sold cars in Poland were medium-sized (Table 8) and a third small-sized. Sales figures of large cars were considerably lower than sales figures of EU-15 (IHS, 2014).

Table 11. Vehicle segment shares in Poland and EU-15 (2010)

| | Share | *Share EU15* |
|---|---|---|
| **Small** | 33.5% | *39.8%* |
| **Medium** | 63.3% | *51.9%* |
| **Large** | 3.2% | *8.3%* |

In 2010, around 70% of the newly sold cars were fuelled by petrol (and, to a lesser extent, dual fuelled by petrol and LPG). Among the new purchases 42% concerned individual buyers.

Passenger car stock renewal in Poland is based on imported used cars, mainly from other EU countries (e.g. Germany). This is by no means negligible as imports of used cars amount to about 65% of Polish vehicle registrations (PZPM, 2014). There is no indication that this trend will change within the next years, justified by the economic situation including a high rate of unemployment, emigration of young educated people and an increasing number of elderly people.

New vehicle sales in Poland as depicted in Figure 12 are based on (ACEA, 2014) for 2010, on (IHS, 2014) for 2011-2013 and on (Waśkiewicz & Chłopek, 2013) for 2020 and 2030. Note that the ACEA-based sales figures in 2010 are higher than sales figures reported in other statistics (CSO, 2011) and might result in a slight overestimate of new vehicle sales.

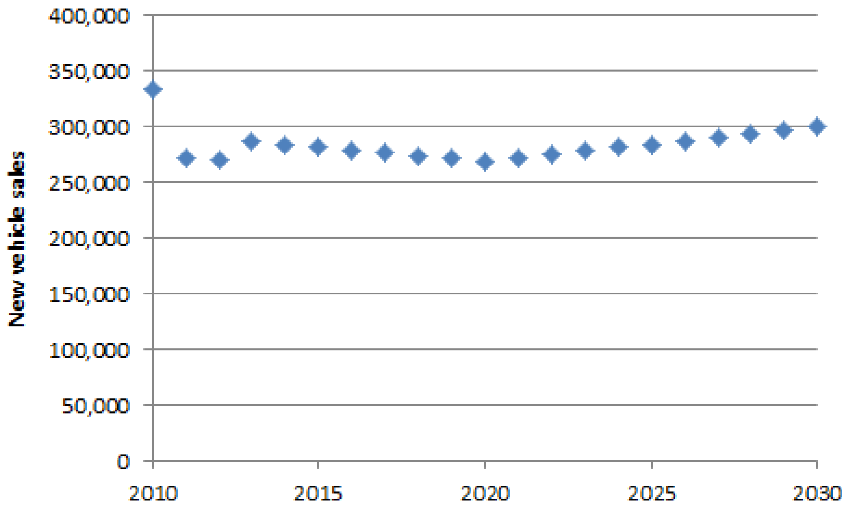


Figure 12. New vehicle sales in Poland 2010-2030 (ACEA, 2014; IHS, 2014; Waśkiewicz & Chłopek, 2013)

**Yearly mileage distribution**

Mileage distribution curves per new vehicle segment as implemented for Poland are shown in Figure 13. Small vehicles are driven less than large vehicles per year. It is assumed that the minimum mileage is 1,000 km annually. In comparison to Finland and Germany, average mileage is relatively low.

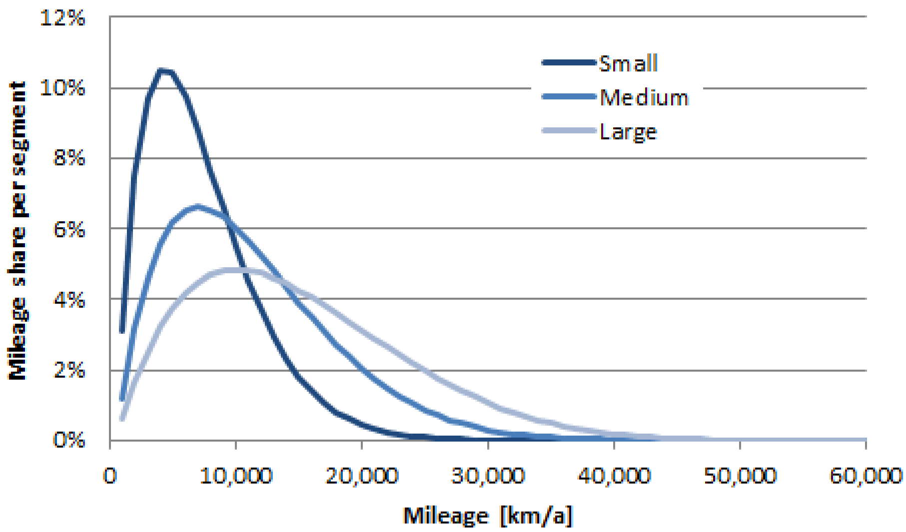


Figure 13. Yearly mileage distribution per new vehicle segment in Poland based on (ITS, 2015) and own calculations

### Infrastructure

The assumption for fuel/charging infrastructure coverage until 2030 is given in Table 12. The European Commission has set a target of 460.000 electric charging points in Poland in 2020, of which 10% should be available in public (Kleiner et al., 2015). It is assumed that this target cannot be met (ITS, 2015).

Table 12. Hydrogen, CNG and electricity infrastructure coverage in Poland

| Infrastructure coverage | 2010 | 2020 | 2030 |
|---|---|---|---|
| Gasoline/Diesel | 100% | 100% | 100% |
| Electricity | 0% | 3% | 28% |
| Hydrogen | marginal | | |
| CNG | 1% | 10% | 13% |

By 2030, Poland is not expected to significantly develop a CNG infrastructure. Likewise, a significant build-up of hydrogen infrastructure is not to be expected by 2030 (Waśkiewicz & Chłopek, 2013).

### Electricity prices

Electricity in Poland today is mainly produced by fossil sources, mostly coal (92%). There are plans to enhance the number of nuclear power plants by 2030 (IEA, 2011).

The electricity price scenario is based on data for average electricity prices for retail customers in 2010 and an expected increase in electricity prices (Figure 14). Starting from an average electricity price of 0.55 PLN/kWh (14 €ct./kWh) in 2010, electricity prices will increase to 20 €ct./kWh.

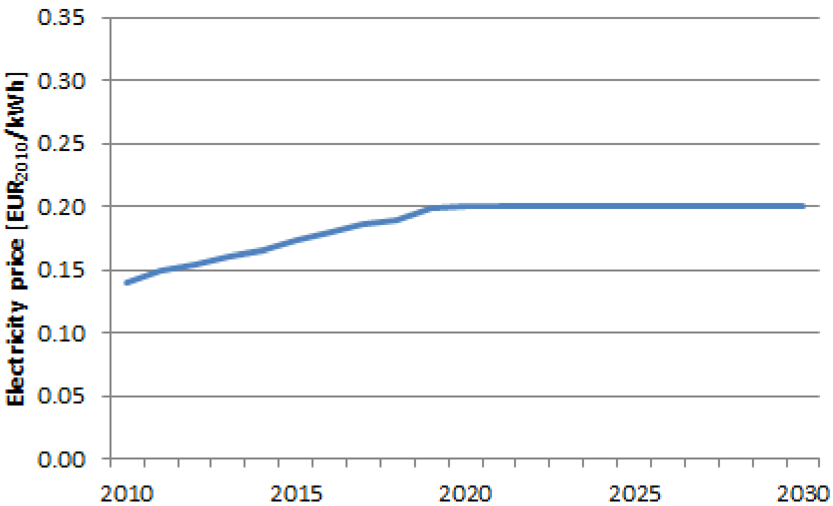

Figure 14. Electricity prices used for Poland 2010-2030 with taxes included (based on ITS 2015)

**Fuel prices**

Gasoline and diesel fuel prices are calculated using a regression analysis of historical oil prices and Polish historical fuel prices following the methodology of (Mock, 2010). Figure 15 shows the resulting graphs. Figures are real prices up to 2014 taken from the Oil Bulletin of the European Commission (2014) and then estimated to 2030 using the oil price scenario as described in chapter 3.1.

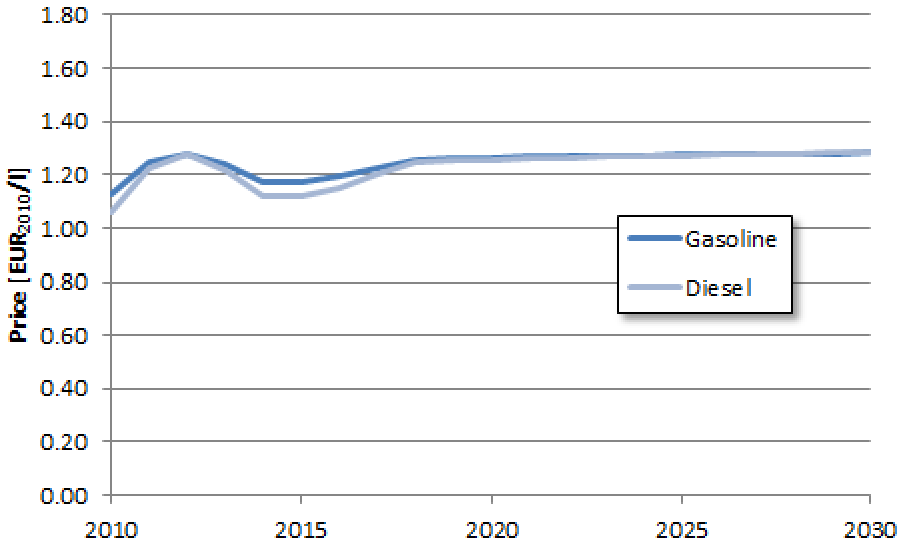


Figure 15. Gasoline and Diesel fuel prices used for Poland 2010-2030

**Imports from other European markets**

In Poland, the market for new vehicles is comparatively small as a significant number of second-hand vehicles are imported from other European countries: about 65% of Polish vehicle registrations are imports (ITS, 2015). As this has a non-negligible effect on the composition of the Polish car stock and thus energy consumption and $CO_2$ emissions, this feature was incorporated in the VECTOR21 market for Poland. Investigations have shown that the size share of imported vehicles is similar to the size share of the new vehicles sold in the corresponding years. Also, the share of different powertrains of the imported vehicles resembles that of the new vehicles sold in Poland. The imported vehicle fleet is thus expected to have the same composition as the new vehicle fleet – with the difference of a slightly higher energy consumption due to the higher age of the imported vehicles, which is considered in VECTOR21.

### 3.2.4 Other VECTOR21 markets

Apart from Finland, Germany and Poland, the European markets France, Italy and the United Kingdom were modelled individually thus covering about three quarters of the EU28 new vehicle market (Schimeczek et al. 2015). The same level of detail as for Finland, Germany and Poland was used for modelling France, Italy and the UK. Most important features are described in the following.

**France**

**Taxation scheme**

In France, the automobile taxation scheme includes VAT (19.6% in 2010, 20% in 2015), ownership taxes and taxes on fuel and electricity. Ownership taxes are at 160 € per year for vehicles over a certain $CO_2$ emission threshold: ≥ 245g/km in 2010 and 2011 and ≥ 190g/km in 2012. From 2013 on, ownership taxes are based on a Bonus-Malus system.

**Bonus-Malus system**

France is a highly regulated market with a Bonus-Malus ownership tax system based on a $CO_2$ emission threshold (135 g $CO_2$/km in 2013, 130 g $CO_2$/km in 2014). Within the BaU scenario, the underlying assumption was twofold (Table 13):

- Malus payments are assumed to be kept until 2030 (with a $CO_2$ emission threshold of 105 g/km from 2017 on);
- Bonus credits are assumed to be kept until 2022 (with a stepwise reduction of the $CO_2$ emission threshold to 5 g/km in 2022).

Table 13. BaU scenario: Assumptions on the Bonus-Malus system in France

<table>
<tr><th></th><th>2014</th><th colspan="2">2015</th><th colspan="2">2020</th><th>2025</th><th>2030</th></tr>
<tr><td rowspan="2">Bonus Minimum [CO2/km]</td><td colspan="5">-150 €</td><td colspan="2" rowspan="3">No Bonus assumed</td></tr>
<tr><td>(≤ 85 g)</td><td colspan="2">(≤ 75 g)</td><td colspan="2">(≤ 25 g)</td></tr>
<tr><td rowspan="2">Bonus Maximum [CO2/km]</td><td>-6,300 €</td><td>-5,000 €</td><td>-5,600 €</td><td>-550 €</td><td>-2,100 €</td></tr>
<tr><td colspan="2">(≤ 20 g)</td><td>(0 g)</td><td>(≤ 10 g)</td><td>(0 g)</td><td colspan="2">-</td></tr>
<tr><td rowspan="2">Malus Minimum [CO2/km]</td><td colspan="3">+150 €</td><td colspan="2">+350 €</td><td colspan="2">+500 €</td></tr>
<tr><td>(> 130 g)</td><td colspan="2">(> 120 g)</td><td colspan="4">(> 100 g)</td></tr>
<tr><td rowspan="2">Malus Maximum [CO2/km]</td><td>+8,000 €</td><td colspan="2">+10,000 €</td><td colspan="4">+10,000 €</td></tr>
<tr><td colspan="3">(≥ 200 g)</td><td colspan="2">(> 185 g)</td><td>(> 175 g)</td><td>(> 155 g)</td></tr>
</table>

**Prices for fuel and electricity**

Fuel prices in France up to 2030 (Figure 16) were derived using the same methodology as in Germany, Finland and Poland. Prices in 2030 are expected to have moderately increased to 1.50 $€_{2010}$/l Gasoline and 1.37 $€_{2010}$/l Diesel.

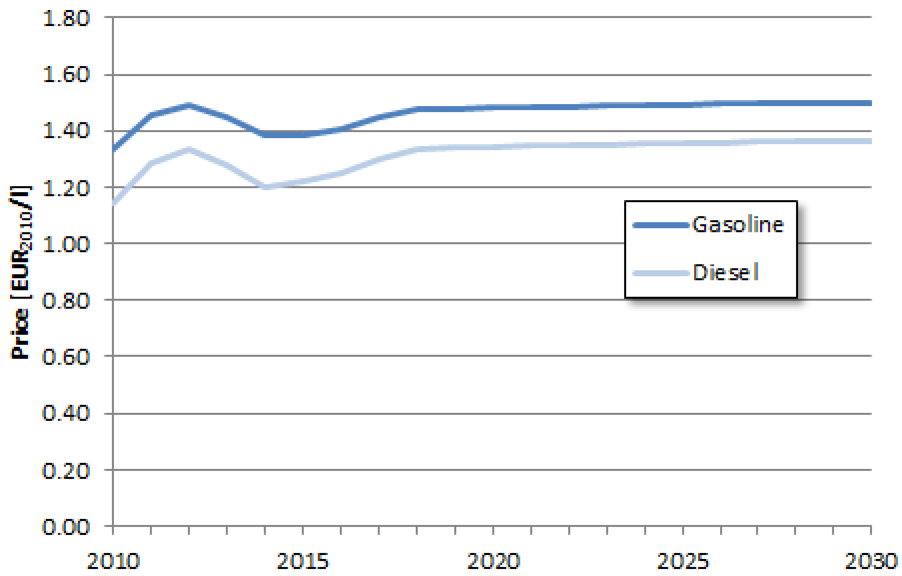


Figure 16. Gasoline and diesel prices used for France 2010-2030 (VAT and fuel taxes included)

Electricity prices in France are comparatively low. By trend analysis, they are expected to show a slight increase towards 2030 to 17 $€ct_{2010}$/kWh.

**Italy**

**Taxation scheme**

The automobile taxation scheme in Italy includes VAT (20% in 2010, 22% in 2015), registration fees, taxes on ownership and taxes on fuel and electricity.

Ownership taxes for gasoline, diesel and hybrid vehicles are the following:

Ownership tax [€] = 2.65*engine power [kW]
(if <=100 kW) Equation 5

Ownership tax [€] = 3.97*engine power [kW]
(if >100 kW) Equation 6

There are no ownership taxes for alternative powertrains like CNG, PHEV or BEV.

Registration fees are a sum of a base fee of 125 € and a variable fee depending on engine power.

**Prices for fuel and electricity**

Italian Gasoline and Diesel prices have seen a significant increase in the last years and are expected to remain at a relatively high level towards 2030 (Figure 17).

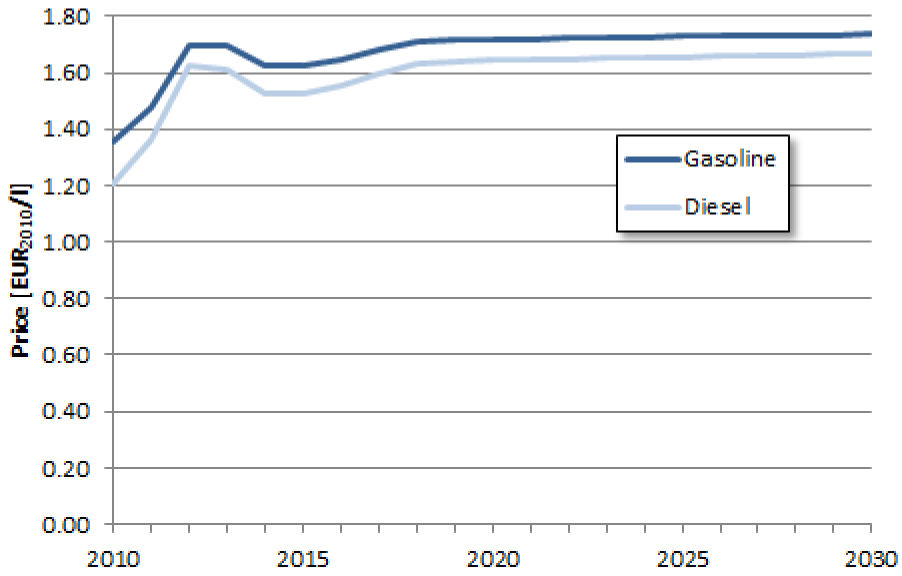


Figure 17. Gasoline and diesel prices used for Italy 2010-2030 (VAT and fuel taxes included)

Electricity prices in Italy are slightly higher than average EU household prices and are expected to remain relatively constant up to 2030 at 21 €ct$_{2010}$/kWh.

CNG prices are comparatively low at 0.98 €$_{2010}$/kg on average (NGVA 2015). In addition, and in contrast other European markets, the Italian CNG refuelling infrastructure is well developed.

**United Kingdom**

**Taxation scheme**

Taxes for automobiles in the United Kingdom include taxes on ownership, registration fees, VAT (17.5% in 2010, 20% in 2020) and taxes on fuel and electricity. Taxes on ownership are depending on $CO_2$ emissions, where gasoline and diesel fueled cars are paying “Standard Rates” and other vehicles “Alternative Rates” (Table 14).

Table 14. Ownership tax bands in the United Kingdom

| $CO_2$ band | Standard Rate [€] | Alternative Rate [€] |
|---|---|---|
| 0-100 | 0 | 0 |
| 100-110 | 19.1 | 9.5 |
| 110-120 | 28.6 | 19.1 |
| 120-130 | 104.8 | 95.3 |
| 130-140 | 165.1 | 152.4 |
| 140-150 | 184.2 | 171.5 |
| 150-165 | 228.6 | 215.9 |
| 165-175 | 287.3 | 274.6 |
| 175-185 | 323.9 | 311.2 |
| 185-200 | 406.4 | 393.7 |
| 200-225 | 568.3 | 555.6 |
| 225-255 | 735 | 722.3 |
| >255 | 822.3 | 809.6 |

Registration fees are at 70 € (55 £) for all vehicles.

**Prices for fuel and electricity**

Contrary to most other countries, diesel is slightly more expensive in the United Kingdom than Gasoline as differences in taxation are not as pronounced. Using the methodology as described previously, Diesel prices are assumed to be at 1.63 €$_{2010}$/l and Gasoline prices at 1.56 €$_{2010}$/l in 2030 (Figure 18).

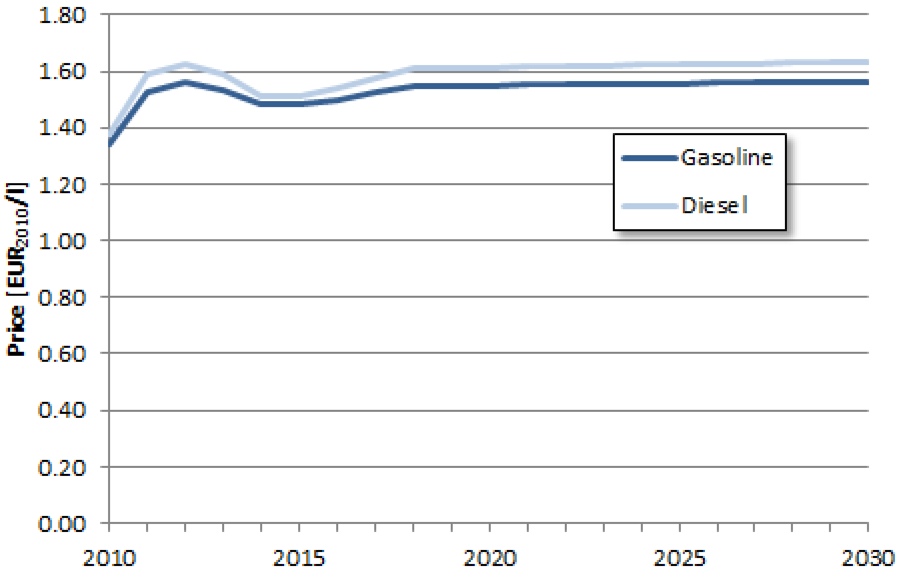


Figure 18. Gasoline and diesel prices used for the United Kingdom 2010-2030 (VAT and fuel taxes included)

In the UK, electricity prices have seen an upward trend in the past years and are thus expected to further increase to 29 €ct$_{2010}$/kWh in 2030.

## 3.3 BaU scenario results

### 3.3.1 Finland

**Market shares**

Vehicle sales per powertrain in the small segment in Finland 2010-2030 under the assumptions of the BaU scenario are shown in Figure 19. Until 2025, this segment is dominated by gasoline driven vehicles. Diesel vehicles rapidly disappear from the market due to an increase in diesel fuel taxes in 2012 and 2014, respectively. In 2030, electrified powertrains (gasoline hybrids, plug-in hybrids, range extended and battery electric vehicles) make up for 50% of new vehicle sales in the small segment. Firstly, this is due to a strong linkage of $CO_2$ emissions with purchase and ownership taxes in Finland (see chapter 3.2.1). Secondly, Finnish drivers have a relatively high mileage in comparison to other countries allowing – in combination with relatively low electricity prices - for a faster amortisation of the additional costs of electrified vehicles. CNG-powered vehicles do not enter the Finnish market as CNG filling station infrastructure is marginal, whereas fuel cell vehicles are too costly, both in acquisition and refuelling.

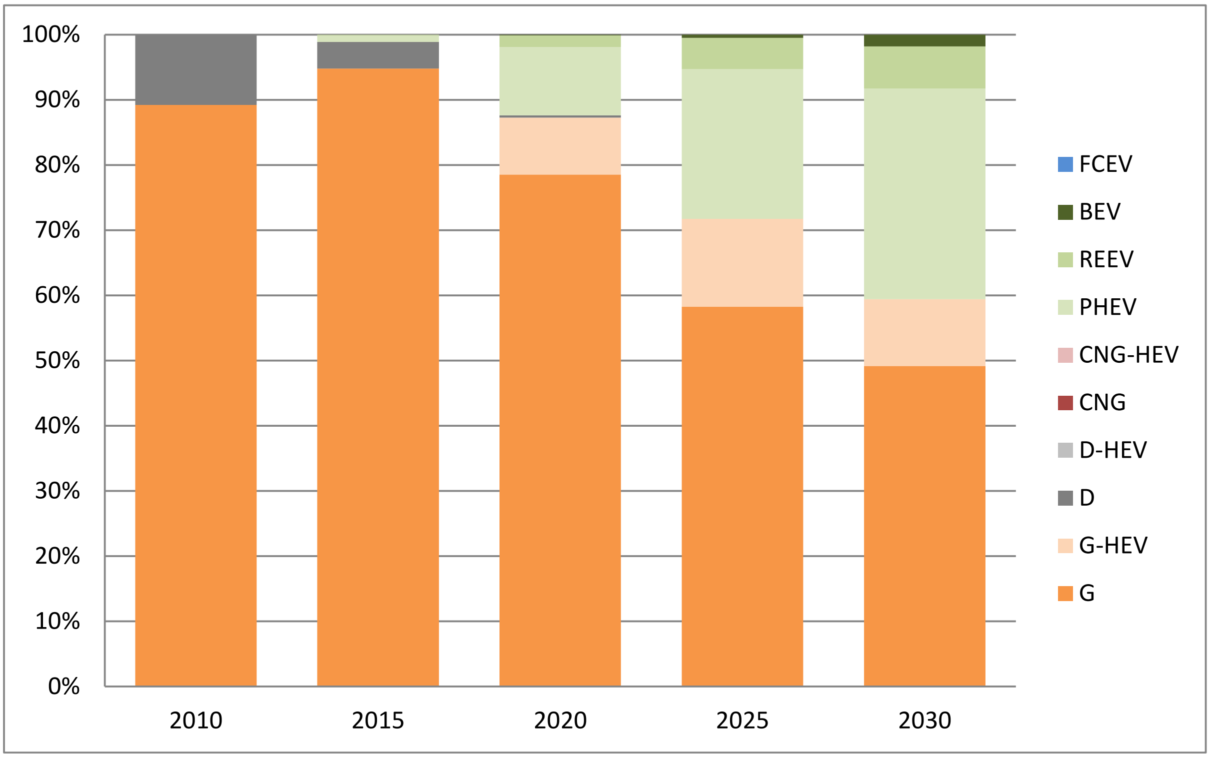


Figure 19. BaU scenario: vehicle sales in Finland, small segment

With a share of 74% of the Finnish new vehicle market, the medium segment (Figure 20) has a large impact on powertrain shares and thus energy consumption and decarbonisation of the Finnish fleet. Gasoline driven vehicles (including gasoline HEV) are less dominant than in the small vehicle segment, but still shape the medium segment up to the year 2025 in the BaU scenario. Due to the larger average mileage of the medium segment diesel vehicles are more popular than in the small segment, but still fade out until 2025 because of relatively high excise taxes for diesel (see chapter 3.2.1). In this segment, a significant amount of battery electric vehicles is chosen, as amortisation is faster - a fact that is also directly connected to the large Finnish mileage and cheap electricity prices.

Finnish tax policies under the assumptions of the BaU scenario result in an almost 50% electrification in the medium segment in 2025 (BEV, REEV, PHEV and gasoline HEV), increasing to over 60% in 2030. Following the line of argument of Figure 19, CNG and fuel cell vehicles are also not bought in the medium segment until 2030.

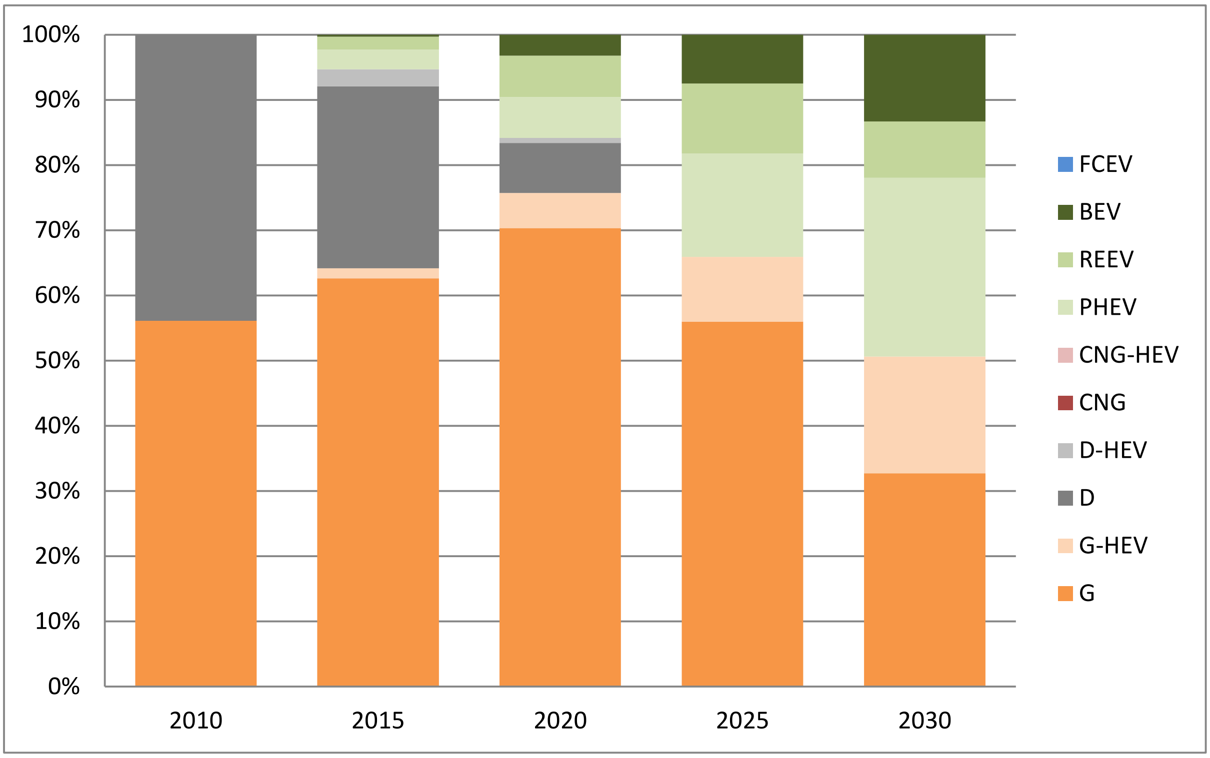


Figure 20. BaU scenario: vehicle sales in Finland, medium segment

The percentage of purchase taxes in Finland increases according to a vehicle's $CO_2$ emissions. Therefore, large conventional powered cars are more affected by the purchase tax, in absolute terms, than smaller conventional vehicles. In combination with a very high average mileage the focus is shifted towards fuel-efficient vehicles. The large segment, depicted in Figure 21, is thus dominated by diesel vehicles in 2010. In the following years under BaU scenario assumptions, diesel-powered vehicles are gradually replaced by electrified vehicles, reaching a market share of more than 90% in that segment in the year 2030. The short and small comeback of gasoline-powered vehicles, reaching a maximum market share of about 11% in 2020, is connected to an efficiency increase of late gasoline-powered vehicles, which are attractive to a few number of Finnish customers with an annual mileage with and below 10,000 km.

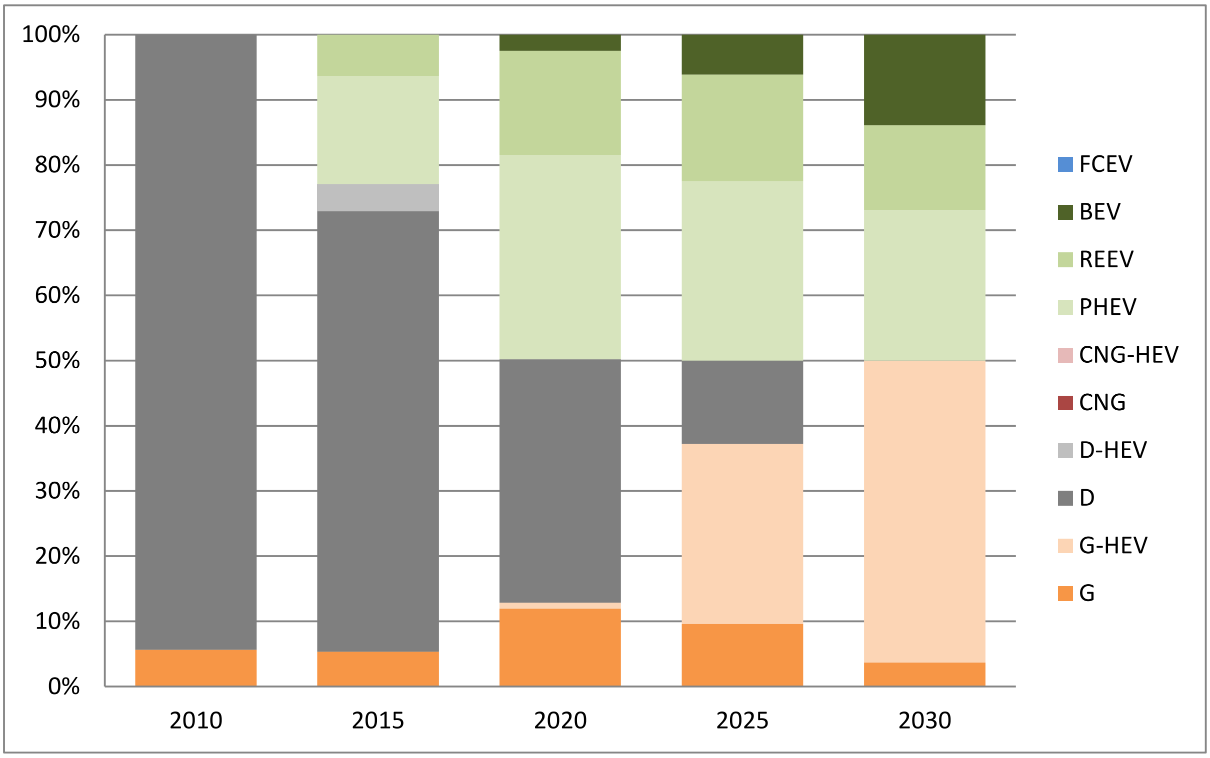


Figure 21. BaU scenario: vehicle sales in Finland, large segment

**Stock**

Results for the Finnish stock under the assumptions of the BaU scenario as total numbers for all segments are shown in Figure 22. In general, the diffusion of powertrains in the stock is much slower than in the new vehicle market, since old vehicles remain in the stock for the duration of the respective vehicle lifetime. However, Finnish vehicles have a particularly long lifetime of about 19 years on average, which is why the Finnish stock, despite the strong sales of electrified vehicles, still features almost 70% conventional diesel and gasoline vehicles in 2030 (the majority being gasoline-powered).

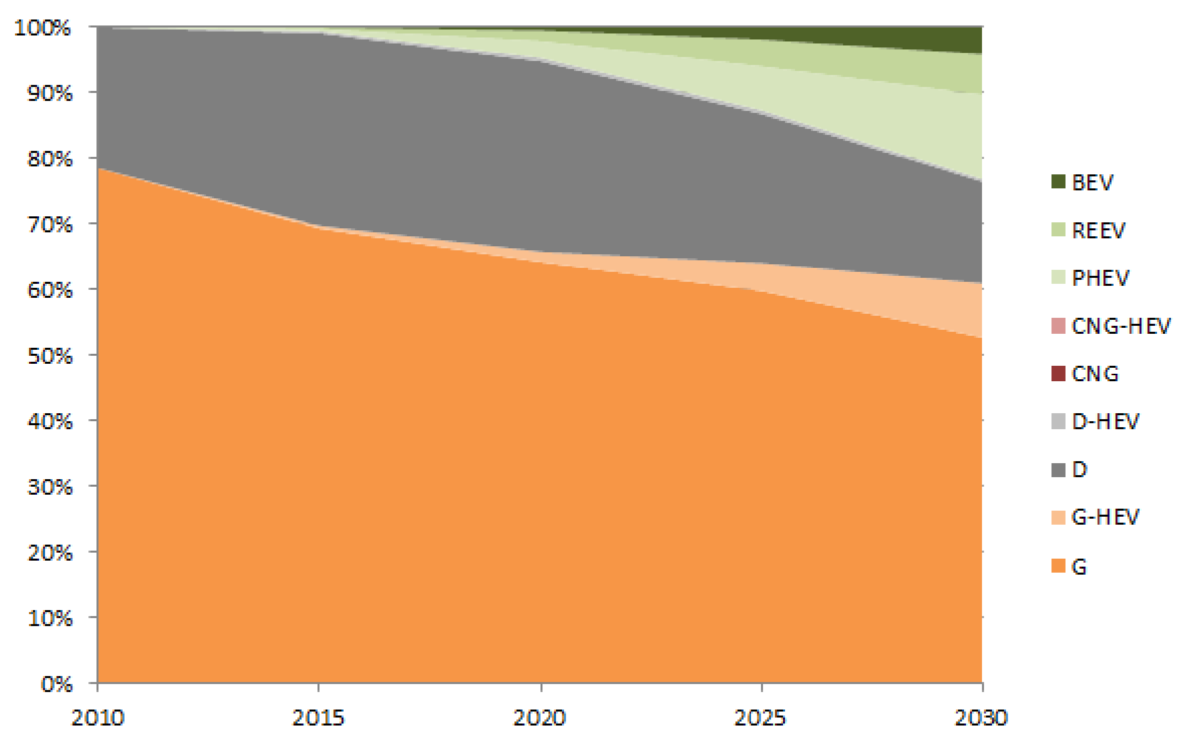


Figure 22. BaU scenario: total vehicle stock in Finland

Figure 23 shows the total energy consumption of the Finnish vehicle stock. Total energy consumption decreases by 21% in that period achieved by increasing efficiencies of conventional powertrains as well as by the market penetration of highly-efficient electrified vehicles. Energy savings per individual vehicle in 2030 compared to 2010 are high. This is levelled, however, by the strong growth of the stock by 25% up to 2030 (as new vehicle sales increase, c.f. Figure 4).

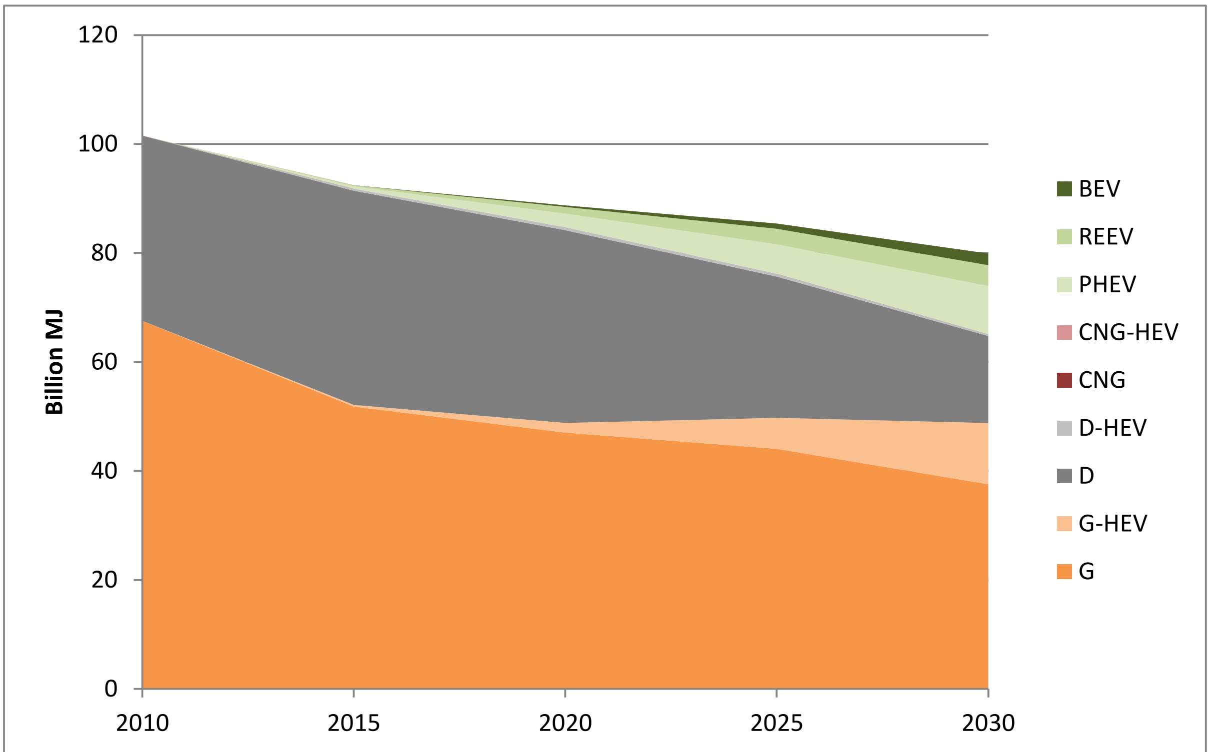


Figure 23. BaU scenario: total annual energy consumption of vehicles in Finnish stock

In Figure 24, annual Well-to-Wheel $CO_2$ emissions of the Finnish vehicle stock are presented, following the trend of the total energy consumption with a decrease of 27% in 2030. In that year, PHEV, REEV and BEV cause around 14% of total $CO_2$ emissions, whereas they consume 19% of the total energy and cover 31% of the total Finnish mileage (not shown). This illustrates the low $CO_2$-emissions of Finnish electricity production as well as the high energy efficiency of electrified powertrains.

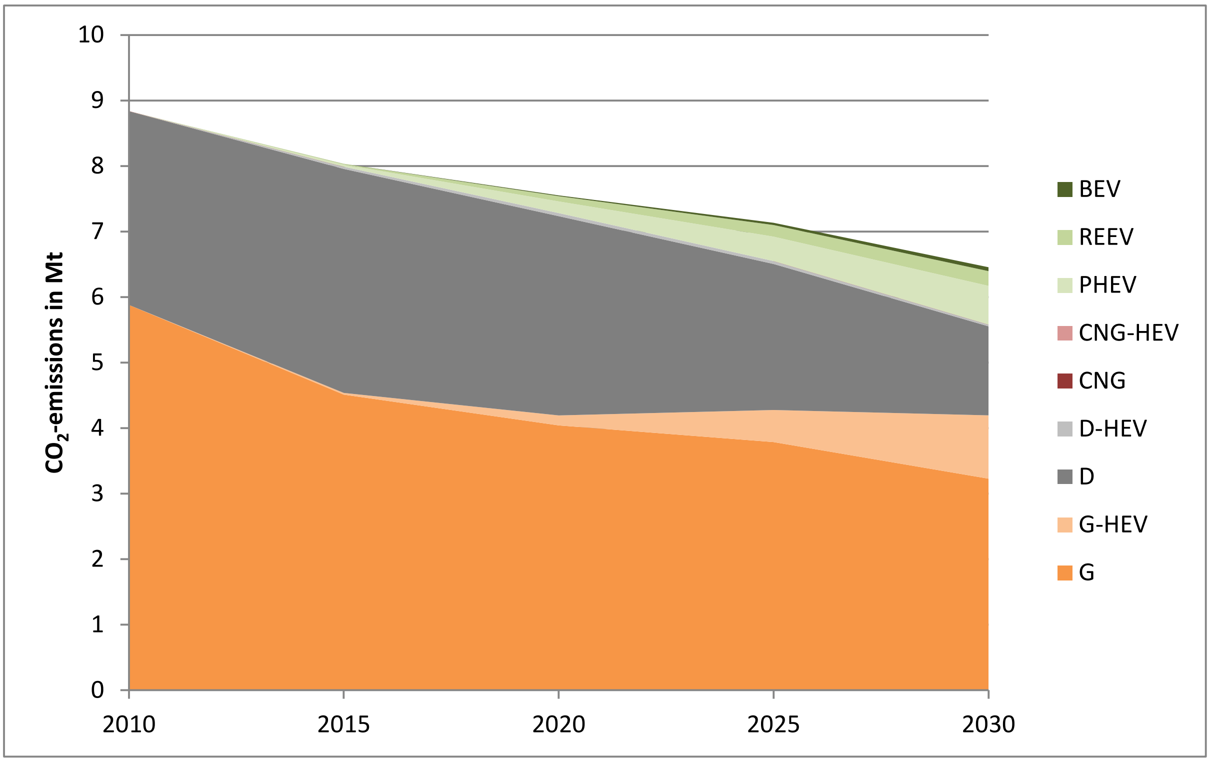


Figure 24. BaU scenario: annual Well-to-Wheel $CO_2$-emissions of the Finnish vehicle stock

### 3.3.2 Germany

#### Market shares

In the small segment of the German new vehicle market, gasoline vehicles are, as is known from the past, the preferred choice (Figure 25). After 2020 however, under BaU assumptions, they are gradually replaced by gasoline hybrids, which achieve the largest market share in 2030. Diesel vehicles lose their already small market share after 2020, whereas PHEV show a strong increase from that year on, reaching about 20% of market share in 2030. In that year, electrified vehicles (hybrids, range extender and plug-in hybrids) make up for over 70% of the market share in the small segment. However, neither pure battery electric vehicles nor fuel cell or CNG-powered vehicles enter the market in significant numbers until 2030 in the BaU scenario.

In contrast to Finland, there are no significant fiscal incentives for electrified vehicles in Germany, and the financial penalties for $CO_2$ emission-intensive vehicles are comparatively low. Additionally, electricity prices in Germany are high and average mileages of German drivers are lower than those of Finnish drivers, which results in a reduced financial pay-off of electrified vehicles, rendering pure battery electric vehicles too expensive in this segment. CNG-fuelled vehicles, however, suffer from a poor refuelling infrastructure in the first years and cannot compete with electrified vehicles in terms of costs of ownership and well-to-wheel $CO_2$ emissions after the year 2020.

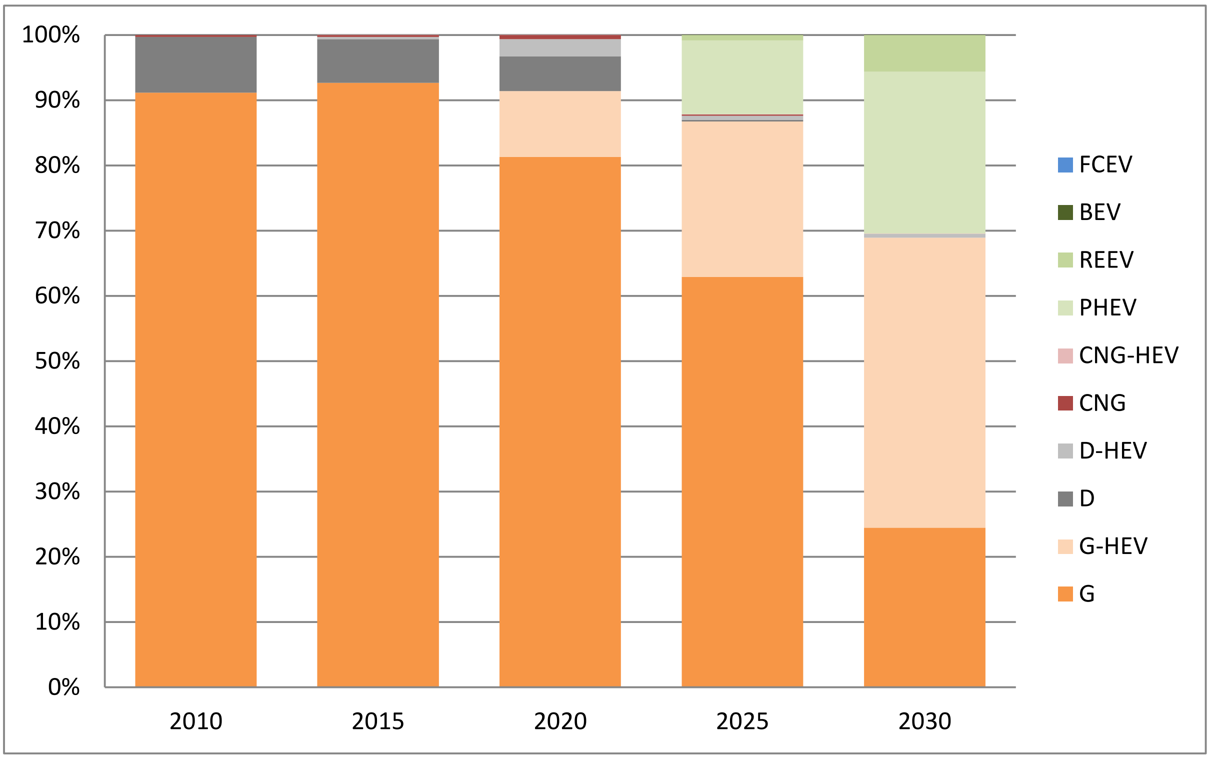


Figure 25. BaU scenario: vehicle sales in Germany, small segment

In Germany the medium segment represents about 60% of the country's new vehicle market (see Chapter 3.2.2). In this segment diesel and gasoline vehicle sales are balanced until 2015 (Figure 26), but due to the lowered EU $CO_2$ emission target for passenger cars in 2020/2021, the share of sold diesel vehicles is increasing significantly in 2020 under BaU assumptions. The progress towards more fuel-efficient vehicles in combination with reduced prices for batteries and electric components and a lowered EU $CO_2$ emission target in 2030 (to 75 g/km, see chapter 2) is shifting the market balance again after 2025 towards electrified vehicles, which reach a combined share of about 65% in 2030 (of which a third can be driven electrically – PHEV, REEV and BEV).

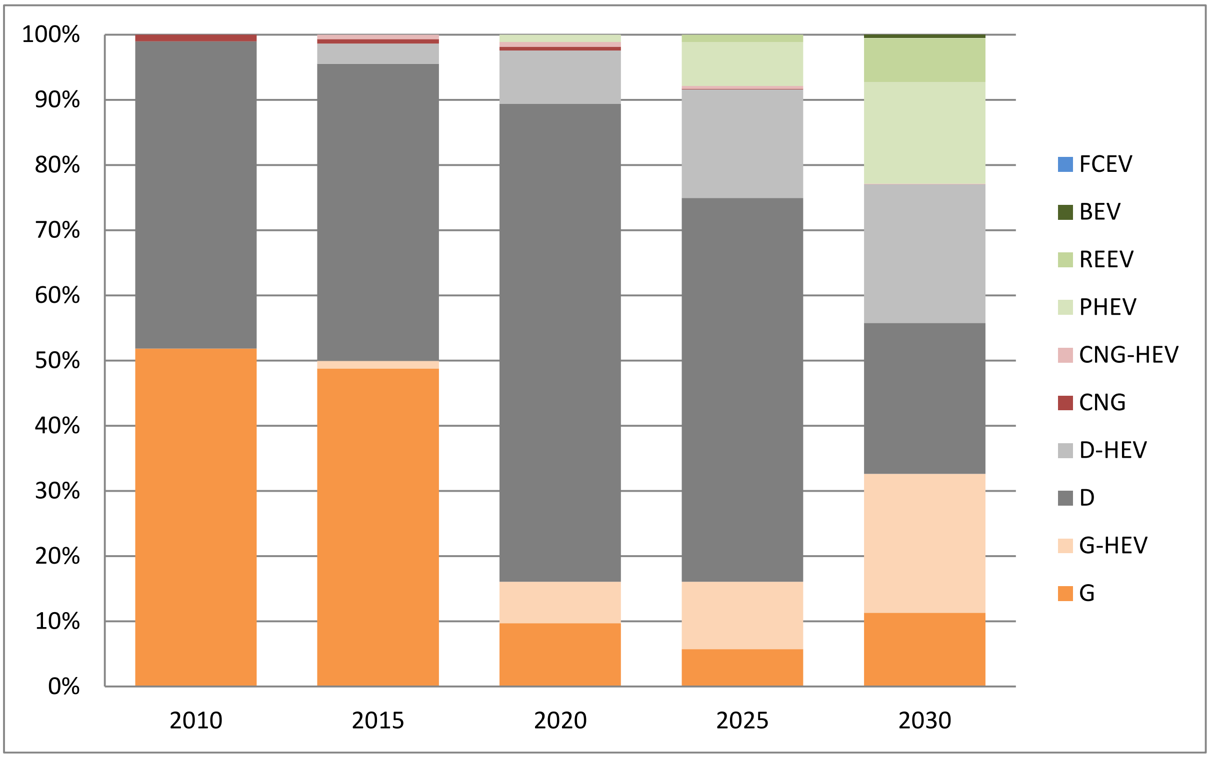


Figure 26. BaU scenario: vehicle sales in Germany, medium segment

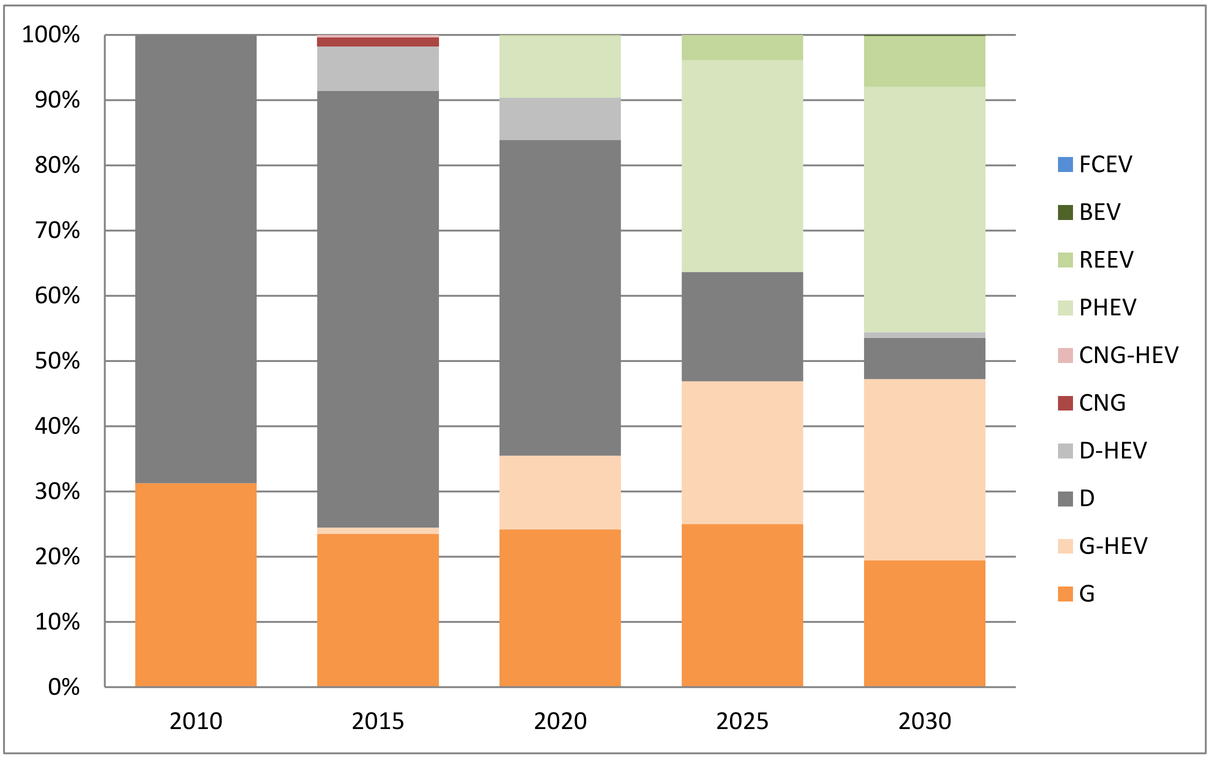


Figure 27. BaU scenario: vehicle sales in Germany, large segment

The purchase decision process of VECTOR21 customers is multifaceted considering refuelling/recharging infrastructure coverage, relevant cost of ownership (RCO) and well-to-wheel $CO_2$ emissions. In the large segment, due to higher average mileages, the RCO of conventional diesel cars are lower than the ones of conventional gasoline cars. Thus, diesel fuelled powertrains are dominating Germany's large vehicle sales up to 2020 (Figure 27). Fuel-efficiency upgrades of conventional vehicles shift this balance slightly towards gasoline powertrains over the years. Diesel

HEV enter the market in 2015 but are replaced mostly by PHEV just after 2020 due to a lowering of the EU $CO_2$ target for passenger cars. Gasoline HEV reach a market share of over 20% in 2025, but their increase in share is slightly reduced in 2030 in favour of PHEV. Neither BEV nor FCEV are sold due to high investment costs, low availability of hydrogen refuelling infrastructure and relatively high hydrogen and electricity fuel costs. Large CNG-fuelled vehicles never reach a significant market share and are unfavourable in comparison to electrified vehicles in terms of fuel cost.

**Stock**

Results for the German stock as total for all segments in the BaU scenario are shown in Figure 28. Although the German new vehicle market is quite conservative, the stock share of PHEV, REEV and BEV rises to about 10% in 2030. This corresponds to a faster diffusion of electrified powertrains into the stock in comparison to Finland, which is caused by the much lower lifetime of about 12 years of vehicles in the German stock. The total number of cars rises from 41 Mio vehicles in 2010 to about 44 Mio vehicles in 2030, as new vehicle sales reach their pre-crisis level in 2020 (compare Figure 8). These numbers follow the qualitative vehicle stock development in (Knörr et al., 2012) with a slightly higher total number due to higher sales in 2011-2014 (KBA, 2015).

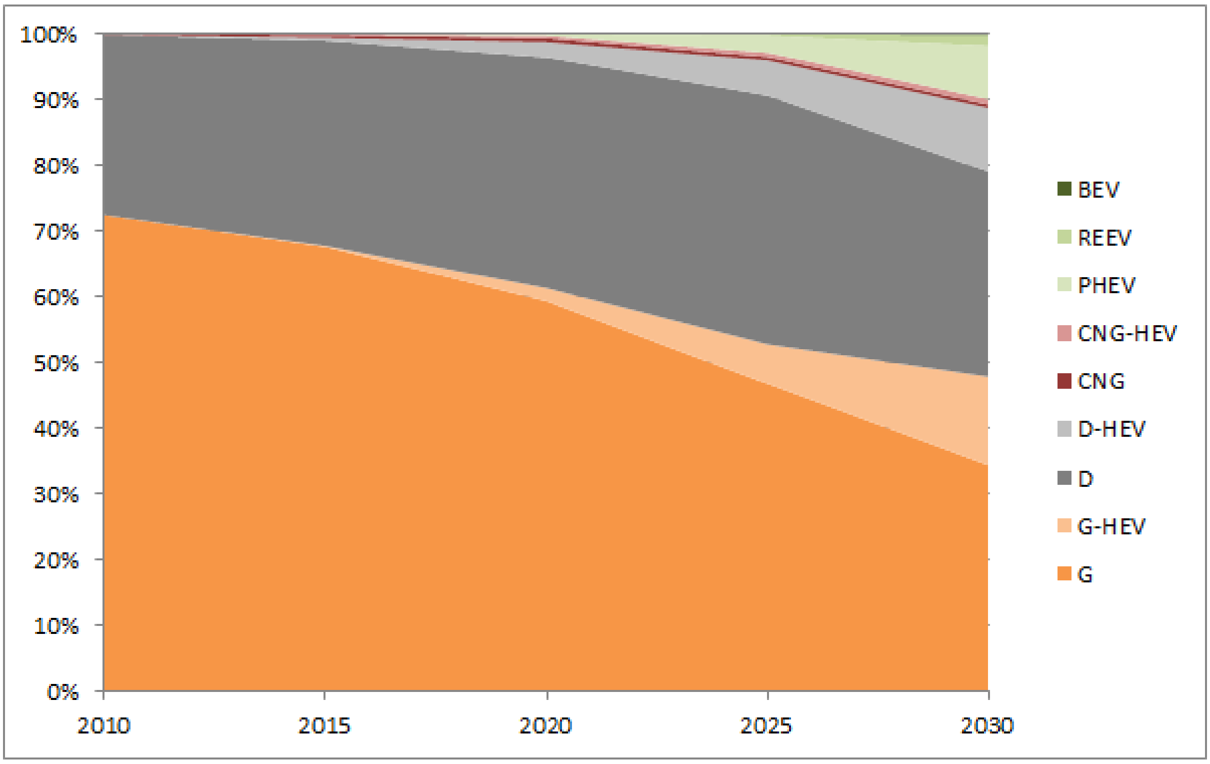


Figure 28. BaU scenario: total vehicle stock in Germany

Figure 29 depicts the annual energy consumption of the German vehicle stock. In 2030 the total energy consumption has decreased by 31%. Similar to Finland, this reduced energy consumption is caused by increased powertrain efficiencies and the deployment of electrified vehicles. In addition to that, a shift of the vehicle usage further reduces the overall energy consumption: Gasoline vehicles represent 73% of the stock in 2010 and contribute to 52% of the total driven mileage, whereas in 2030, the share of gasoline vehicles in the stock is reduced to 34% and their driven mileage share to 17%. In contrast to this, PHEV contribute about 15% of the total mileage in 2030 but their stock share is only 8%. This means that highly efficient cars contribute more to the total mileage and their influence on the energy consumption is strengthened.

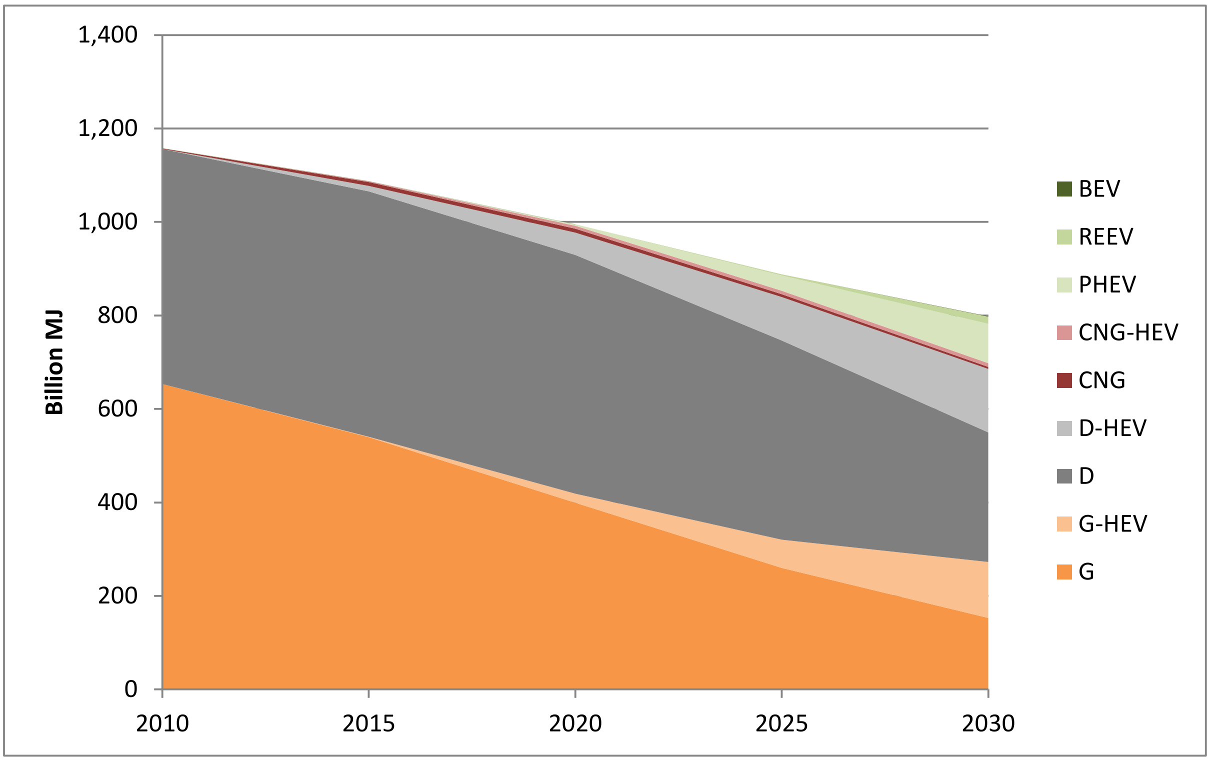


**Figure 29. BaU scenario: annual energy consumption of the German vehicle stock**

German annual Well-to-Wheel $CO_2$-emissions, as shown in Figure 30, are decreased by 34% in 2030, in accordance to the reduction of the total energy consumption. Part of these $CO_2$ emission savings are achieved by an increasing share of renewables in electricity production where Well-to-Tank $CO_2$ emissions are lowered by over 60% in 2030 compared to 2010 (see also chapter 3.2.2).

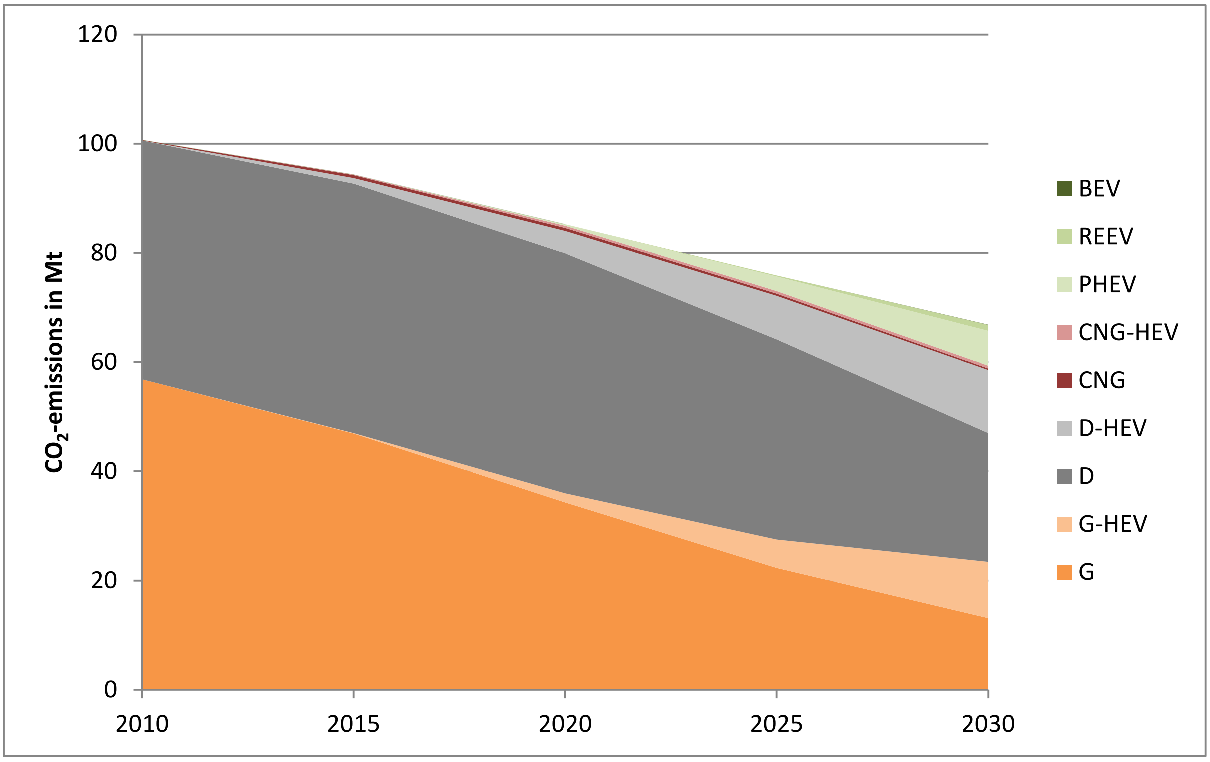


**Figure 30. BaU scenario: annual Well-to-Wheel $CO_2$-emissions of the German vehicle stock**

### 3.3.3 Poland

The VECTOR21 scenario framework for Poland is significantly different from those assumed for other markets. Firstly, Polish drivers have a comparatively low average mileage and secondly, policies in favour of vehicles with low $CO_2$ emissions are not adopted. Consequently, Polish experts do not expect a compliance of the EU $CO_2$ targets for new passenger cars in Poland (ITS, 2015).

**Market shares**

Under the assumptions mentioned above, the small segment of the new vehicle market in Poland is dominated by gasoline powered vehicles up to the year 2030 (Figure 31). The share of diesel fuelled vehicles increases only marginally towards 2030. No electrified vehicles are sold in this market, as emission based policies are not assumed to be adopted. The Polish purchase tax does not differ between electrified and non-electrified powertrains, causing the initially more cost-intensive alternative powertrains to be more affected by the purchase tax, in absolute terms, than conventional vehicles. Furthermore, average mileages in Poland are relatively low (see Figure 13), which leads to a reduced pay-off for fuel-efficient but initially more expensive vehicles.

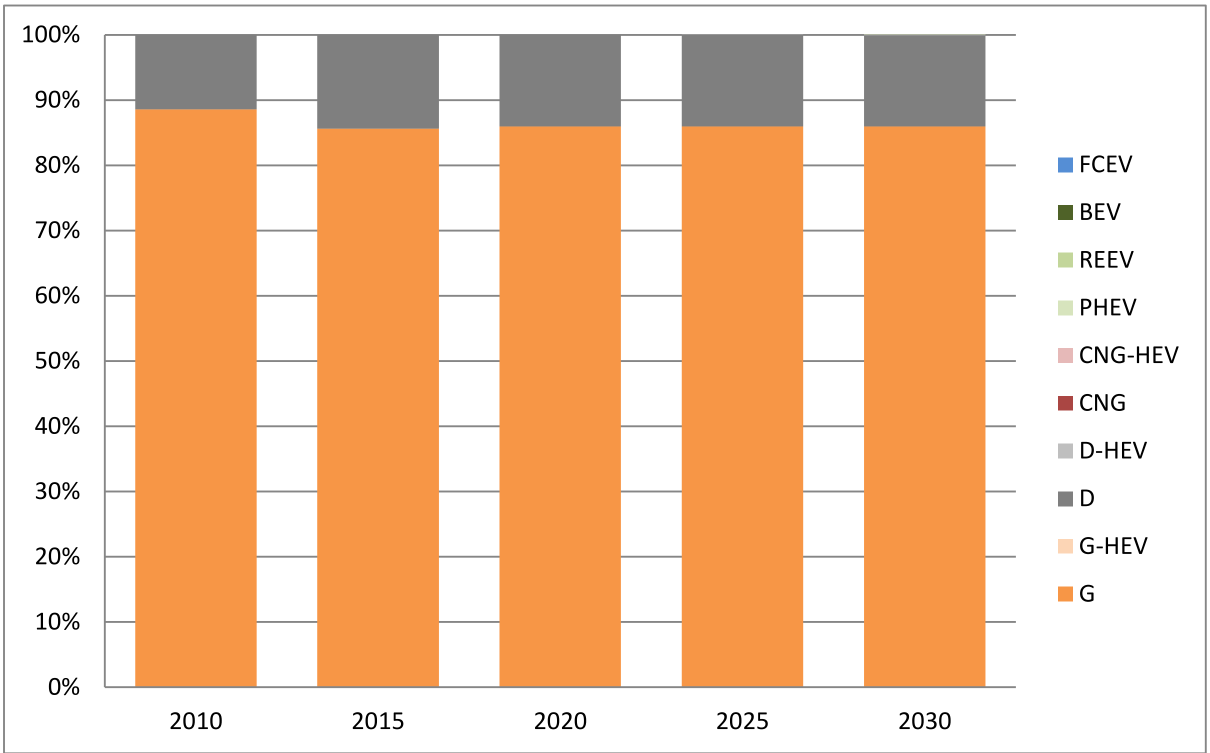


Figure 31. BaU scenario: Vehicle sales in Poland, small segment

The Polish medium segment is depicted in Figure 32. Similar to the small segment, conventional vehicles dominate market under the assumptions of the BaU scenario. Diesel vehicles have a market share of almost 40% in 2010, which increases to 55% in 2030 due to a slightly higher average mileage in this segment. Although CNG infrastructure is not widely spread there is a very small amount of CNG customers in the medium segment (<1%). Qualitatively, the behaviour resembles that of the small segment and can be explained in a similar way.

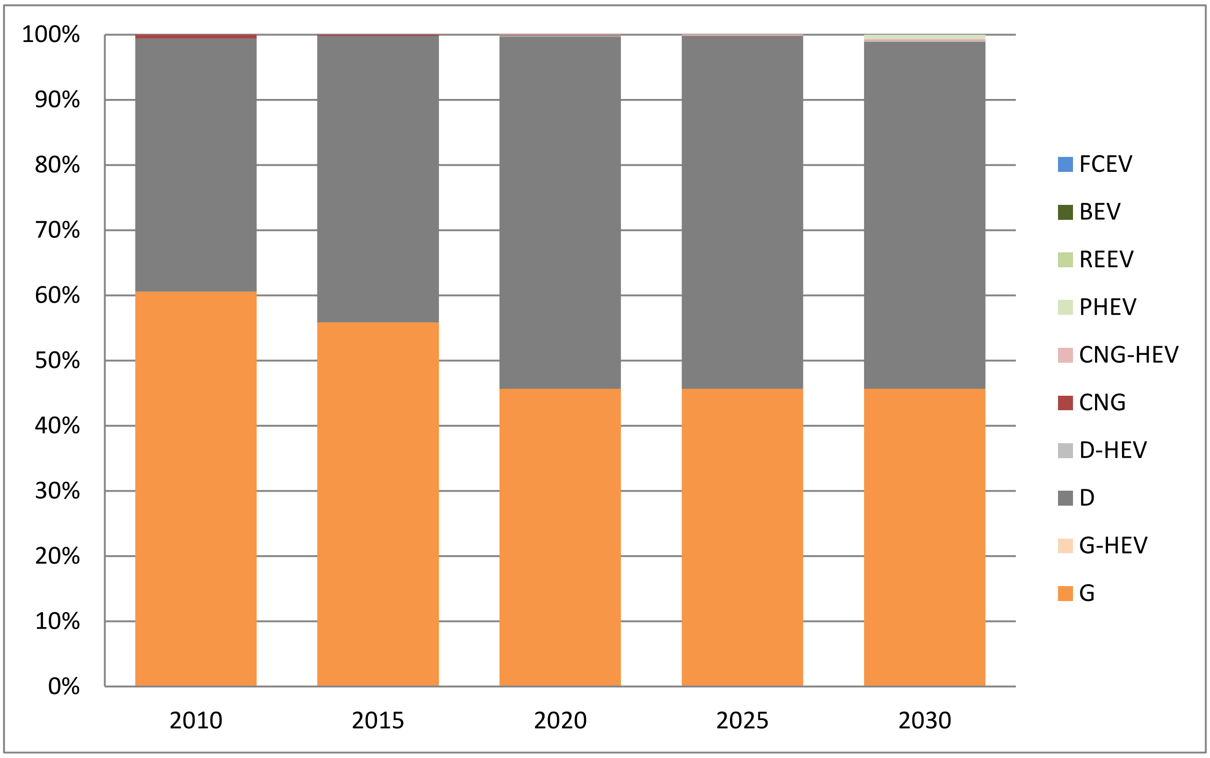


Figure 32. BaU scenario: vehicle sales in Poland, medium segment

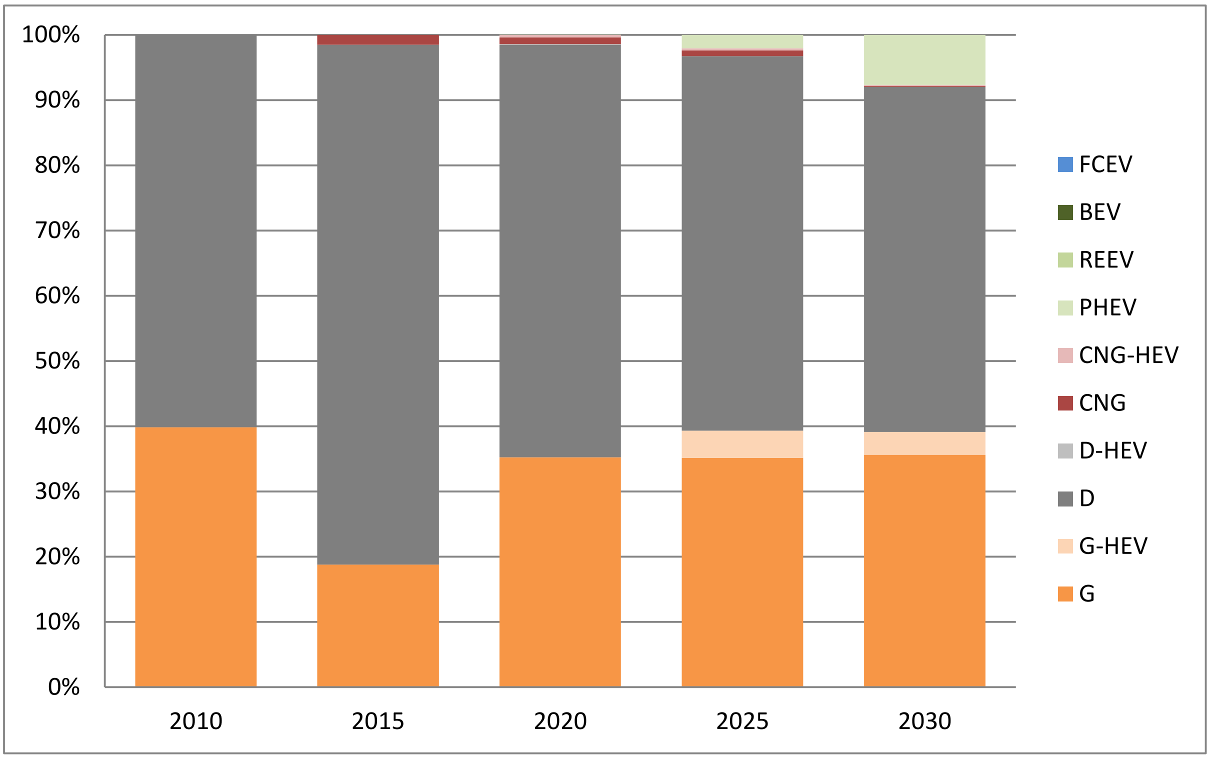


Figure 33. BaU scenario: vehicle sales in Poland, large segment

Diesel vehicles are even more popular in the Polish large segment, shown in Figure 33. Starting out with a market share of 60% in 2010, diesel fuelled powertrains reach market dominance in 2015. It is not until 2025 that electrified vehicles can be observed, but they retain a market share of less than 15% until 2030. As mentioned before, this dieselisation is caused by an assumed lack of Polish policies to e.g. impose (higher) taxes on high-emission vehicles. Consequently, in the Polish market under the assumptions of the BaU scenario, the EU $CO_2$ target curve for new passenger cars is exceeded throughout all years. OEMs will then have to make greater efforts in other European markets to be able to comply with the $CO_2$ target for their new vehicle fleet.

**Stock**

The Polish stock is modelled using information on fleet composition, vehicle age distribution and survival rates (amongst others), starting in the year 1988. The Polish market is differing from the other modelled markets as there is a high number of imported second-hand cars (about 65% of vehicle registrations, see also chapter 3.2.3). Those imported cars have a higher age and their survival curves might differ from those of newly bought vehicles. However, information on the Polish second hand market is scarce. Therefore, a similar usage of imported and newly bought vehicles was assumed. For the stock model, the same level of detail as for the new vehicle sales model is needed concerning powertrain concepts and vehicle technologies as newly bought vehicles will merge into the stock over time.

Model results for the Polish stock for all segments under the assumptions mentioned above are shown in Figure 34. Due to the continuous high popularity of diesel vehicles in Poland, a reduction of the gasoline vehicle share can be observed in the stock. The advance of diesels is also propelled by a huge share of imported diesel vehicles.

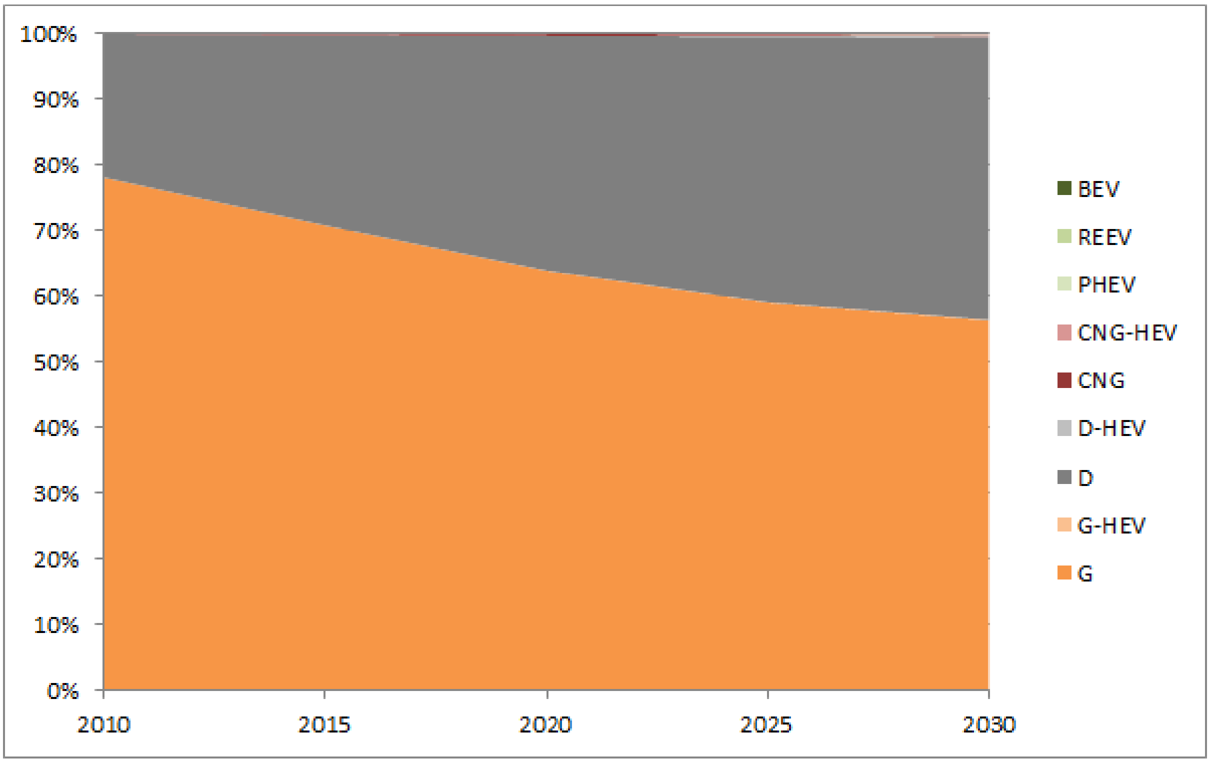


Figure 34. BaU scenario: total vehicle stock in Poland

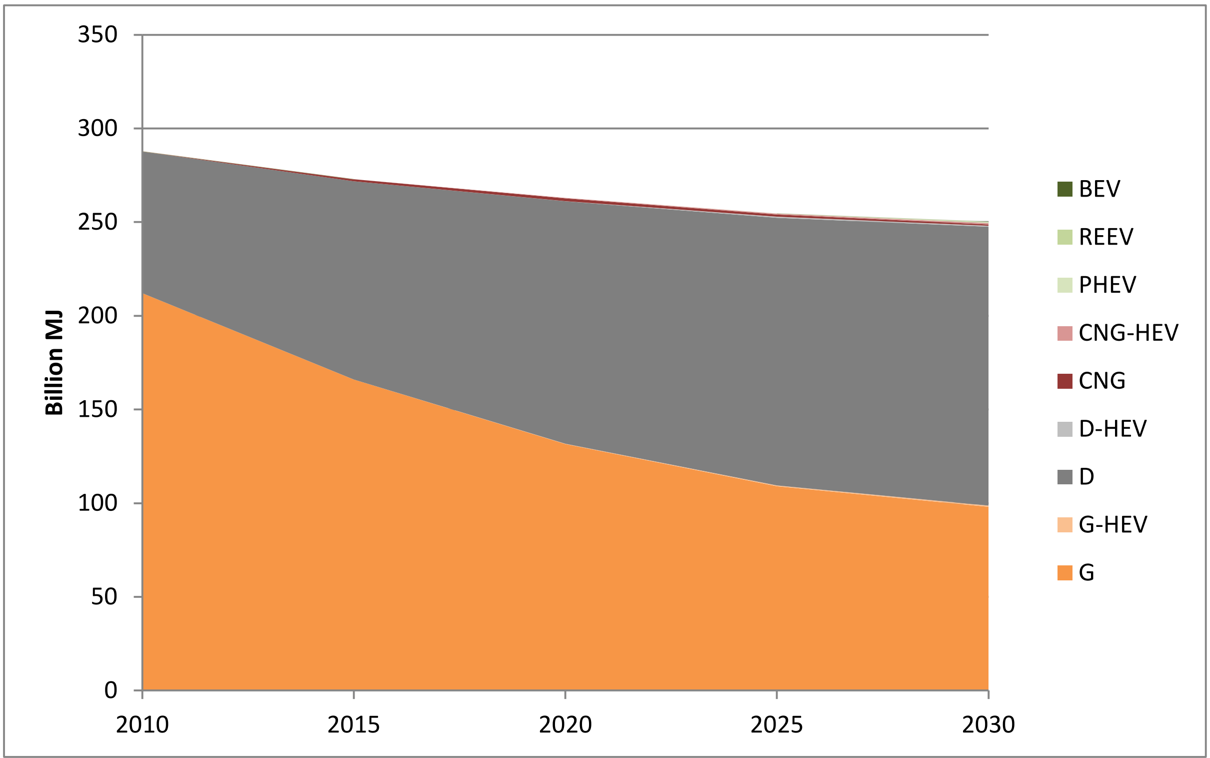


Figure 35. BaU scenario: total energy consumption per year of Polish vehicle stock

The total energy consumption of the Polish vehicle stock is depicted in Figure 35. Although electrified vehicles play only a minor role in Polish market and stock, total energy consumption is reduced by about 13% in 2030 in comparison to 2010 due to increased efficiencies of conventional powertrains (see also Figure 2). Compared to Germany and Finland, this is a rather moderate energy reduction.

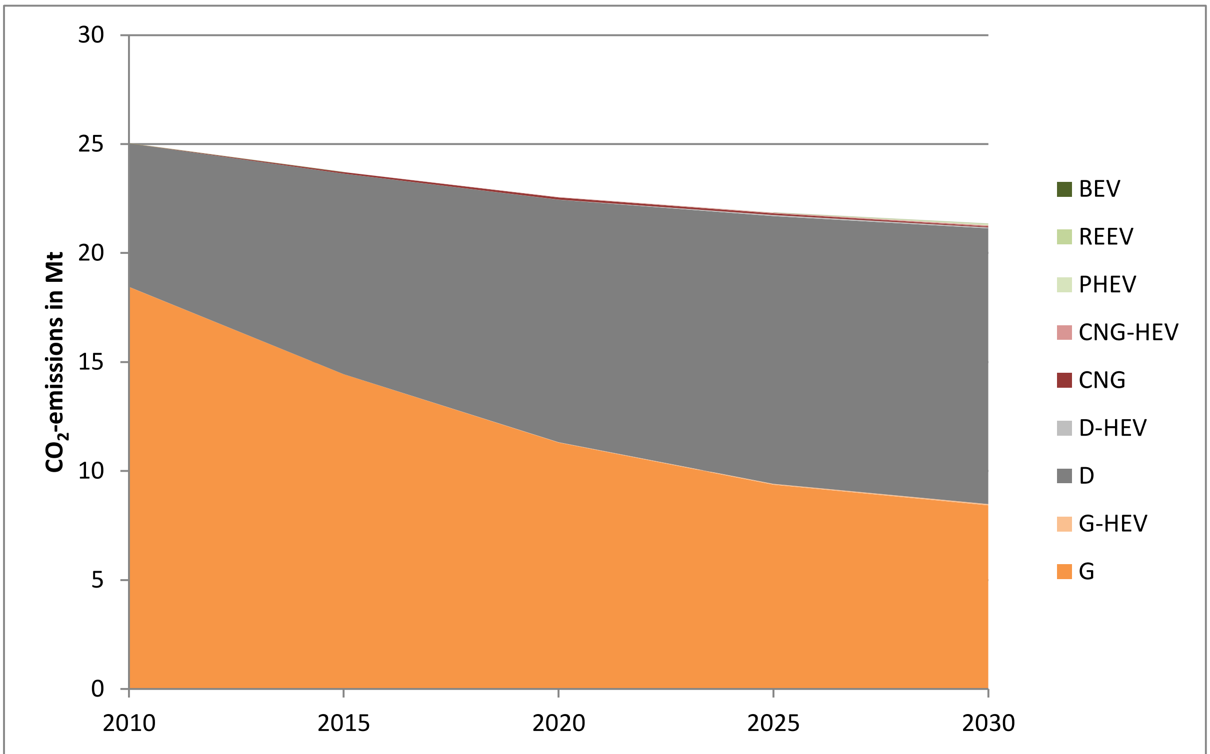


Figure 36. BaU scenario: total Well-to-Wheel $CO_2$-emissions per year of Polish vehicle stock

In Figure 36, annual $CO_2$-emissions of the Polish vehicle stock under BaU assumptions are shown, starting out at 25 Mt $CO_2$ in 2010 and then dropping by about 15 % until 2030, a direct consequence of the reduction of the total energy consumption.

### 3.3.4 Other VECTOR21 markets

**France**

In France, the share of new passenger car sales is almost equal for the small and medium segment (43% and 44%, respectively). One important factor in the French market is the $CO_2$ emission-based Bonus-Malus system. Within the BaU scenario, it is assumed that Malus payments are kept until the end of the modelling period and that Bonus credits are reduced step by step until 2022 (c.f. Table 13). Consequently, gasoline-based powertrains are no longer bought after 2020 and higher electrified powertrains, mostly PHEV and, to a lesser extent, REEV and BEV, are gaining market shares (up to 20% in the small and medium segment in 2030 and 50% in the large segment).

In contrast to the Finnish taxation system, the French taxation system is solely $CO_2$-based and does not have other environmentally-based elements. Diesel is thus the preferred conventional powertrain in France while in Finland with its powertrain based high tax on diesel, it is gasoline.

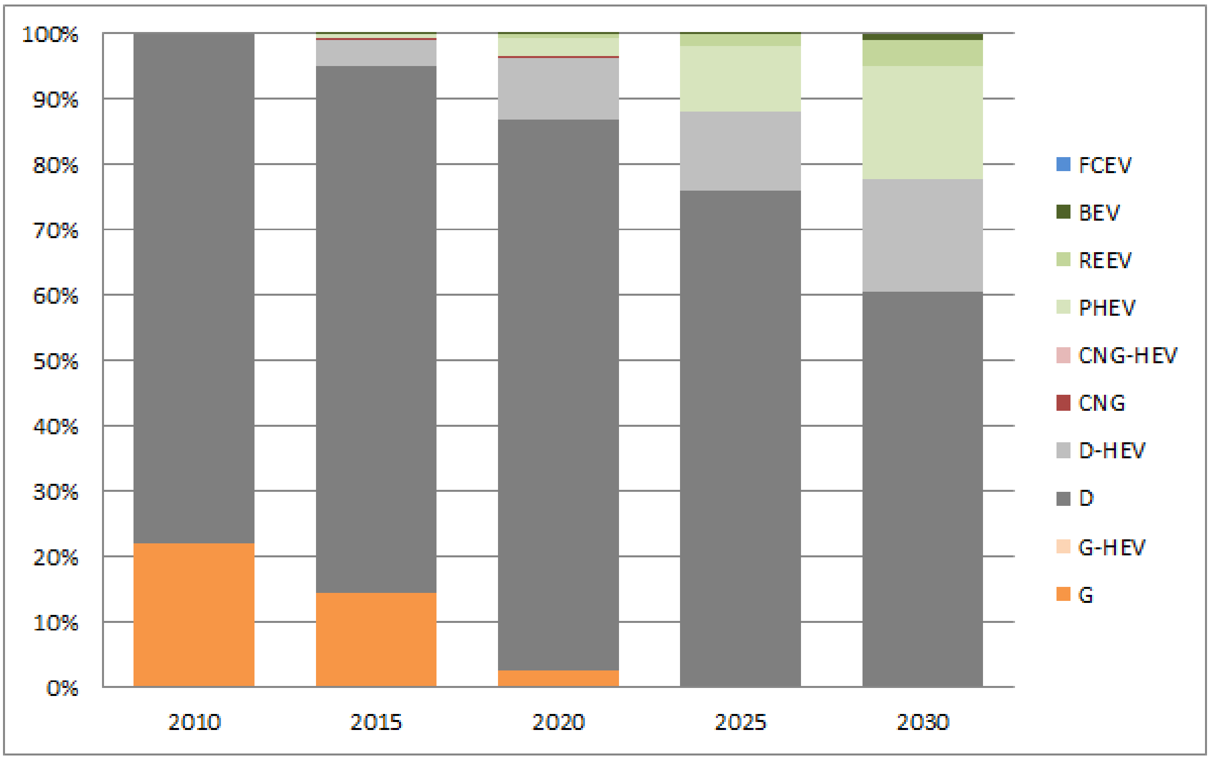


Figure 37. BaU scenario: total vehicle sales in France

The French stock is more and more dominated by conventional diesel powertrains (75% in 2030, Figure 38). Due to efficiency gains in conventional powertrains and due to a 22% share of electrified vehicles, total energy consumption in 2030 is 31% lower than in 2010. Likewise, Well-to-Wheel $CO_2$ emissions of the French stock in 2030 are 34% below 2010.

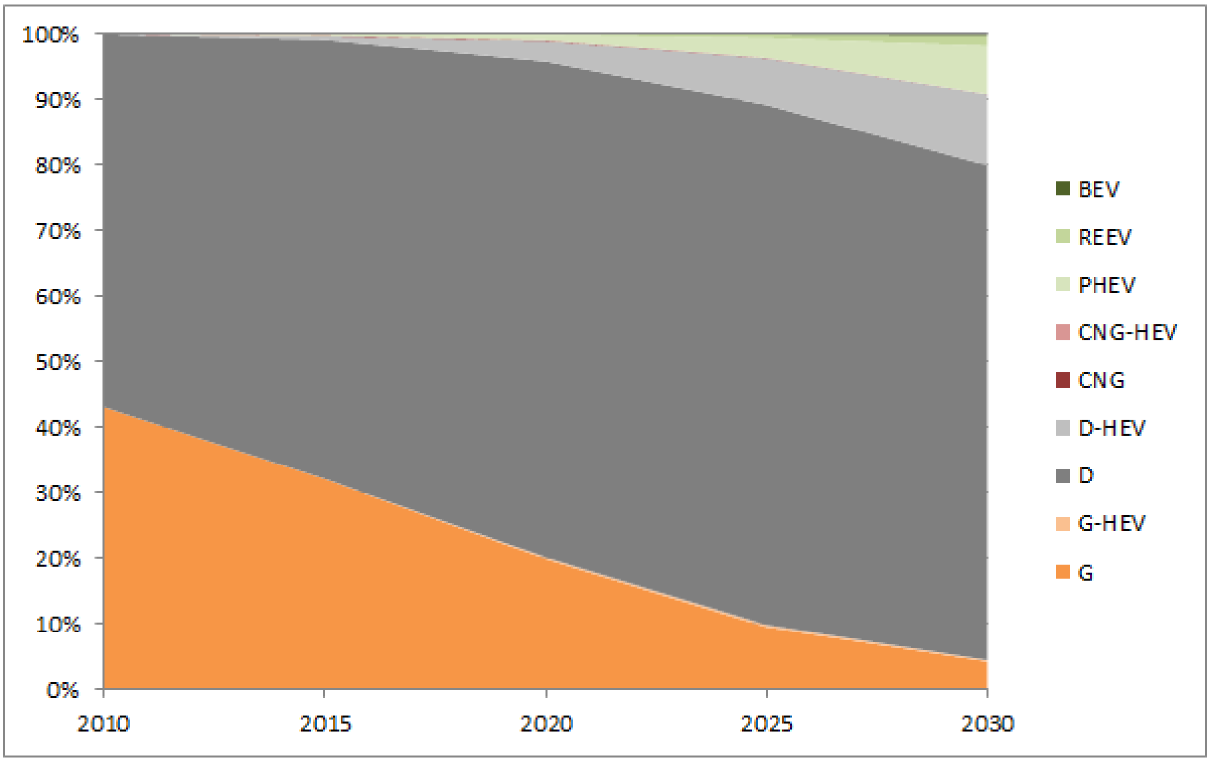


Figure 38. BaU scenario: total vehicle stock in France

**Italy**

As mentioned in chapter 3.2.4, Italian CNG infrastructure is already today well developed and prices are comparatively low. Thus, a significant share of CNG and CNG hybrid cars is seen in the BaU scenario for Italy throughout all years (Figure 39). Of both powertrains, conventional CNG vehicles are dominant in the small segment while its hybrid alternative is chosen equally in the medium and large segment. 56% of all newly sold vehicles belong to the small segment, 32% to the medium and 12% to the large segment.

In 2030, diesel is the preferred conventional powertrain (50% of total new vehicle sales), followed by CNG (17%) and gasoline (4%). PHEV is the electrified powertrain of choice (17%).

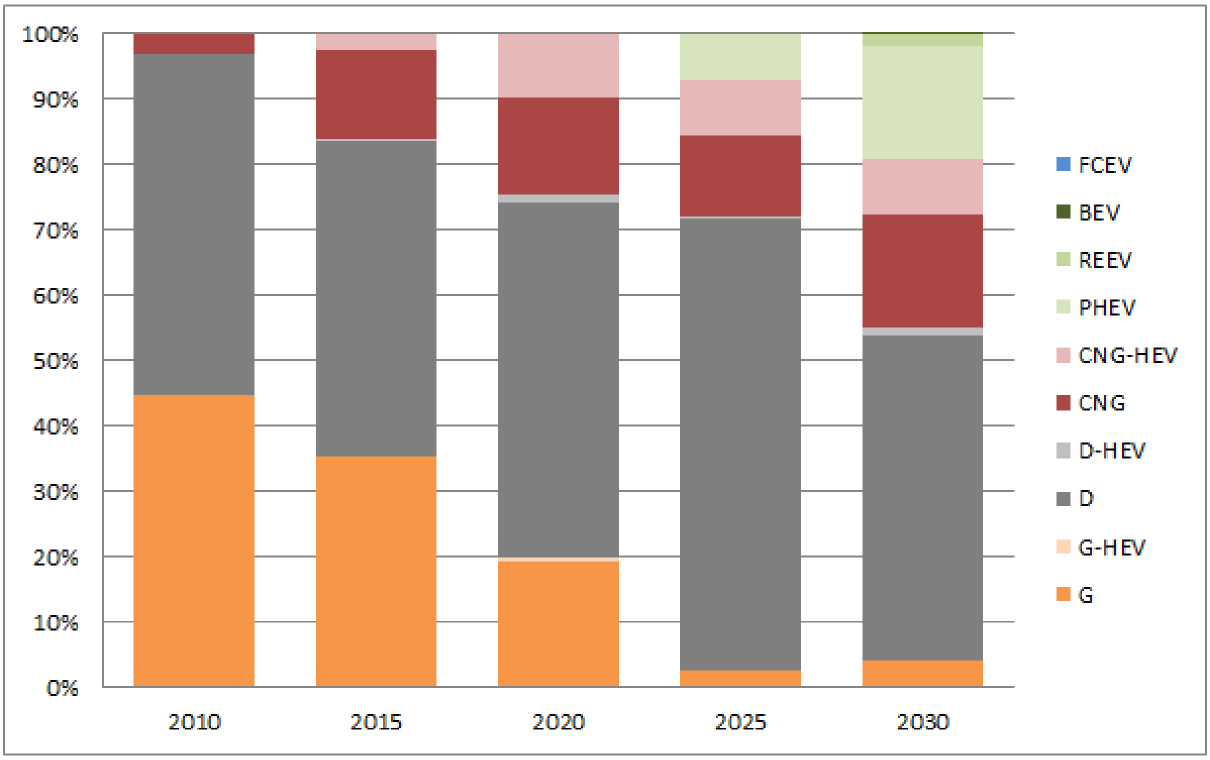


Figure 39. BaU scenario: total vehicle sales in Italy

In 2030, a fifth of the Italian passenger car stock is CNG-driven (CNG and CNG hybrids) and half of the stock is diesel-driven (Figure 40). Total energy consumption is reduced by 12% in 2030 compared to 2010, mostly due to increased efficiencies of conventional powertrains (c. f. Figure 10). In spite of these relatively moderate energy savings, Italy is able to decrease its Well-to-Wheel $CO_2$ emissions by 22% in 2030 compared to 2010 – the WTW $CO_2$ emission balance is lower for CNG vehicles than for other conventional powertrains.

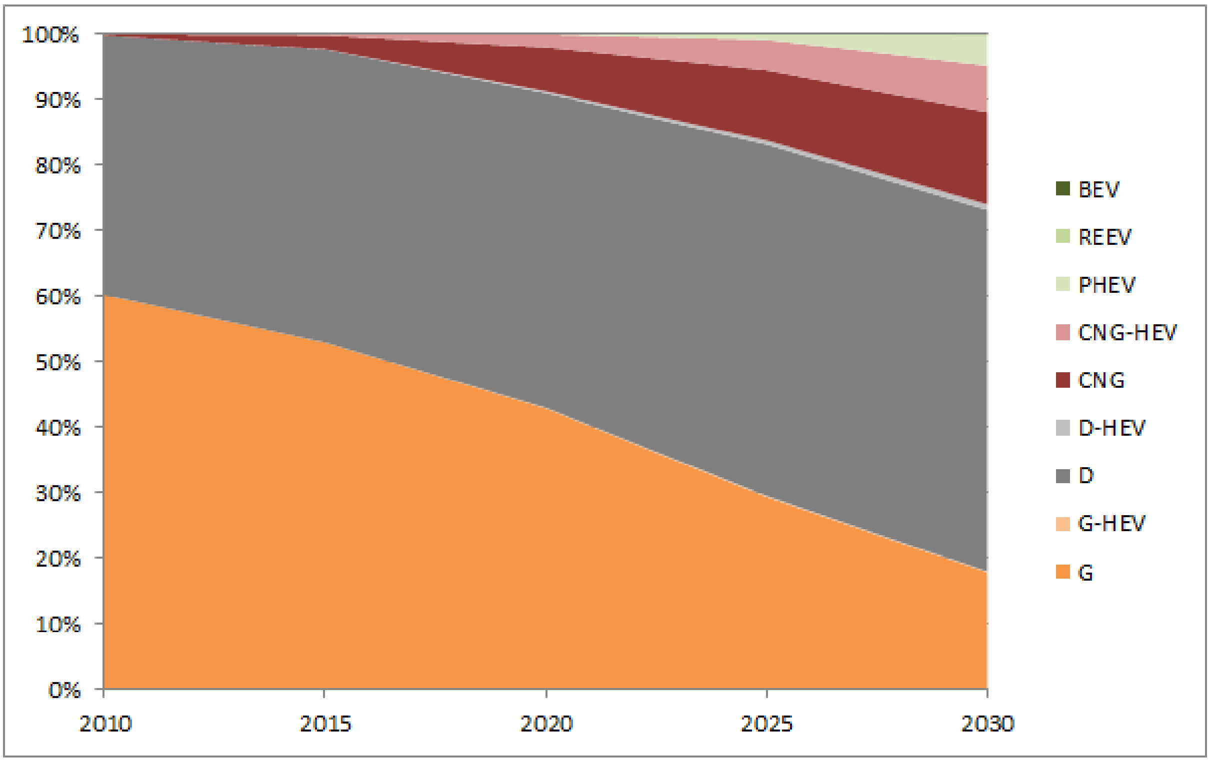


Figure 40. BaU scenario: total vehicle stock in Italy

**United Kingdom**

Diesel is slightly more expensive than gasoline in the United Kingdom and thus, conventional gasoline powertrains are able to keep their relatively high share up to the year 2025 in the BaU scenario (Figure 41). However, as $CO_2$ emissions of gasoline powertrains are higher, this trend enables an earlier and more pronounced market entrance of electrified powertrains (gasoline and diesel HEV as well as PHEV) in comparison to other countries (on the implementation of OEM strategies to meet EU $CO_2$ targets with their fleet, see (Schimeczek et al., 2015). In 2030, the share of plug-in electric vehicles (PHEV, REEV and BEV) is 27% of new passenger car sales. Almost half of them are sold in the medium segment which is the main size class (52% of all new passenger cars), followed by the small segment (36% of all new vehicle sales) and the large segment (12% of all new vehicle sales).

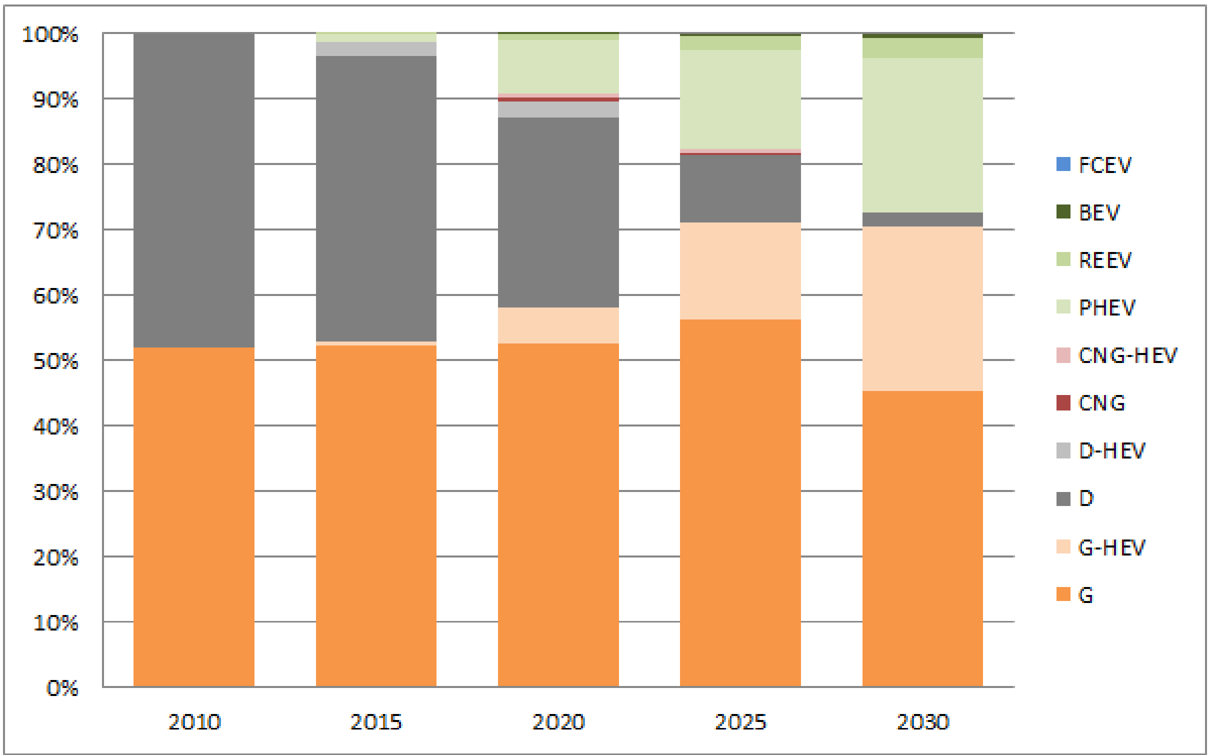


Figure 41. BaU scenario: total vehicle sales in the United Kingdom

The stock of the United Kingdom is dominated by gasoline-based powertrains (conventional and hybrids, 66% in 2030), followed by diesel-based powertrains (conventional and hybrids, 18% in 2030) and EV (PHEV, REEV and BEV, 15% in 2030). Energy consumption in 2030 is 23% lower than in 2010, $CO_2$ emission reductions are in the order of 26% within the same period.

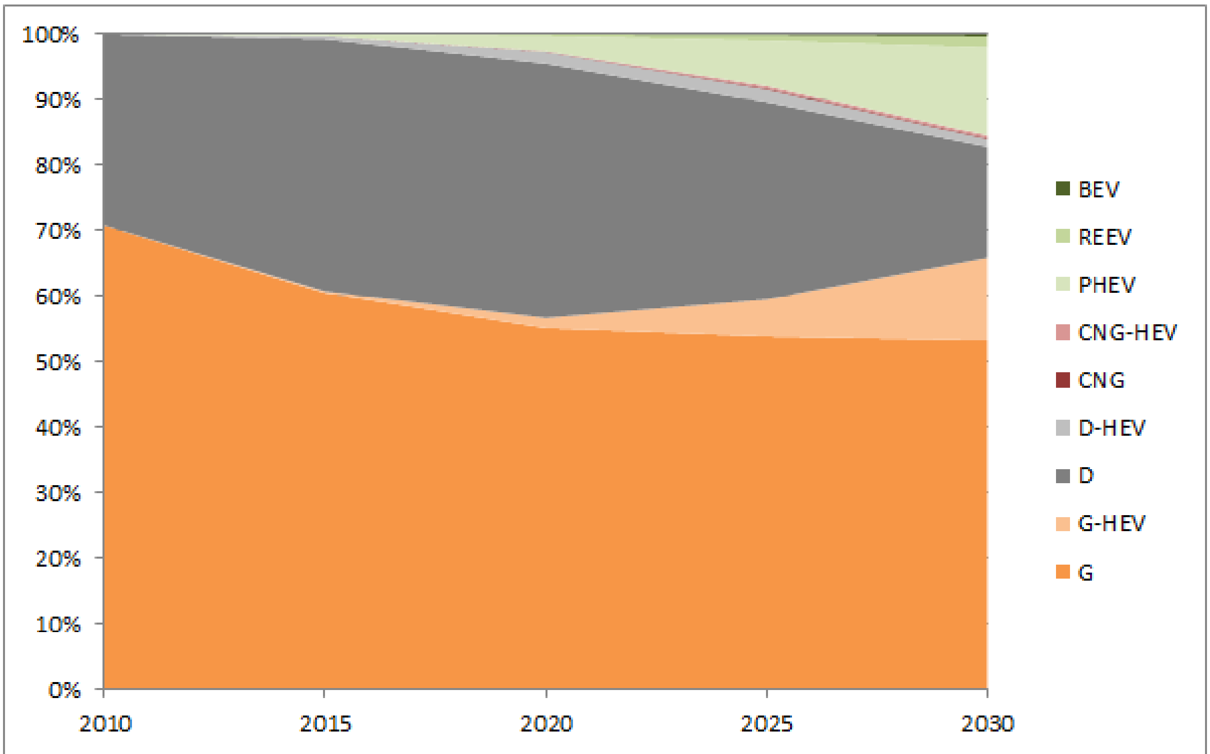


Figure 42. BaU scenario: total vehicle stock in the United Kingdom

### 3.3.5 EU28

Besides modelling the prospects of electromobility in the countries Finland, Germany and Poland represented in the project consortium, EU28 scenarios were also among the objectives of the eMAP project. The explicit modelling of scenarios for all EU28 markets, however, was out of scope due to data and time restrictions. Therefore, the approach of modelling the 6 major car markets in EU28 (Finland, France, Germany, Italy, Poland and the UK, covering three quarters of all new vehicle sales per year) was chosen and combined with a simple but profound upscaling to 100% of all annual sales (see Schimeczek et al. (2015) for more details).

**Market shares**

The overall development in EU28 of the new vehicle market by powertrain in the BaU scenario as total of all three car segments is shown in Figure 43. In total, a continuous shift to powertrains with higher fuel efficiencies can be observed. Starting with the actual market split between gasoline, diesel and CNG powertrains in the year 2010, the model shows a slight change in 2015 with more CNG cars and some hybrid powertrains entering the market. This behaviour roughly corresponds to observed powertrain sales in the year 2014. The market share of CNG vehicles stems almost exclusively from sales in Italy (Figure 39) and – to a small extend – from sales in Germany (Figure 25 - Figure 27).

Conventional powertrains (diesel, gasoline and CNG) keep their market dominance up to the year 2025, but year by year this dominance is challenged by electrified powertrains – mainly PHEV, as well as gasoline HEV and diesel HEV. REEV and BEV are expected to win only a small overall market share. Due to their high initial costs, low availability of hydrogen refuelling infrastructure and relatively high hydrogen fuel prices, FCEV are not sold in any of the investigated markets in the BaU scenario.

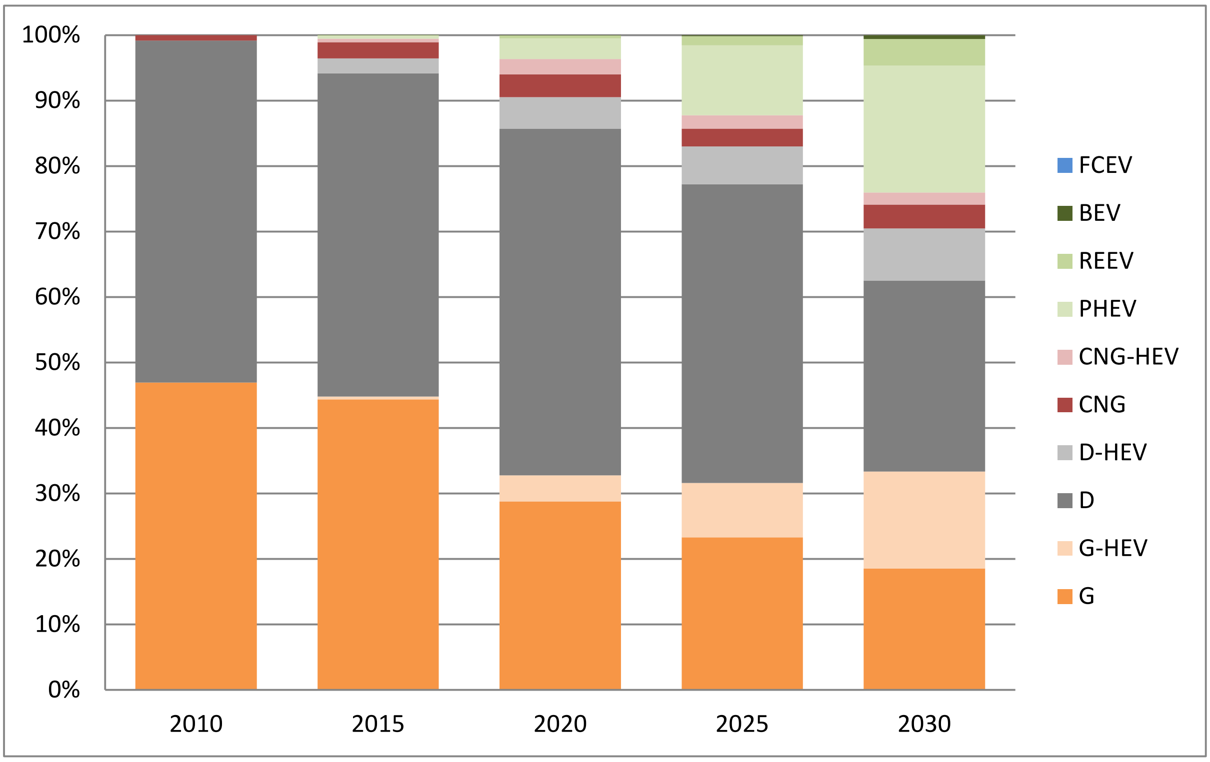


Figure 43. BaU scenario: total new vehicle sales in EU28

A quite similar picture holds for the small segment depicted in Figure 44. The reduced share of diesel vehicles in 2010 corresponds to a smaller average mileage in this segment. However, the market share of diesel vehicles is above the all-segment average in 2030: Due to the lower absolute fuel consumption of vehicles in the small segment it is not necessary to reach the same level of electrification of powertrains to meet the European $CO_2$ emission targets for passenger cars. Instead, highly efficient conventional vehicles are already able to comply with the target values. Additionally, the budget of customers in this segment is smaller, and thus their willingness to pay for $CO_2$-reduced vehicles is not as pronounced as for customers in the other two vehicle segments. Therefore, the market share of electrified vehicles in the small segment is also reduced.

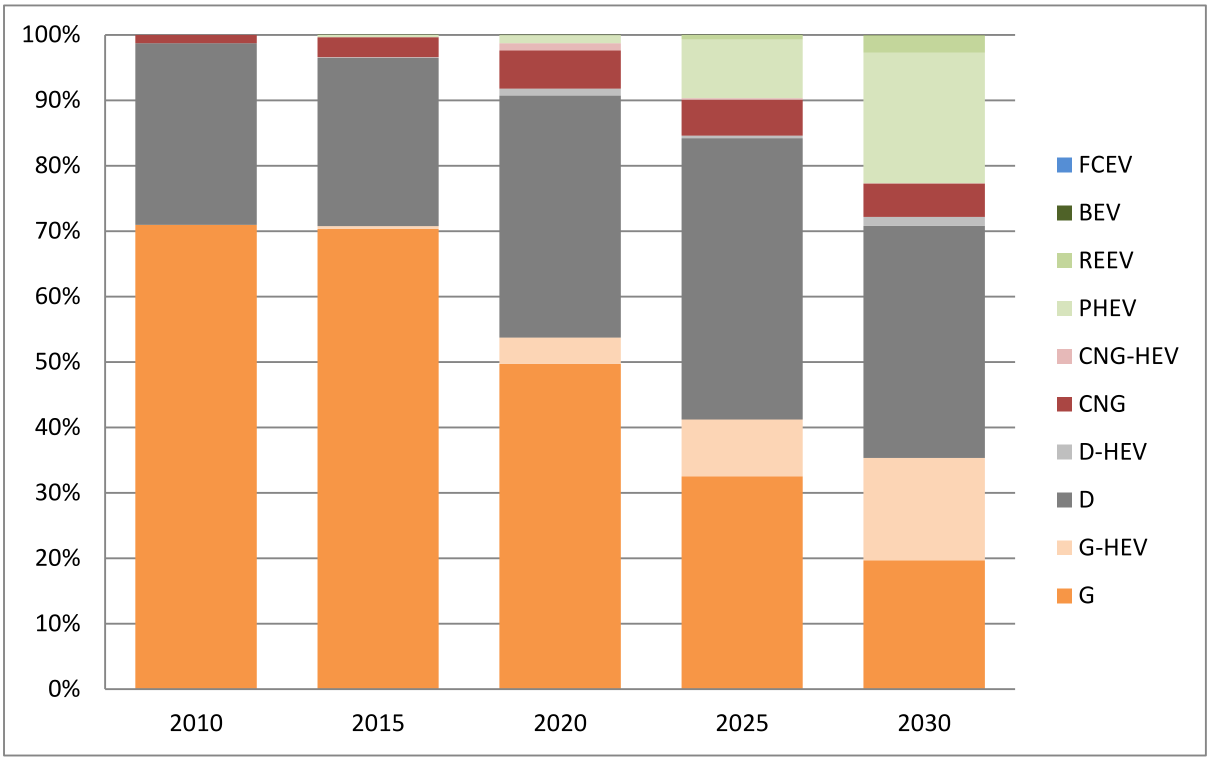


**Figure 44. BaU scenario: new vehicle sales in EU28, small segment**

The EU28 medium segment (Figure 45) has a relatively high share of diesel vehicles, which is quite constant until 2025 under BaU assumptions. Even in 2030, diesel and diesel HEV together yield a market share of about 40%. In contrast, gasoline vehicle market shares are significantly reduced around the year 2020 due to the European $CO_2$ emission targets. However, driven by fuel-efficiency improvements and in combination with gasoline HEV vehicles, the market share of gasoline vehicles is reclaimed in 2030.

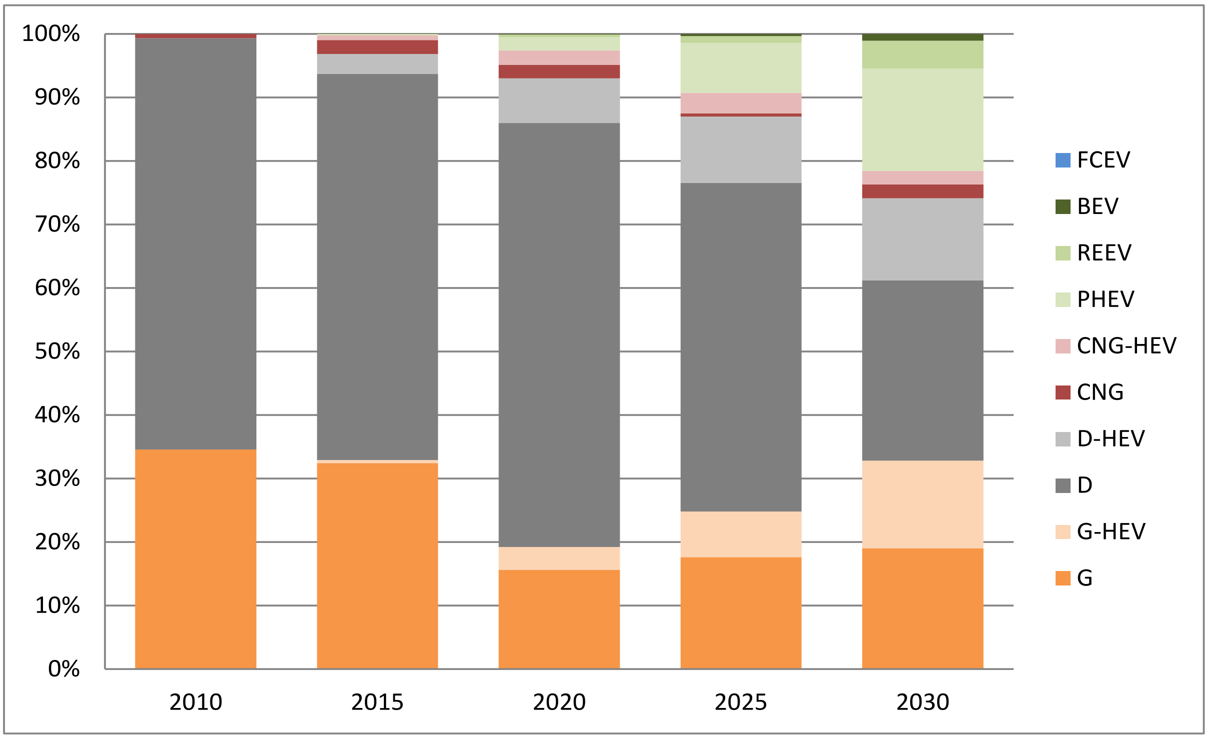


Figure 45. BaU scenario: new vehicle sales in EU28, medium segment

In contrast to the other segments, the large segment starts out with a market share of diesel vehicles of more than 80% (Figure 46). However, the diesel sales steadily decrease to about 20% in 2030, since the large vehicles need a stronger reduction of $CO_2$ emissions to reach the European emission target. In combination with a higher than average annual mileage, this segment has the largest market share of PHEV and REEV, which account for about 40% of the sales in 2030. In combination with HEV, the market share of electrified vehicles reaches about 70% of the large segment's sales in 2030.

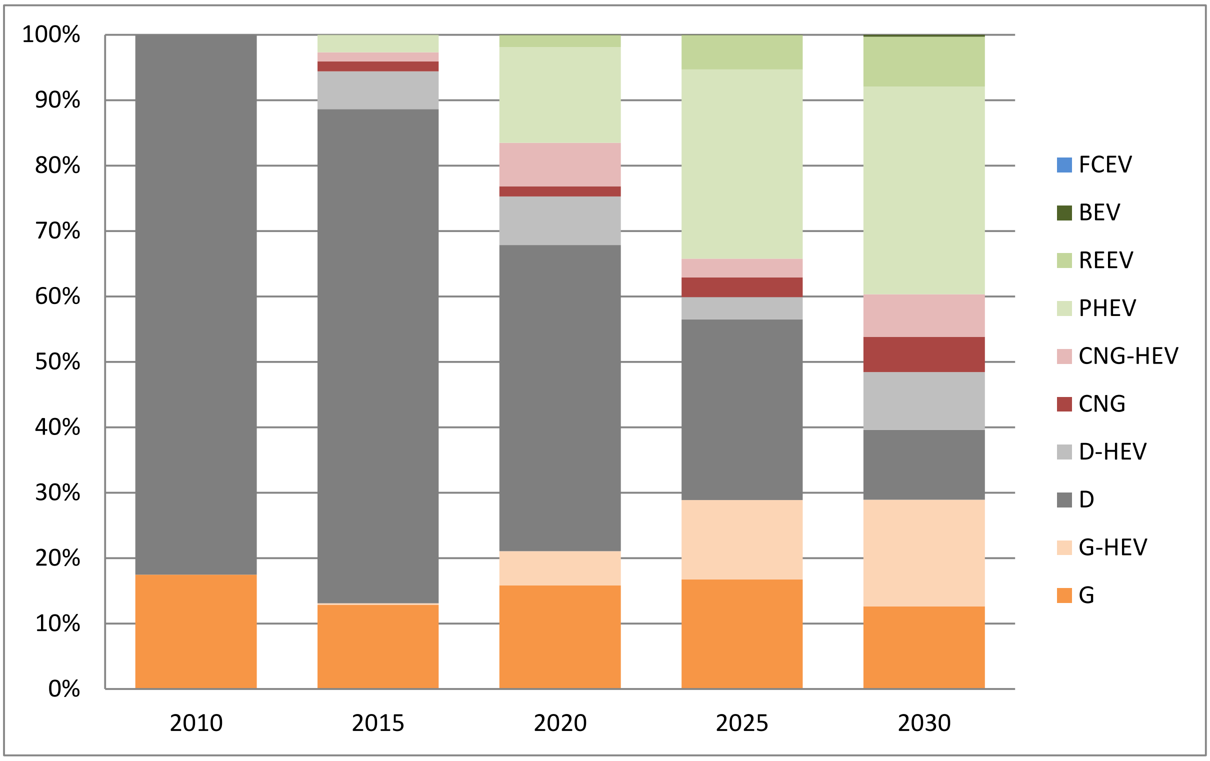


Figure 46. BaU scenario: new vehicle sales in EU28, large segment

**$CO_2$ targets**

In Figure 47, the red dotted line shows the EU target for Tank-to-Wheel $CO_2$ emissions of passenger cars as assumed in the BaU scenario (130 g/km in 2015, 95 g/km in 2021[12], 75 g/km in 2030), as well as, depicted by the blue line, average $CO_2$ emissions of new vehicles in EU28, including super credits for vehicles with extremely low emissions. In the BaU scenario in 2021, average $CO_2$-emissions of new vehicles meet the European target of 95 g/km and even surpass the assumed target of 75 g/km of Tank-to-Wheel $CO_2$ emissions in 2030 by about 2 g/km.

[12] While the EU $CO_2$ target for passenger cars is 95 g/km already in 2020, only 95% of each manufacturer's new passenger cars have to comply to that target; from 2021 on, this percentage is raised to 100% (Regulation (EU) No 333/2014)

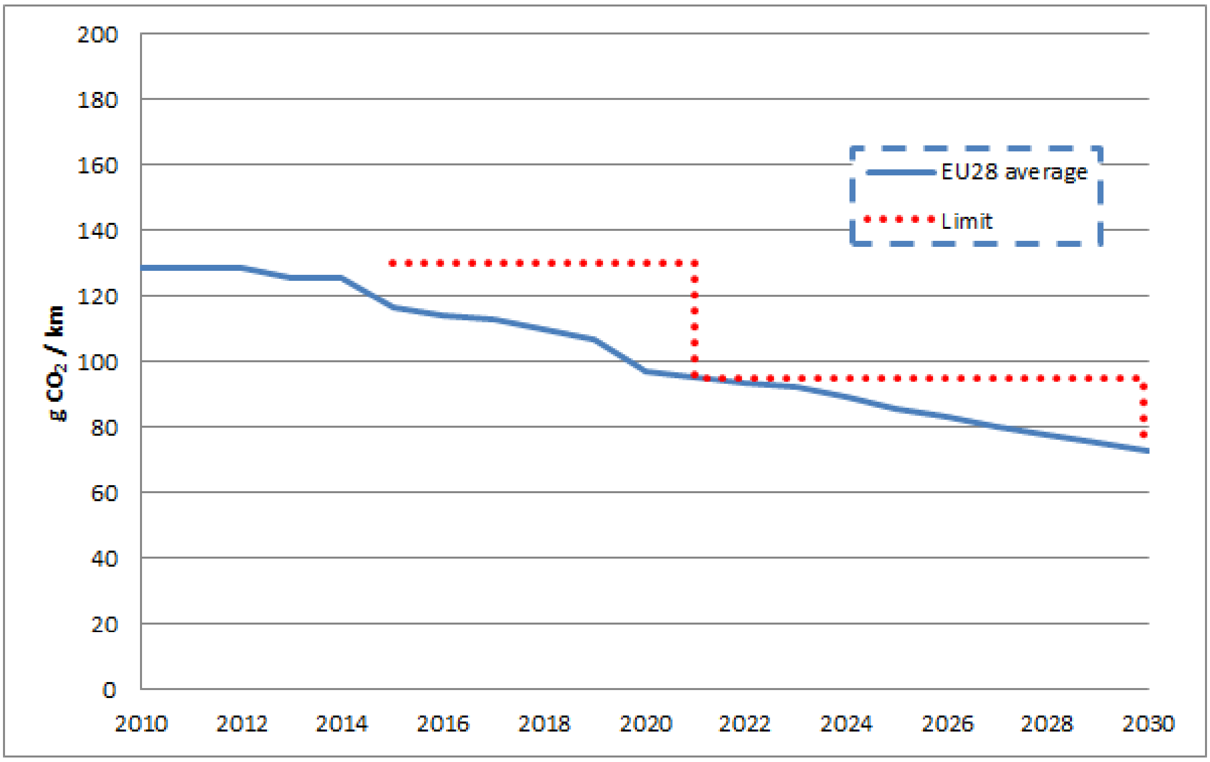


Figure 47. BaU scenario: EU28 average $CO_2$ emissions (including super credits) versus $CO_2$ target

**EV component prices**

The evolution of traction battery prices resulting from the BaU scenario framework is shown in Figure 48. Starting at 450 €/kWh, the number of produced units reaches a threshold value in 2015, thus prices decrease to their floor costs of 230 €/kWh in 2029.

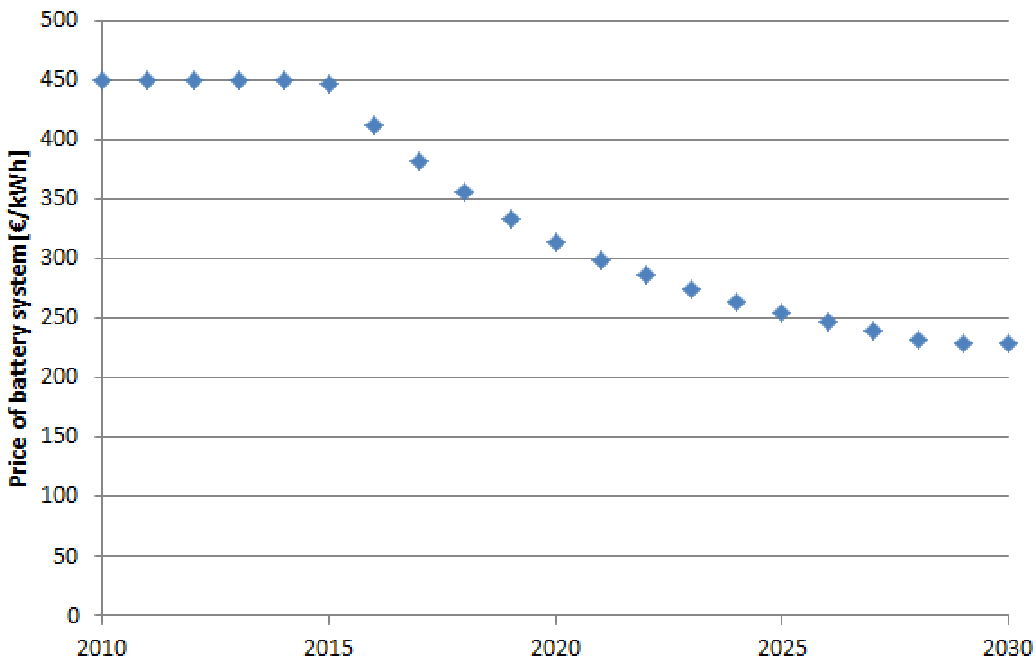


Figure 48. BaU scenario: Evolution of battery system price over time

The evolution of prices for power electronics and the electric motor depending on vehicle sales is shown in Figure 49. Starting at 25 €/kWh for both power electronics and the electric motor, the number of produced units reaches a threshold value shortly thereafter (in 2014 and 2015), thus prices decrease to 15 €/kWh and 13 €/kWh, respectively.

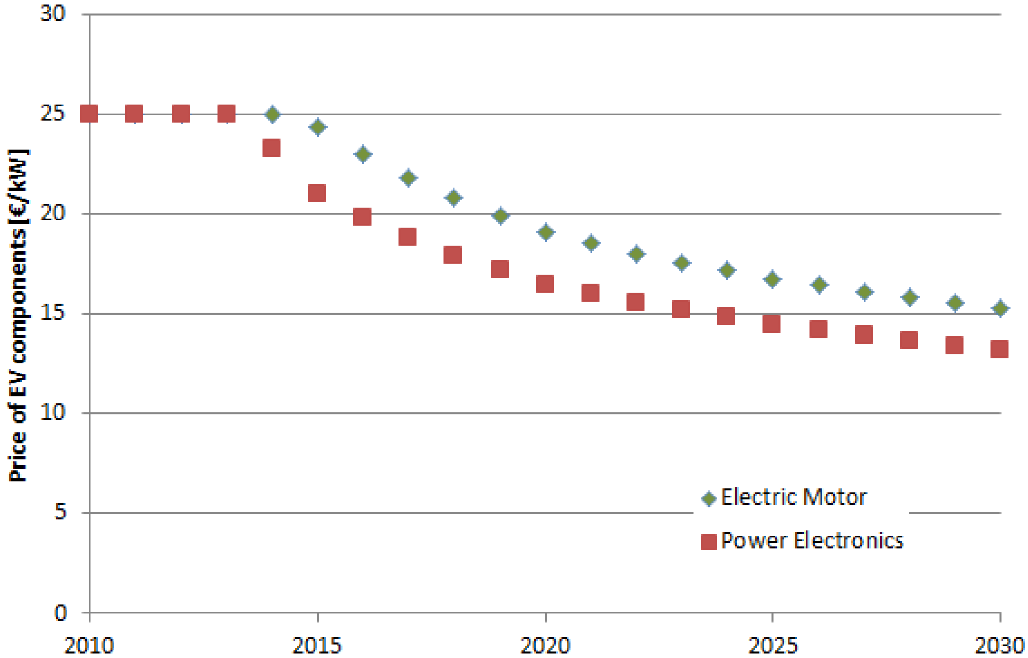


Figure 49. BaU scenario: Evolution of EV component prices over time

**Stock**

Results for the vehicle stock of EU28 countries for all segments in the BaU scenario are shown in Figure 50. The overall size of the vehicle stock decreases slightly until 2015 due to the economic crisis. After that period vehicle sales return to, and in some countries even exceed, their pre-crisis level, leading to an increase of about 4% in 2030 in comparison to the stock size in the year 2010. The composition of the vehicle stock changes considerably in the investigated period: The share of conventional gasoline vehicles decrease from 64% to 32%, whereas diesels enhance their share from 36% in 2010 to 47% in 2025, and suffer only a minor reduction to 43% in 2030. After 2020, the share of electrified vehicles rises rapidly and reaches 11% in 2025 and 22% in 2030, although the major contributors are G-HEV, D-HEV and PHEV vehicles with an almost equal stock share in 2025 and 2030 of around 3% and 6%, respectively.

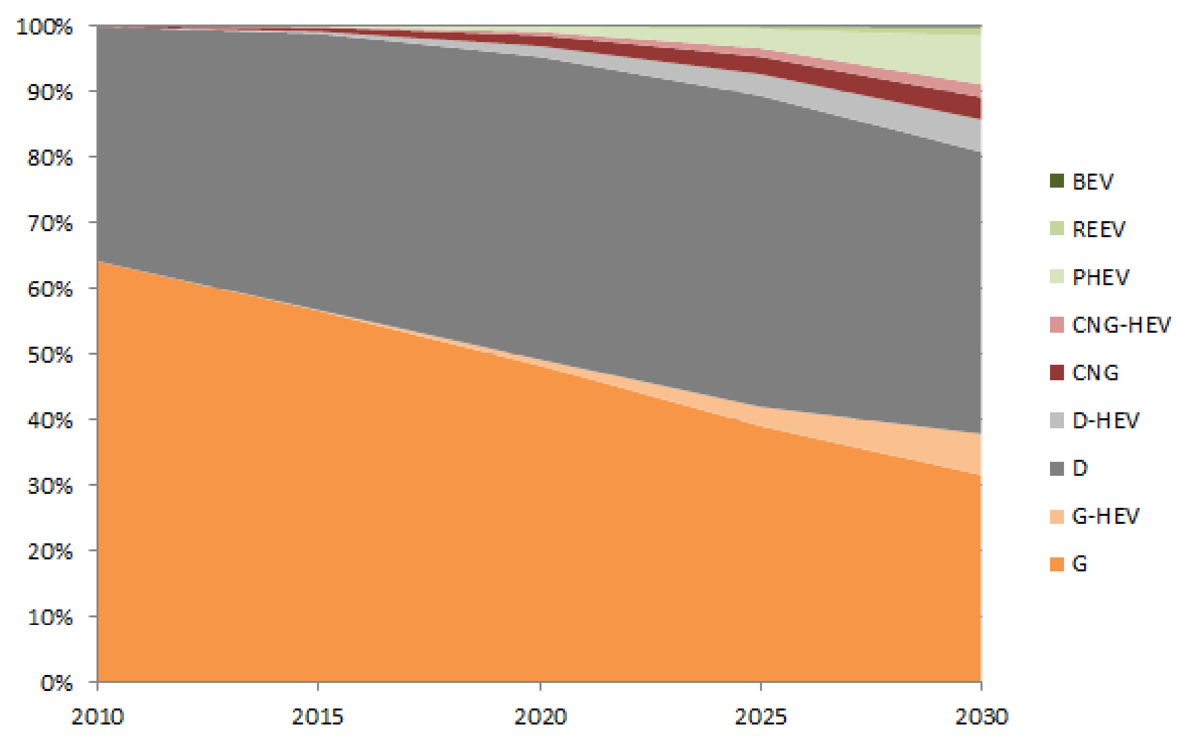


Figure 50. BaU scenario: total vehicle stock in EU28

Figure 51 shows the annual energy consumption of vehicles in the stock of EU28 countries. Total energy consumption decreases from 6.1 TJ in 2010 to about 4.6 TJ in 2030, which corresponds to a relative reduction of roughly 25 %.

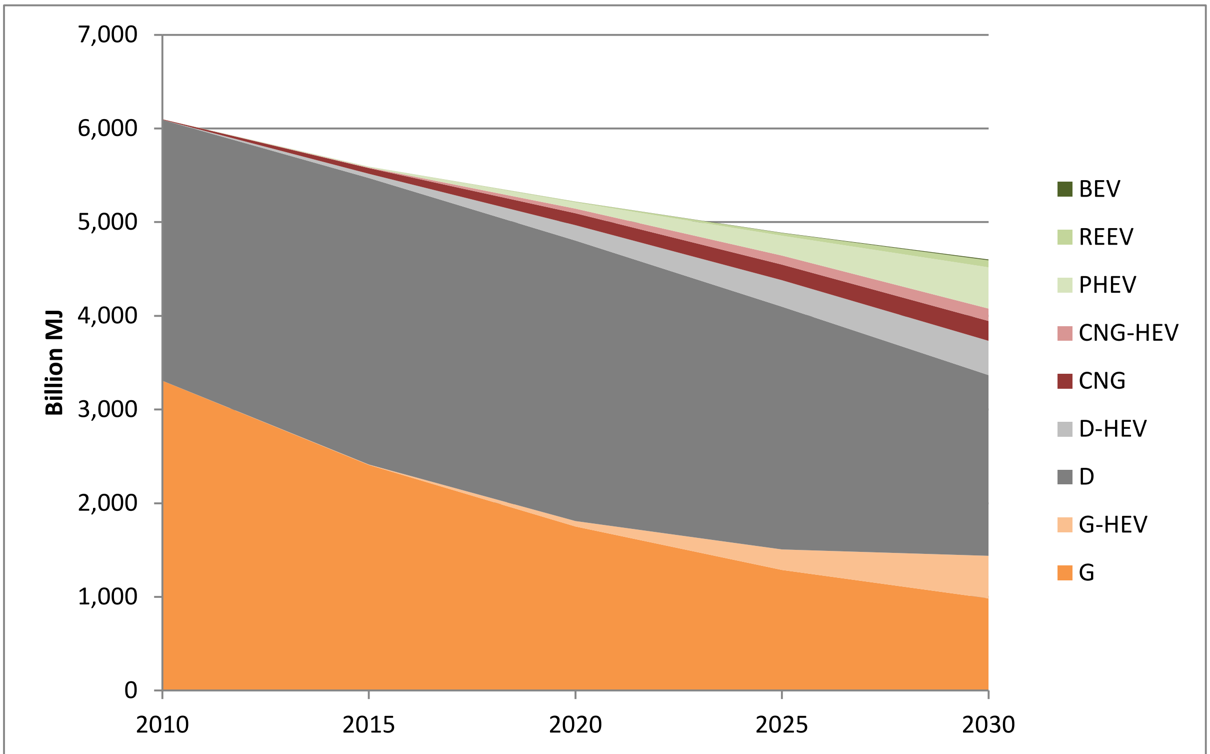


Figure 51. BaU scenario: total annual vehicle energy consumption in EU28

As $CO_2$ emissions are strongly correlated to energy consumption, total Well-to-Wheel $CO_2$ emissions of vehicles in the stock of EU28 countries show qualitatively the same behaviour (Figure 52). WTW $CO_2$ emissions in 2030 are reduced by 29 % compared to 2010.

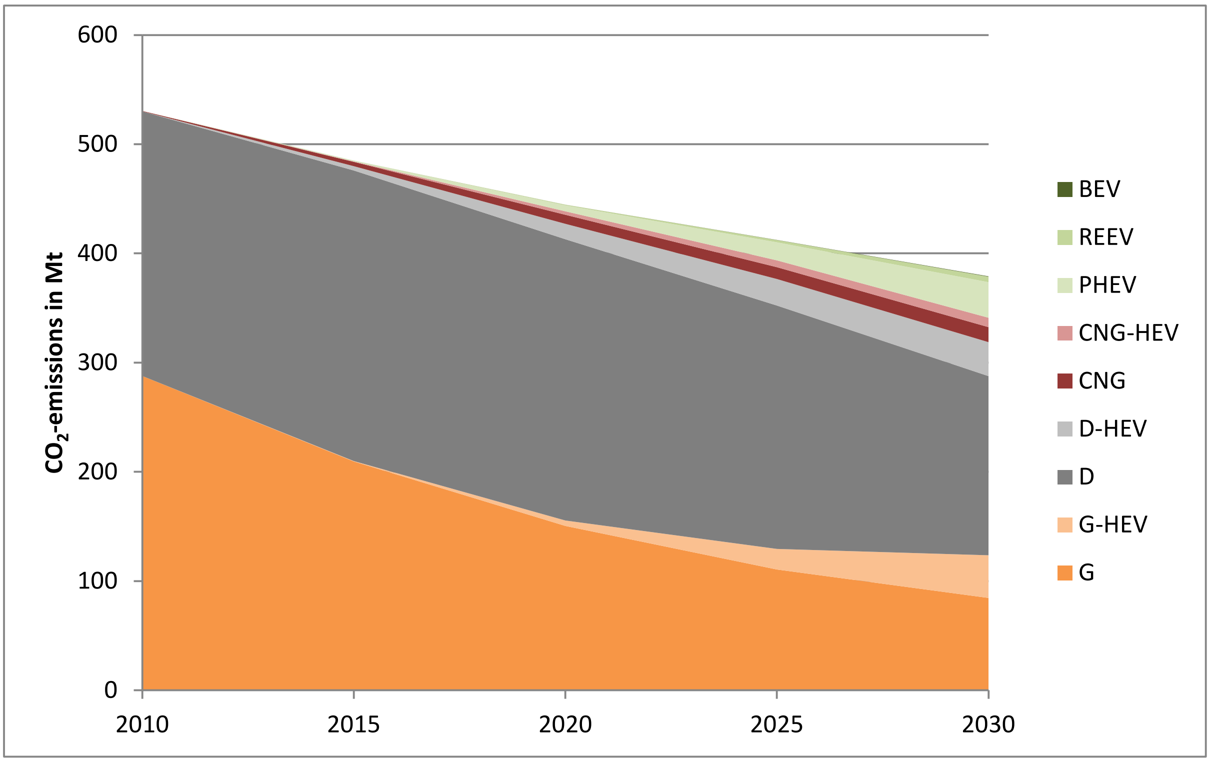


Figure 52. BaU scenario: Well-to-Wheel $CO_2$-emissions per year in the EU28 vehicle stock

## 3.4 BaU scenario: Conclusion

Even under the conservative framework of the BaU scenario, electrified vehicles slowly enter the European (EU28) market from 2020 on. Conventional powertrains (diesel, gasoline and CNG) keep their market dominance up to the year 2025. The most preferred electrified powertrains are PHEV, followed by G-HEV and D-HEV. Due to high initial costs and infrastructure requirements, REEV and BEV are not able to gain a significant market share. For the same reasons, FCEV are not sold in any of the investigated markets. CNG vehicles are not entering new markets but are sold almost exclusively in Italy (with its well-developed refuelling infrastructure and relatively low CNG prices) and, to a small extend, in Germany. As WTW $CO_2$ emissions are lower for CNG vehicles than for other conventional powertrains, total Well-to-Wheel $CO_2$ emissions of the Italian stock in 2030 are lowered by 22% compared to 2010 (although total energy consumption of the stock is reduced by a mere 12% in the same period).

Under the assumptions of the BaU scenario, average $CO_2$ emissions of new vehicles in EU28 are 95 g/km in 2021 and thus meet the European emission target. Towards 2030, average Tank-to-Wheel $CO_2$ emissions fall below 75 g/km. In combination with decreasing Well-to-Tank $CO_2$ emissions of e.g. electricity production, total energy consumption of the EU passenger car stock decreases from 6.1 TJ in 2010 to 4.6 TJ in 2030, which corresponds to a reduction in Well-to-Wheel $CO_2$ emissions of about 29 %. The BaU scenario thus shows already one deployment path towards a low(er)-carbon fleet.

Finland with its tax politics strongly incentivising low $CO_2$ emission and, especially, electrified vehicles show a higher rate of electrification in 2030 than countries like Germany or France where tax policies are less inclined towards EV. In France, under the assumption of the BaU scenario, the solely $CO_2$ emission-based Bonus-Malus system results in a dominance of diesel-based powertrains up to 2030 and a 22% market share of higher electrified powertrains (of which 78% are PHEV, 18% REEV and 4% BEV).

In comparison to Finland and in combination with relatively high electricity prices in Germany, market penetration of EV in Germany starts later, market shares are lower (27% in 2030) and PHEV and, to a lesser extent, REEV are the EV powertrains of choice. The German national target of one million electrified vehicles in 2020 is thus not met in the BaU scenario: cumulated sales of electrified vehicles reach 90,000 in 2020 and 4.6 million in 2030 (reaching the year 2020 target of 1 million sold electric vehicles with about 5 years of delay).

In Poland, where customers have a comparatively low average mileage and where tax policies are not in favour of EV, amortisation rates of the fuel-efficient but initially more expensive EV are significantly reduced. Thus, conventional diesel and gasoline powertrains dominate the vehicle market up until 2030 and concerning $CO_2$ burden sharing, OEMs will have to make greater efforts in other European markets to comply with their $CO_2$ fleet target.

Contrary to most other European markets, diesel is slightly more expensive in the United Kingdom than Gasoline; consequently, conventional gasoline powertrains have a relatively high market share up to the end of the modelling period (45% of all new vehicles sales in 2030). However, $CO_2$ emissions of gasoline powertrains are higher than of diesel powertrains, which thus enables an earlier and more pronounced market entrance of electrified powertrains, with PHEV, REEV and BEV gaining 27% market share in 2030 (on the implementation of OEM strategies to meet EU $CO_2$ targets with their fleet, see Schimeczek et al. (2015).

Generally, it should be kept in mind that there are model restrictions concerning underlying assumptions such that results may vary with varying model parameters.

# 4 Technology Driven scenario (TeD)

## 4.1 Techno-economic scenario parameters

Higher invests into traction battery research and development are assumed in the Technology Driven scenario (TeD). Thereby, a faster price decline for EV technologies, mostly traction battery systems, can be realized compared to the BaU framework. Although a major technological breakthrough in battery research may lead to a technology switch and ultimately to lower floor costs, this is from today's point of view not an expected development and was thus not considered in the simulations. For further methodological details of learning curves and for the corresponding learning rates, refer to Schimeczek et al. (2015).

In addition to lower battery system costs the efficiency of vehicles that can be recharged at the electricity grid (PHEV, REEV and BEV) is slightly improved compared to the BaU-scenario. The underlying socio-technical assumptions are

- more efficient electrified components,
- weight reduction of traction batteries and
- a higher share of pure electric driven mileage (PHEV and REEV).

## 4.2 TeD scenario results

### 4.2.1 Finland

**Market shares**

The boundary conditions of the TeD scenario lead to a faster spread of electrified vehicles in the Finnish small segment (Figure 53). Although the overall market share of these vehicles does not change significantly in 2030, a larger cumulated number of electrified vehicles are expected to be sold up to that date.

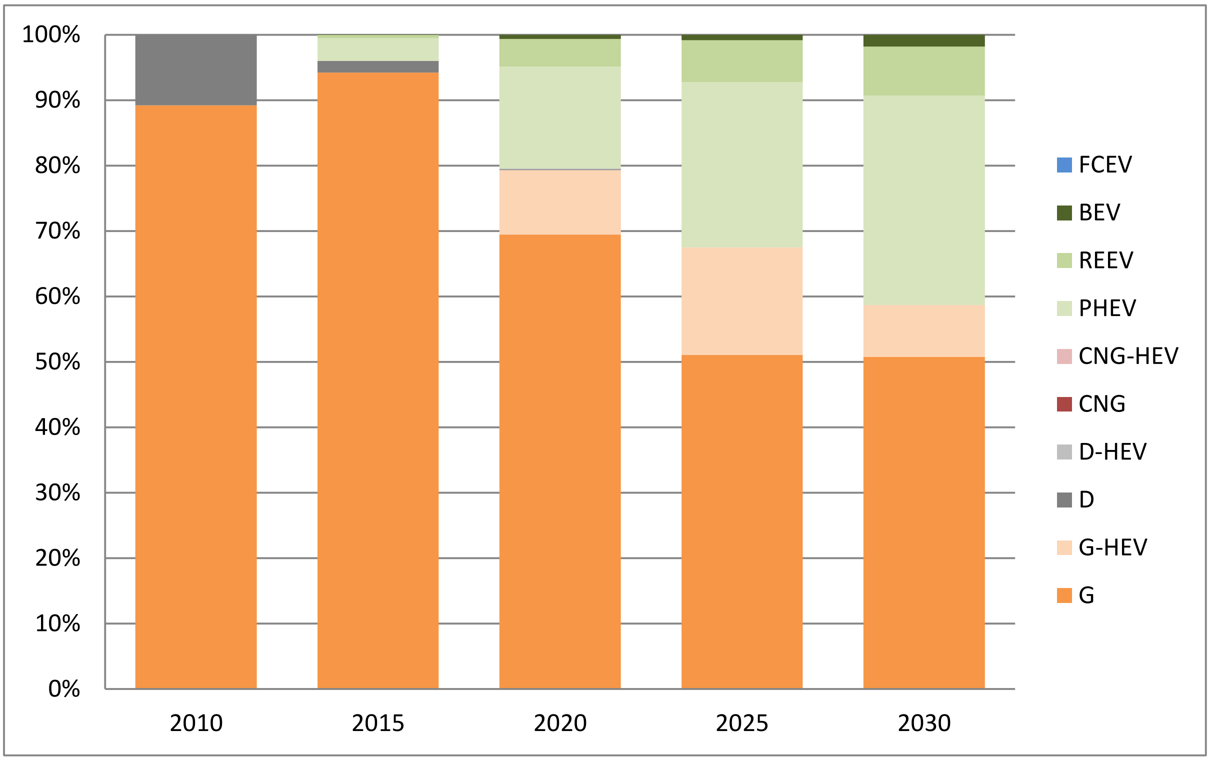


**Figure 53. TeD scenario: vehicle sales in Finland, small segment**

TeD market shares in the Finnish medium segment, as depicted in Figure 54, follow the same trends as in the BaU scenario. However, electrified powertrains enter the market earlier, although this does not result in a higher market share of these powertrains in 2030. Diesel vehicles are forced out of the market earlier. Even more in detail, BEV profit from the positive development of battery prices and gain a significant market share already in 2015, whereas only a very little number was found in the BaU scenario in 2015.

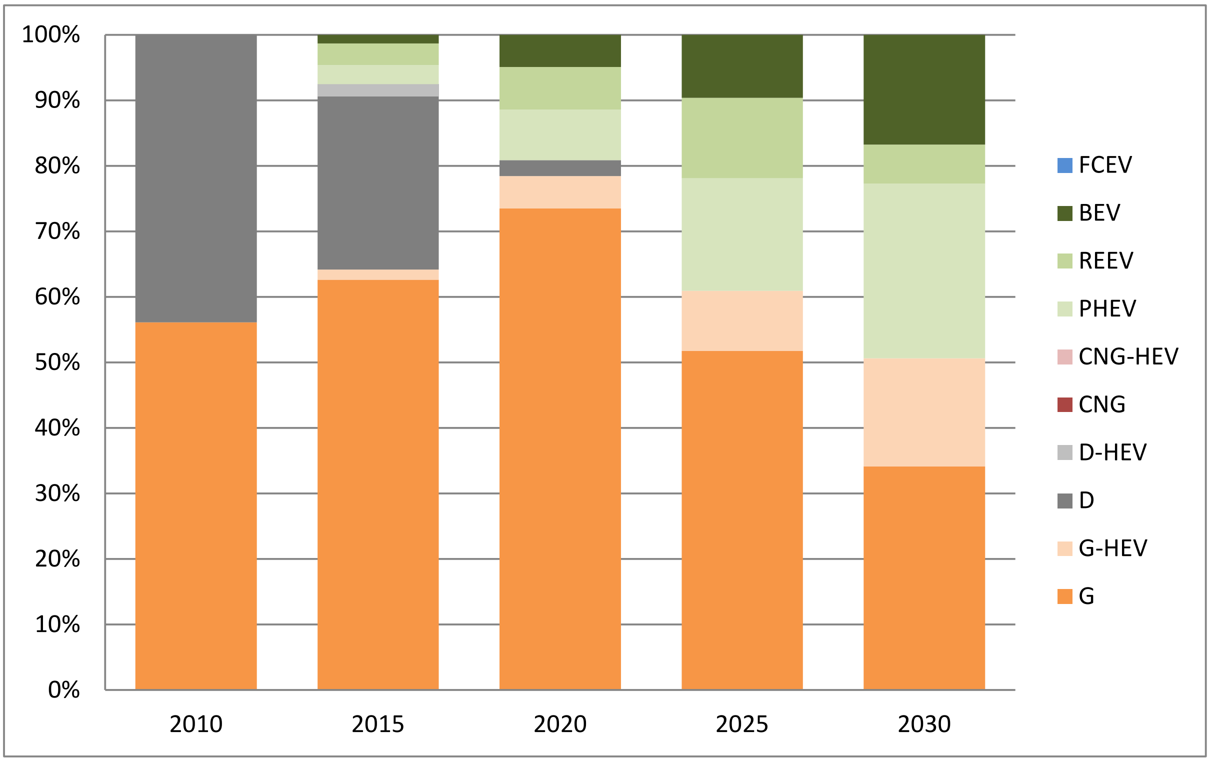


**Figure 54. TeD scenario: vehicle sales in Finland, medium segment**

Figure 55 shows TeD vehicle sales in the Finnish large segment, which also resemble the picture in the BaU scenario. Some differences occur around 2015 and 2020: In 2015, PHEV and REEV reach a slightly larger market share than in the BaU, whereas around 2020, an accelerated uptake of BEV can be seen. However, in 2030 the same market shares apply for BaU and TeD. The weak dependency of the Finnish market shares on the exact technological development is a direct consequence of the powerful Finnish taxation model, which causes high costs for buyers and owners of conventional vehicles and thus strongly supports the electrification of powertrains already in the BaU scenario.

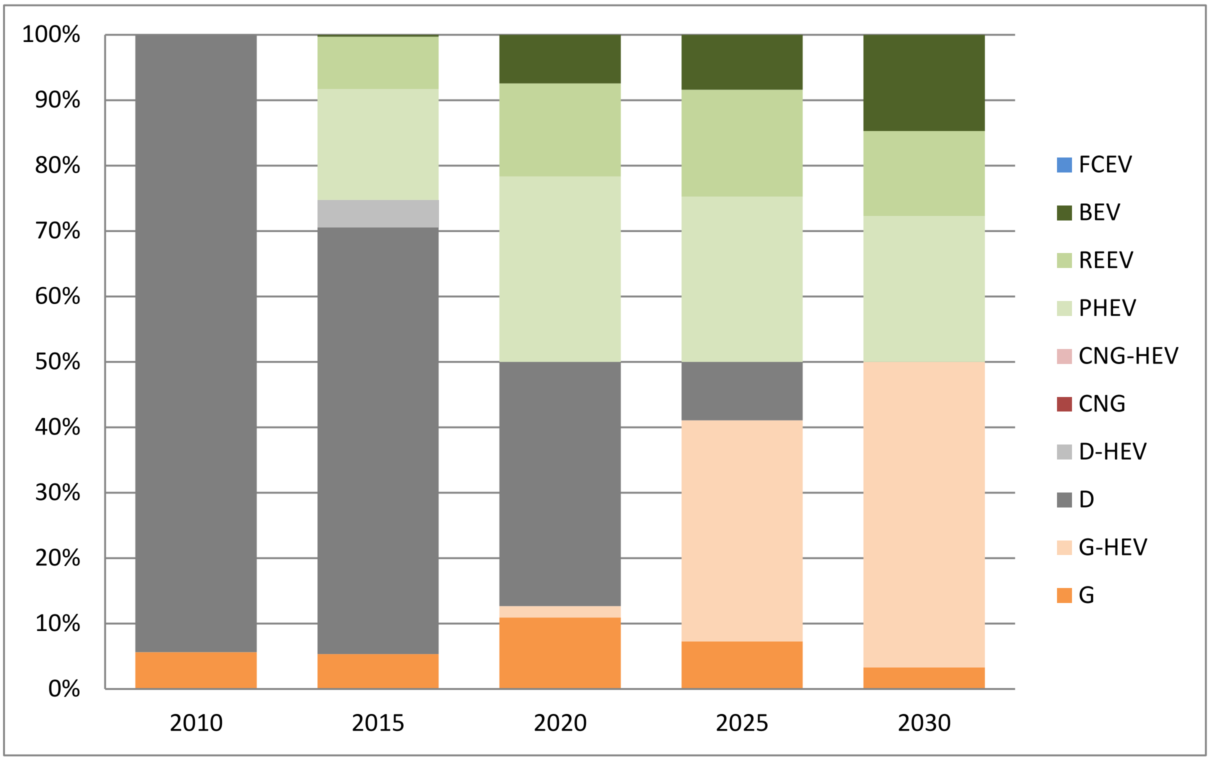

Figure 55. TeD scenario: vehicle sales in Finland, large segment

**Stock**

TeD scenario results for the Finnish stock for all segments are shown in Figure 56. In comparison to the BaU scenario, only minor differences are to be noted: the share of conventional vehicles is slightly reduced in 2030, whereas the total share of BEV, PHEV und REEV in this year is about 3% larger than in the BaU scenario. This is an expected consequence of the minor differences between both scenarios in the new vehicle market.

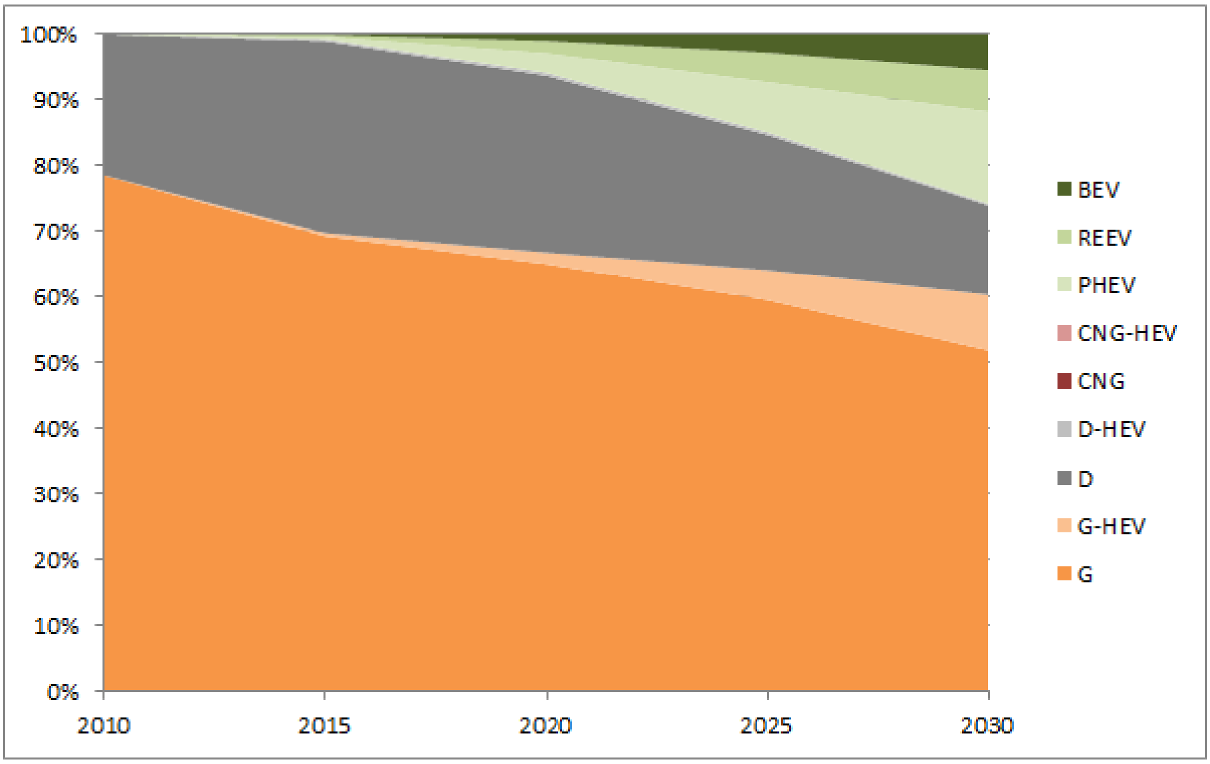


**Figure 56. TeD scenario: total vehicle stock in Finland**

Figure 57 shows the total energy consumption per year of the vehicle stock in Finland. Again, the differences between the TeD and the BaU scenario are rather small. However, in the TeD calculations, total energy consumption drops below 80 PJ in 2030, and is thus reduced by a further 1% in comparison to BaU results. The most noticeable change is found in the consumption of the diesel fleet, which is 15% smaller than in the BaU scenario in 2030. However, this can be fully explained with the size reduction of the diesel fleet by the same percentage.

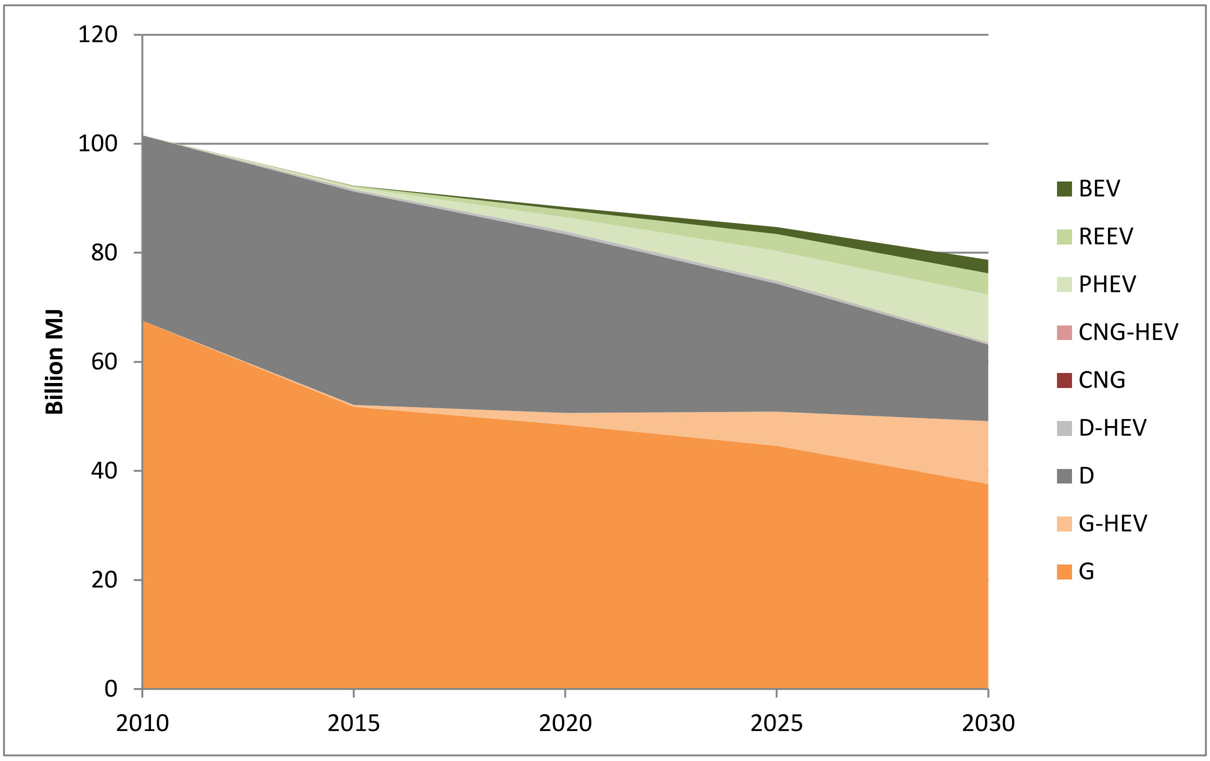


Figure 57. TeD scenario: annual energy consumption of vehicles in Finnish stock

In 2030, in accordance to energy consumption, annual WTW $CO_2$ emissions of the Finnish vehicle stock in the TeD scenario are 1% lower than in the BaU scenario (Figure 58).

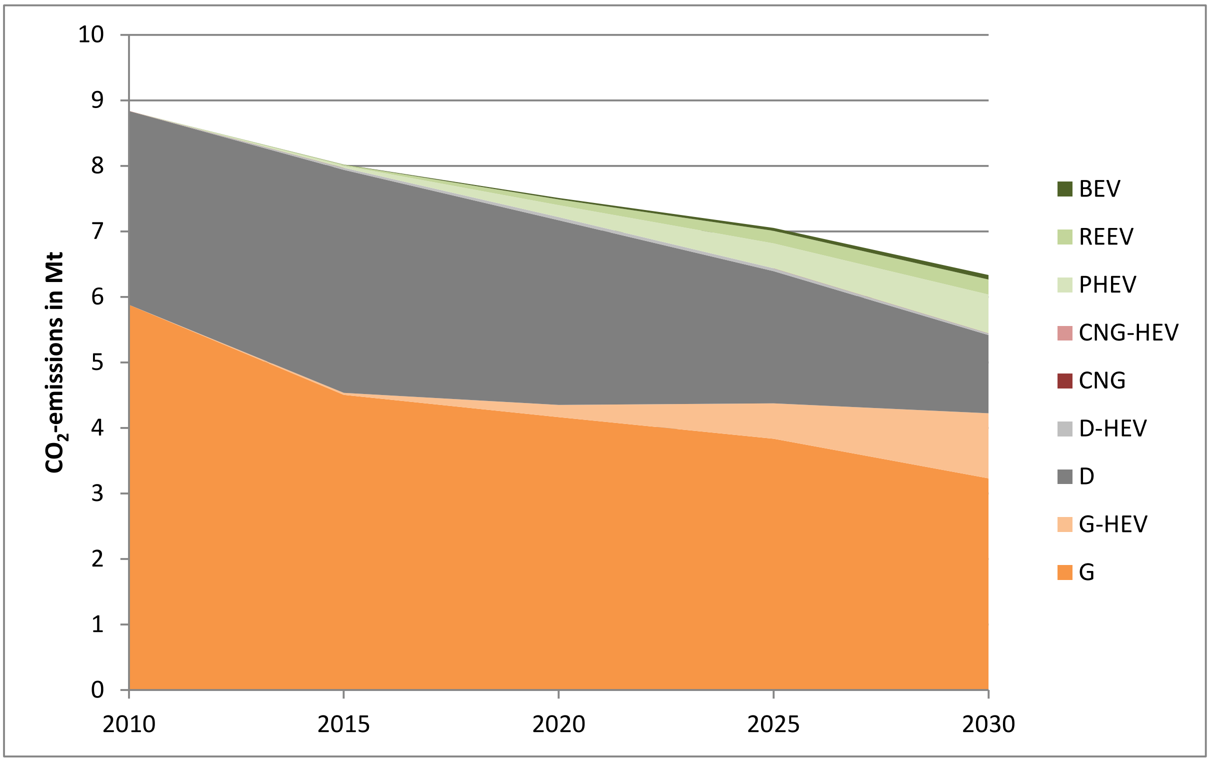


Figure 58. TeD scenario: annual Well-to-Wheel $CO_2$ emissions of vehicles in Finnish stock

### 4.2.2 Germany

**Market shares**

The German small segment market shares change slightly from the BaU to the TeD scenario, depicted in Figure 59. In 2020, the small fraction of CNG vehicles and D-HEV is replaced by PHEV, and, starting around the year 2025, the share of PHEV and G-HEV is much larger than in BaU. As a consequence, the conventional gasoline sales are reduced to about 20% of this segment in 2030.

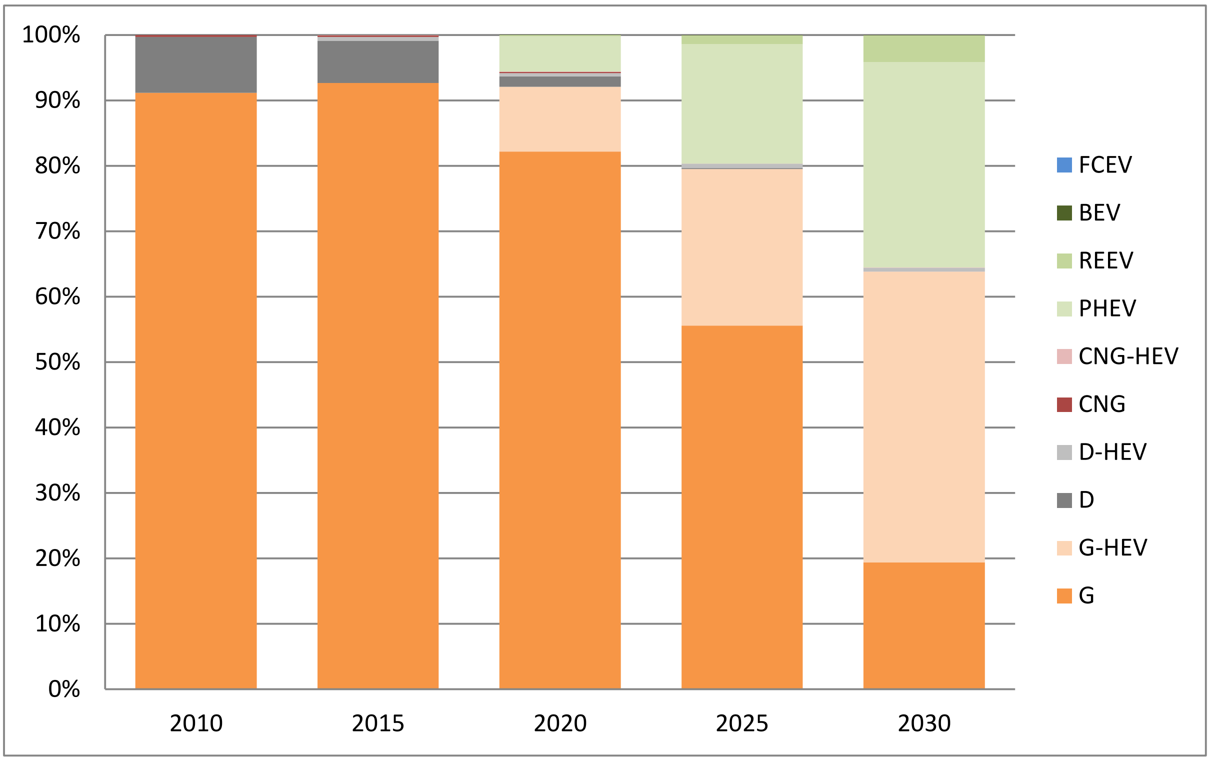


Figure 59. TeD scenario: vehicle sales in Germany, small segment

In comparison to BaU calculations, sales in the German medium segment have quite changed in TeD (Figure 60): PHEV and REEV reach a combined market share of about 30% in 2030 and gasoline-hybrids are sold to a larger extend after 2020. Thus, electrified powertrains make up for more than 75% of the sales at the end of the reporting period. These findings are a consequence of the earlier demand for electrified vehicles, which in turn allows for a faster uptake of corresponding production capabilities, and thus results in a stronger market penetration of these powertrains.

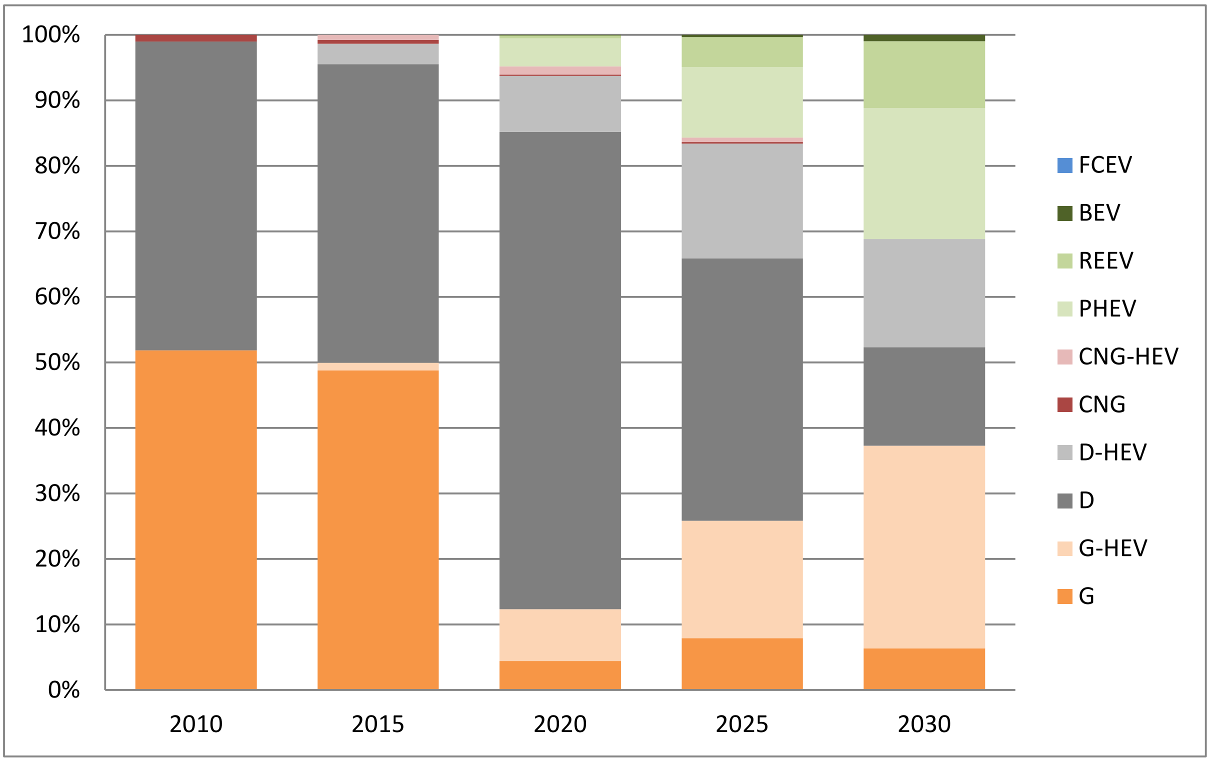


Figure 60. TeD scenario: vehicle sales in Germany, medium segment

Some changes between BaU und TeD simulations can be observed for the German large segment (Figure 61). Especially PHEV enter the market much faster – due to the early availability of low-priced batteries – and attain 20% of market share already in 2020, mainly replacing diesel vehicles. The market share of conventional gasoline vehicles, however, is almost not affected. The share of diesel vehicles is a little bit lower in 2020 and 2025.

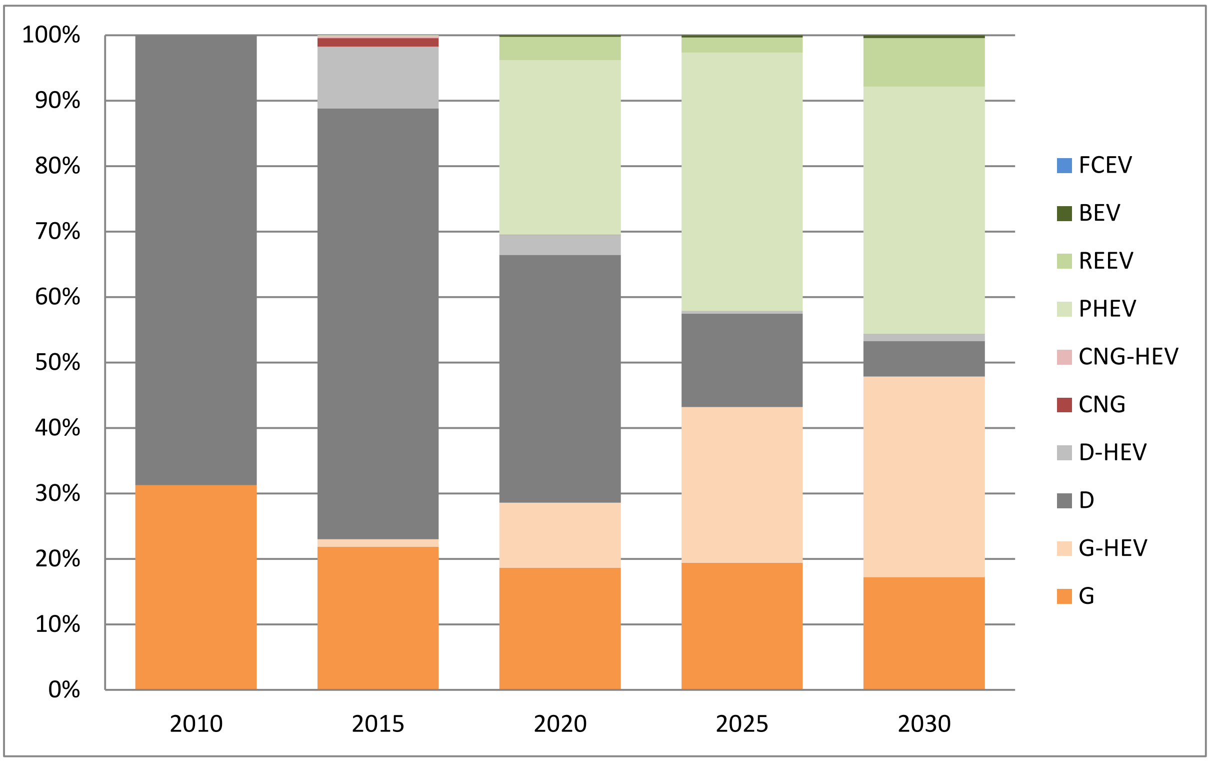


Figure 61. TeD scenario: vehicle sales in Germany, large segment

**Stock**

Results for the German stock for all segments are shown in Figure 62. The share of electrified vehicles in the German stock grows significantly faster and larger in the TeD than in the BaU scenario: In 2020, already 6.2% (4.9%) of the vehicles utilize electrified powertrains and in 2030, their share surpasses 42% (34%) in the TeD (BaU) scenario. This demonstrates, in accordance to the new vehicle sales, the strong sensitivity of the German vehicle electrification on the battery prizes and the efficiency of electrified powertrains.

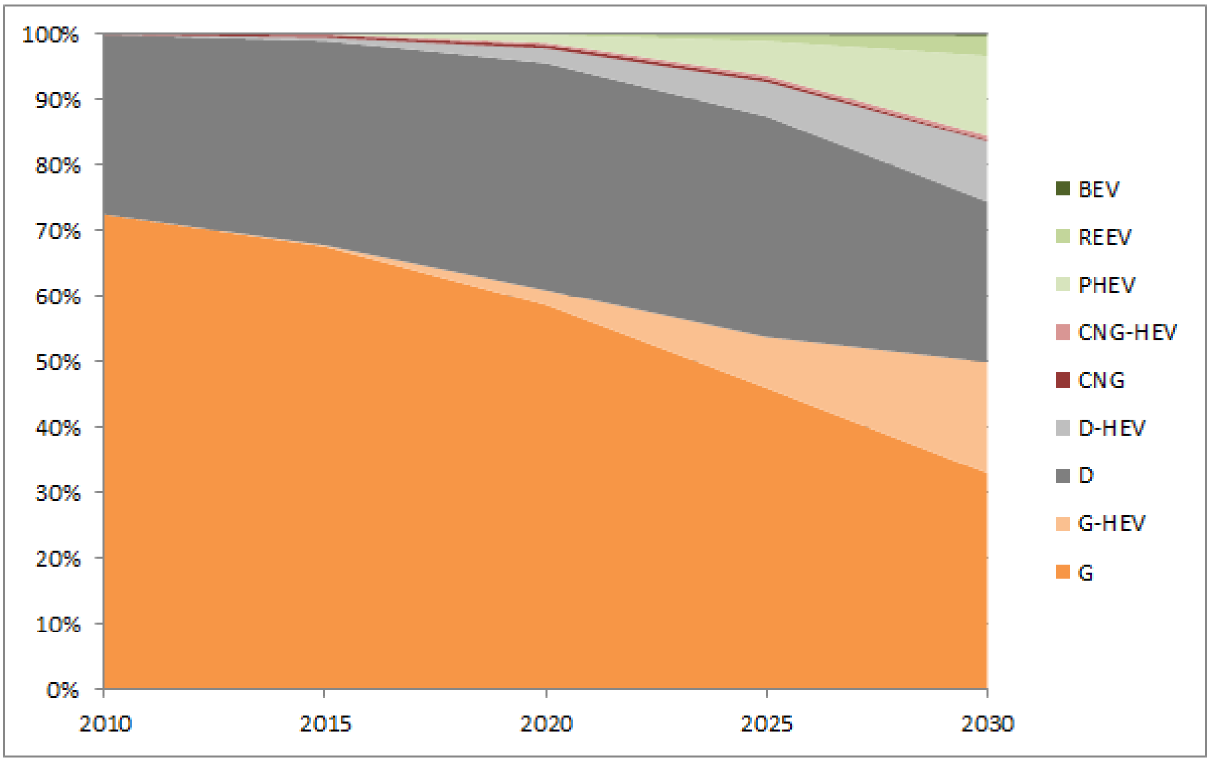


Figure 62. TeD scenario: total vehicle stock in Germany

Total annual energy consumption of German vehicles is shown in Figure 63. Although in the TeD scenario significantly more electrified vehicles enter the German stock, its total energy consumption is not significantly decreased (about 2%) below the energy consumption found in the BaU scenario. This can be explained by the fact that the majority of electrified vehicles in the German stock are G-HEV, D-HEV and PHEV, which are not as energy efficient as BEV. Thus their influence on the total energy consumption is limited.

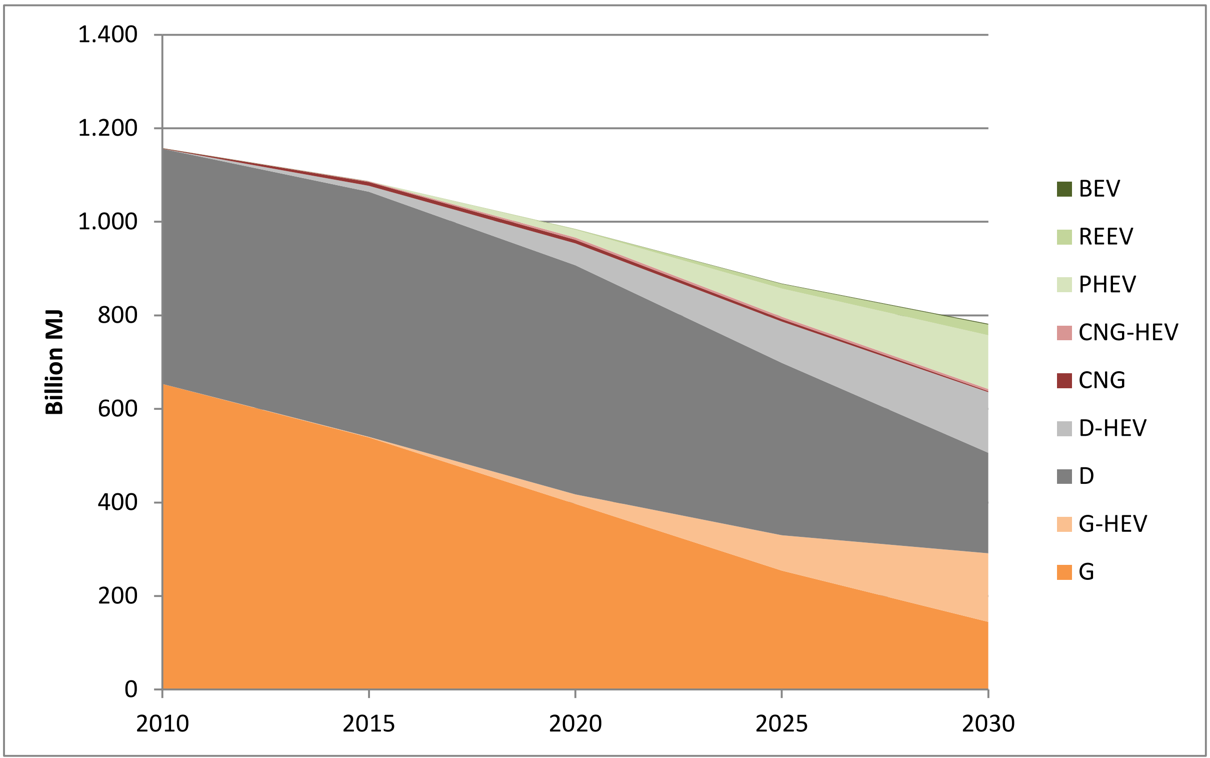


Figure 63. TeD scenario: total annual energy consumption of vehicles in German stock

Figure 64 depicts the German vehicle stock WTW $CO_2$ emission development. The emissions are reduced by more than 35% in 2030 in comparison to the year 2010, and thereby surpass the emission reduction of the BaU scenario in 2030 by 1.5 percentage points, which roughly corresponds to the enhanced total energy consumption reduction discussed in the previous paragraph.

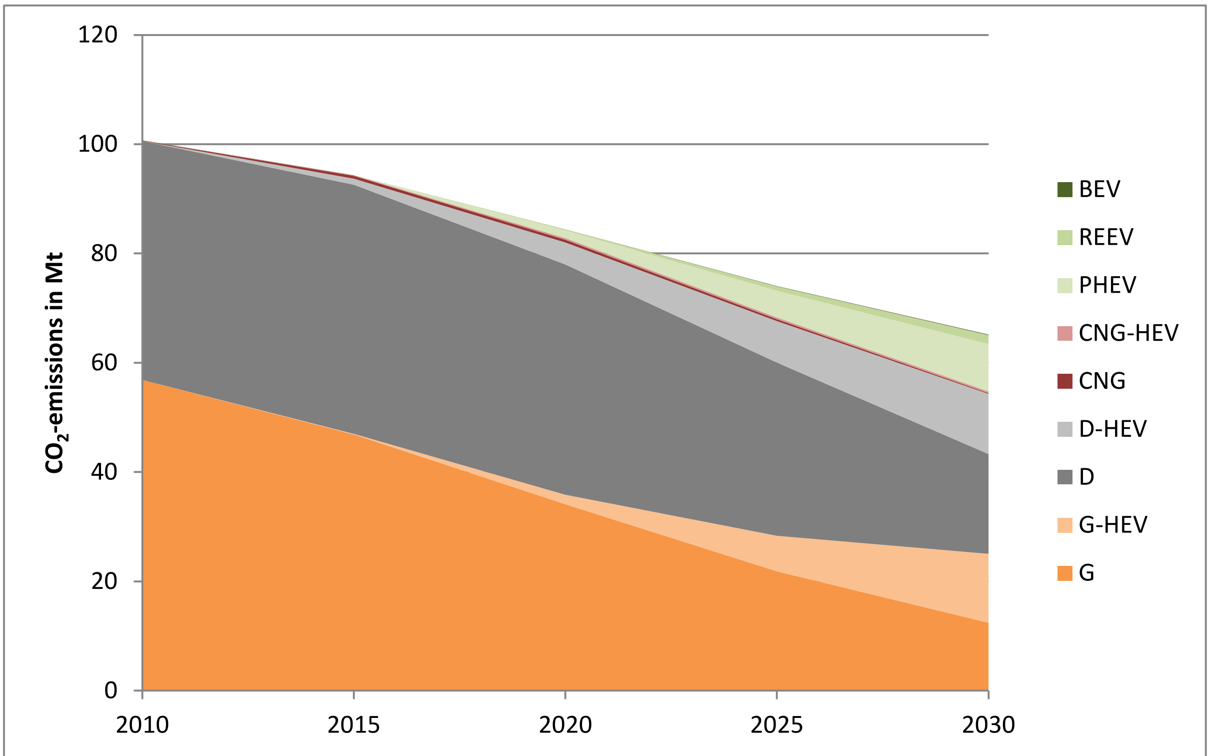


Figure 64. TeD scenario: Well-to-Wheel $CO_2$ emissions per year of vehicles in German stock

### 4.2.3 Poland

**Market shares**

Almost no differences between the BaU and the TeD scenario can be found in Polish market segments (Figure 65 to Figure 67). The share of small D-HEV is marginally increased in 2025, and some large PHEV enter the market in 2025, enhancing the market share of large PHEV in 2030 of about 2%. Still, REEV and BEV do not enter the market.

This shows that lower prices for electric components alone cannot trigger a significant electrification of vehicles in the Polish market, due to the very low Polish average annual mileage as well as the lack of any policies in favour of vehicles with low $CO_2$ emissions. Again, as in the BaU scenario, OEMs will then have to make stronger efforts in other markets to comply with the EU $CO_2$ target for new passenger cars.

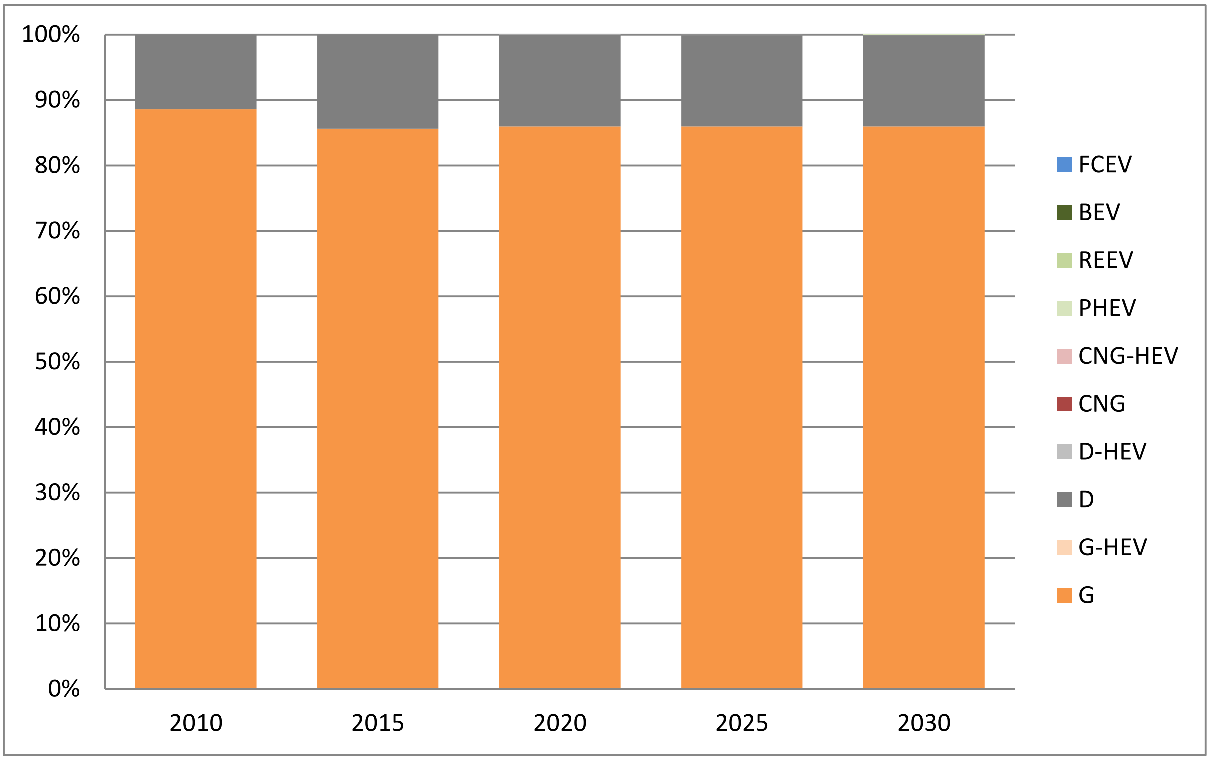


Figure 65. TeD scenario: vehicle sales in Poland, small segment

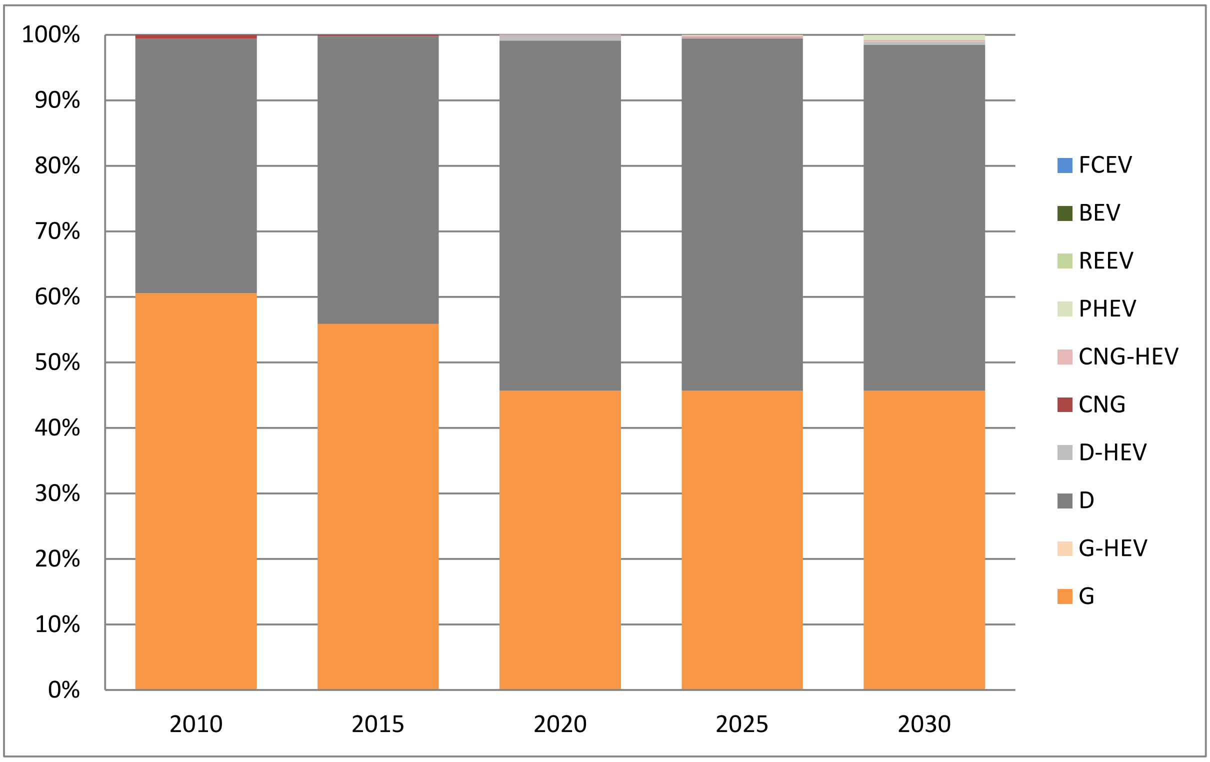


Figure 66. TeD scenario: vehicle sales in Poland, medium segment

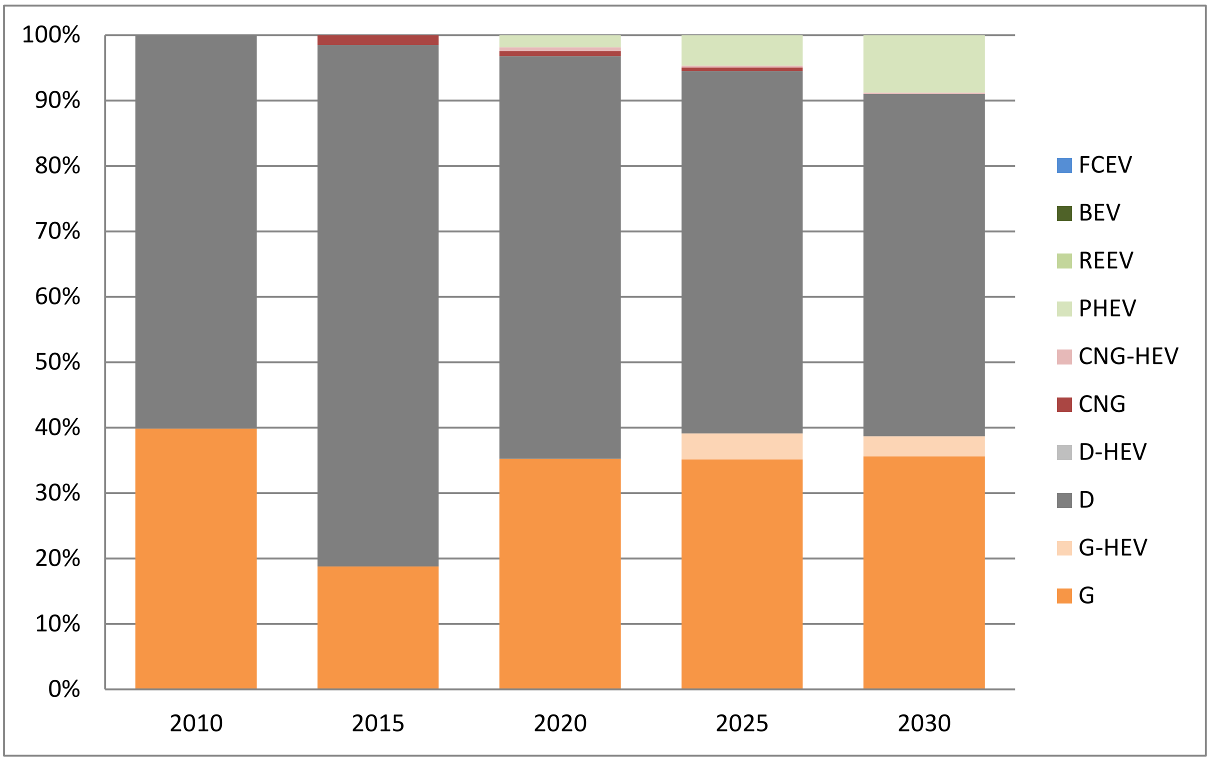


Figure 67. TeD scenario: vehicle sales in Poland, large segment

**Stock**

The development of the Polish vehicle stock as a sum of all segments is shown in Figure 68. Almost no difference to the BaU results can be seen, which corresponds to the negligible changes between the BaU and TeD scenario for the vehicle sales. As a consequence, the same applies to the total energy consumption per year of the Polish vehicle stock, which is presented in Figure 69, and the Polish vehicle stock's $CO_2$ emissions (Figure 70): The results of BaU and TeD scenarios are essentially identical.

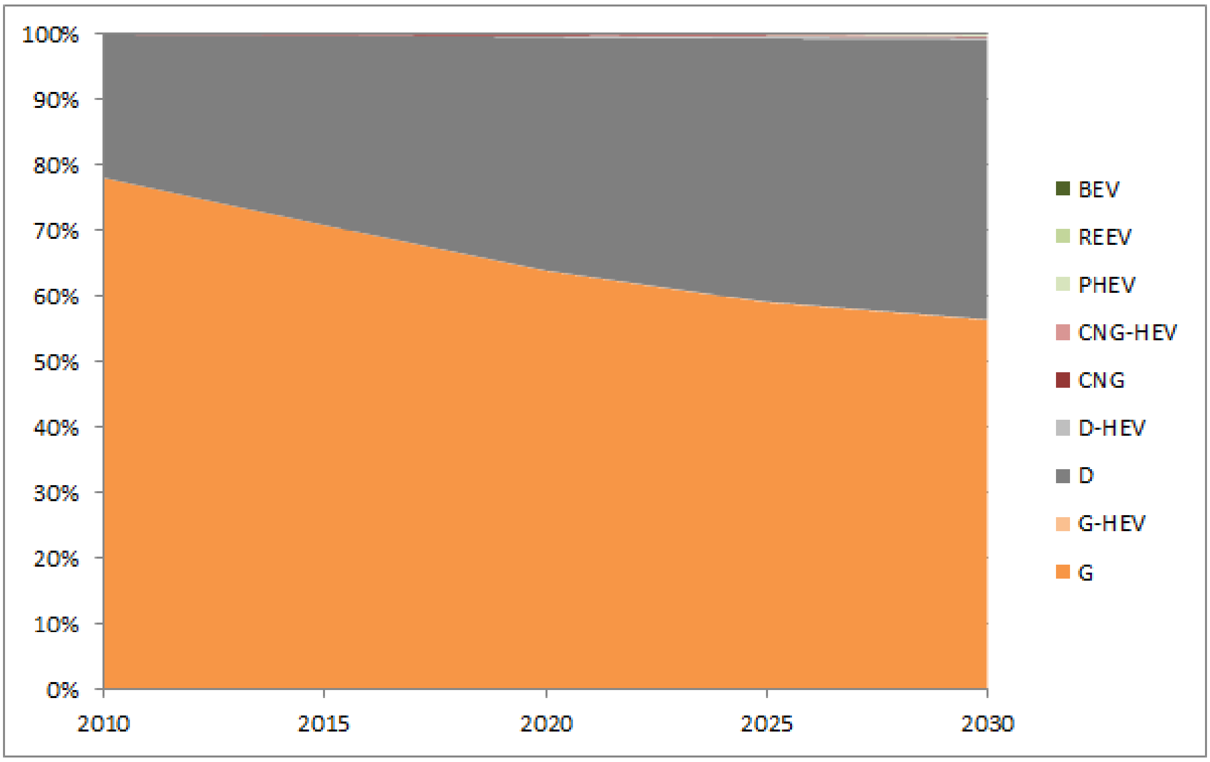


Figure 68. TeD scenario: total vehicle stock in Poland

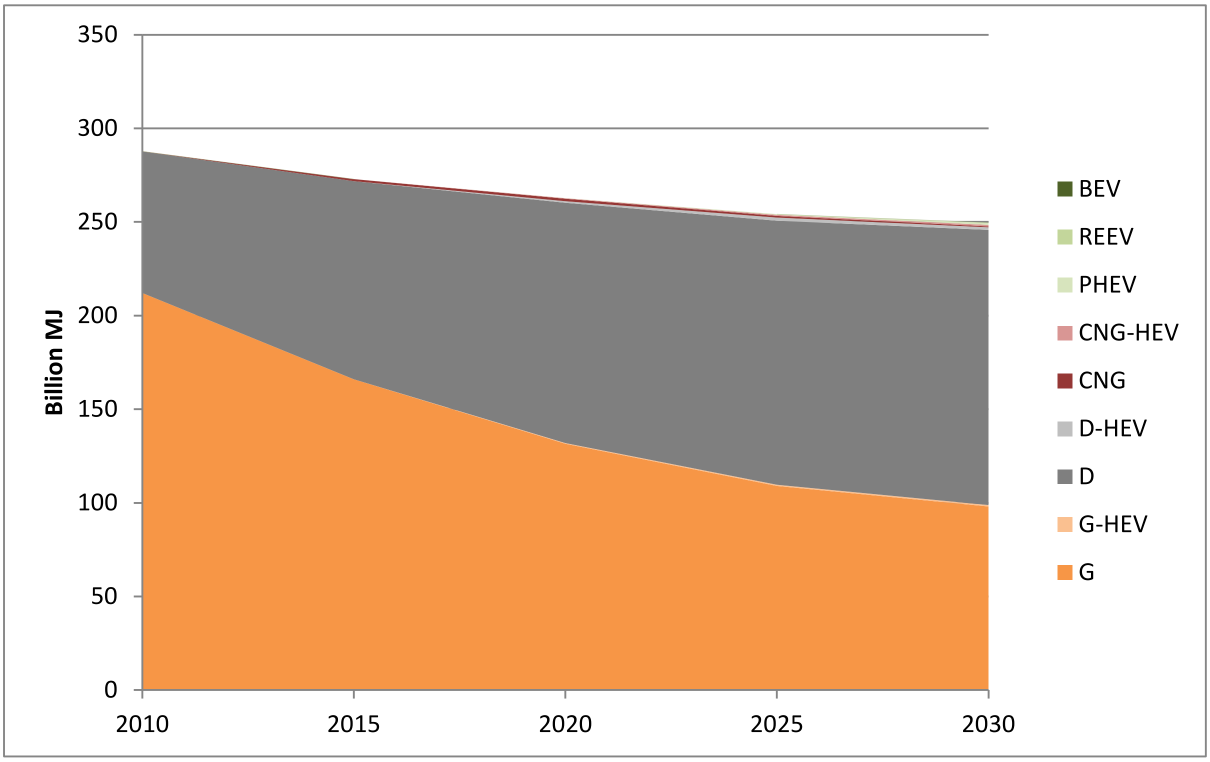


Figure 69. TeD scenario: energy consumption of Polish vehicle stock

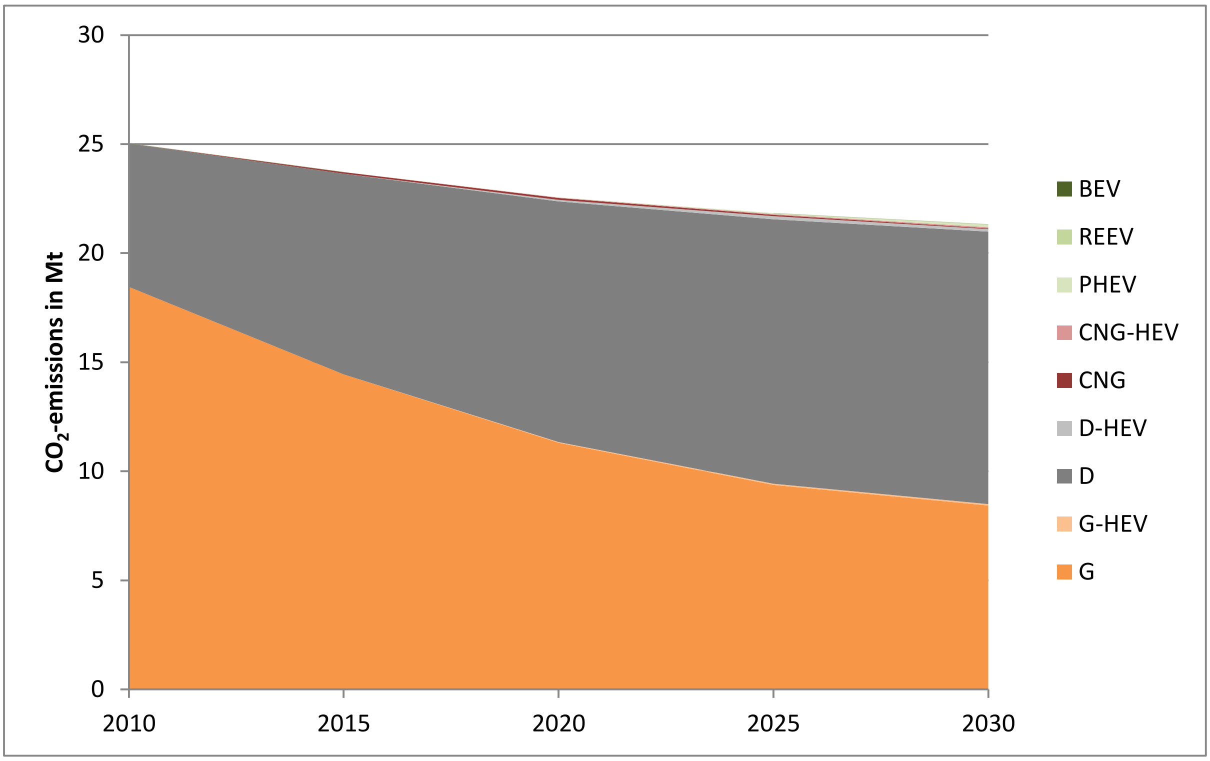


Figure 70. TeD scenario: Well-to-Wheel $CO_2$ emissions of Polish vehicle stock

#### 4.2.4 EU28

**Market shares**

EU28 market shares as totals for all segments in the TeD scenario is shown in Figure 71. As in the BaU scenario, a significant increase of electrified powertrains can be observed. The assumed increased efficiencies of electrified vehicles, regarding prices and energy storage capabilities, however, lead to a 6% larger market share of these vehicles in 2020 and all subsequent years, which also stems from a faster uptake of electrified vehicle sales in the UK, France and Italy in the TeD scenario.

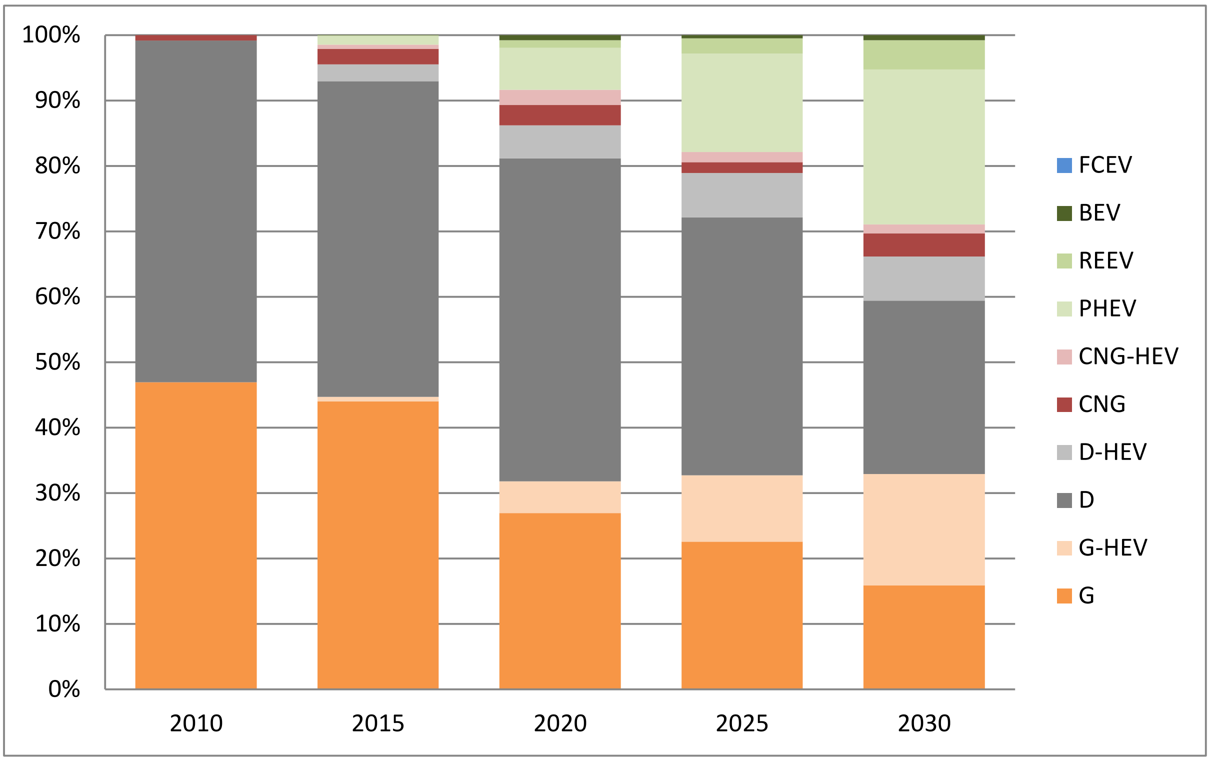


Figure 71. TeD scenario: Total new vehicle sales in EU28

Results of the TeD scenario for the small segment in EU28 is depicted in Figure 72. In comparison to the BaU results, significantly more PHEV can be seen after the year 2020. In 2030, about 5% less G-HEV and conventional gasoline vehicles as well as 5% less diesel vehicles remain in the market, a direct consequence of lower battery prices (as assumed in the TeD scenario). However, conventional gasoline, diesel and CNG vehicles still dominate this segment at the end of the investigated period.

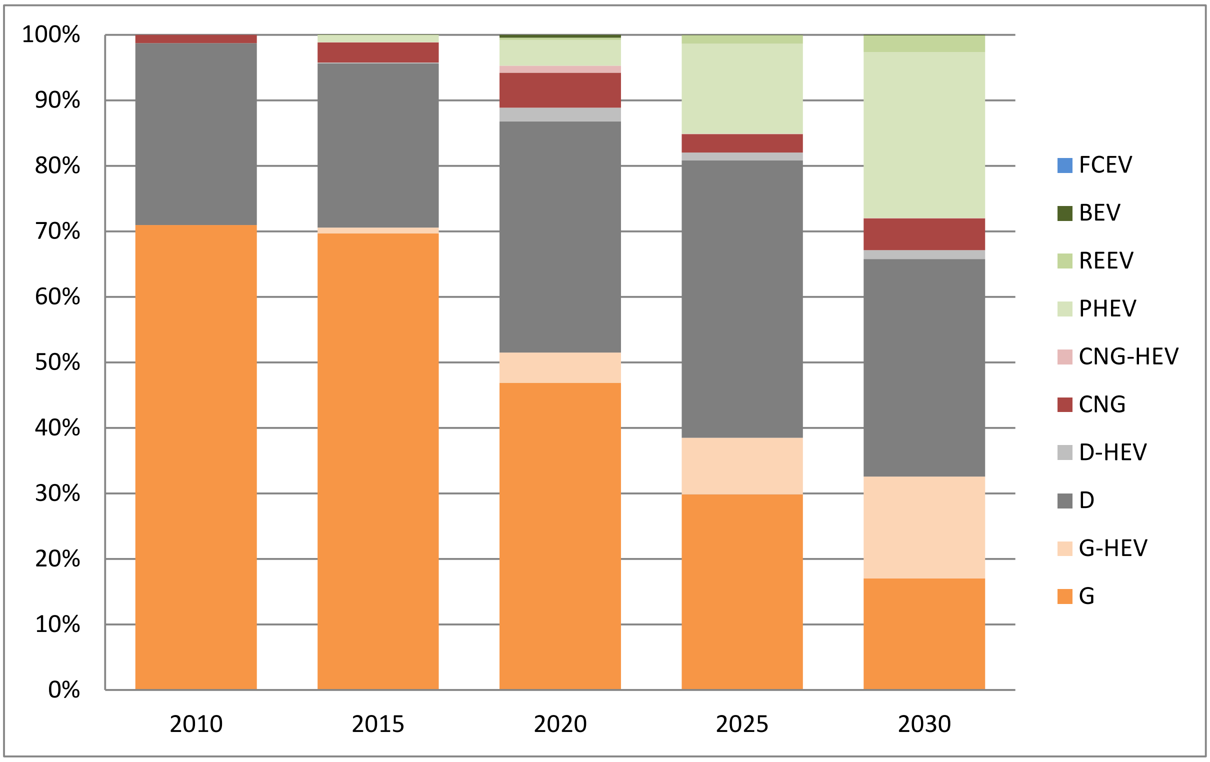


**Figure 72. TeD scenario: New vehicle sales in EU28, small segment**

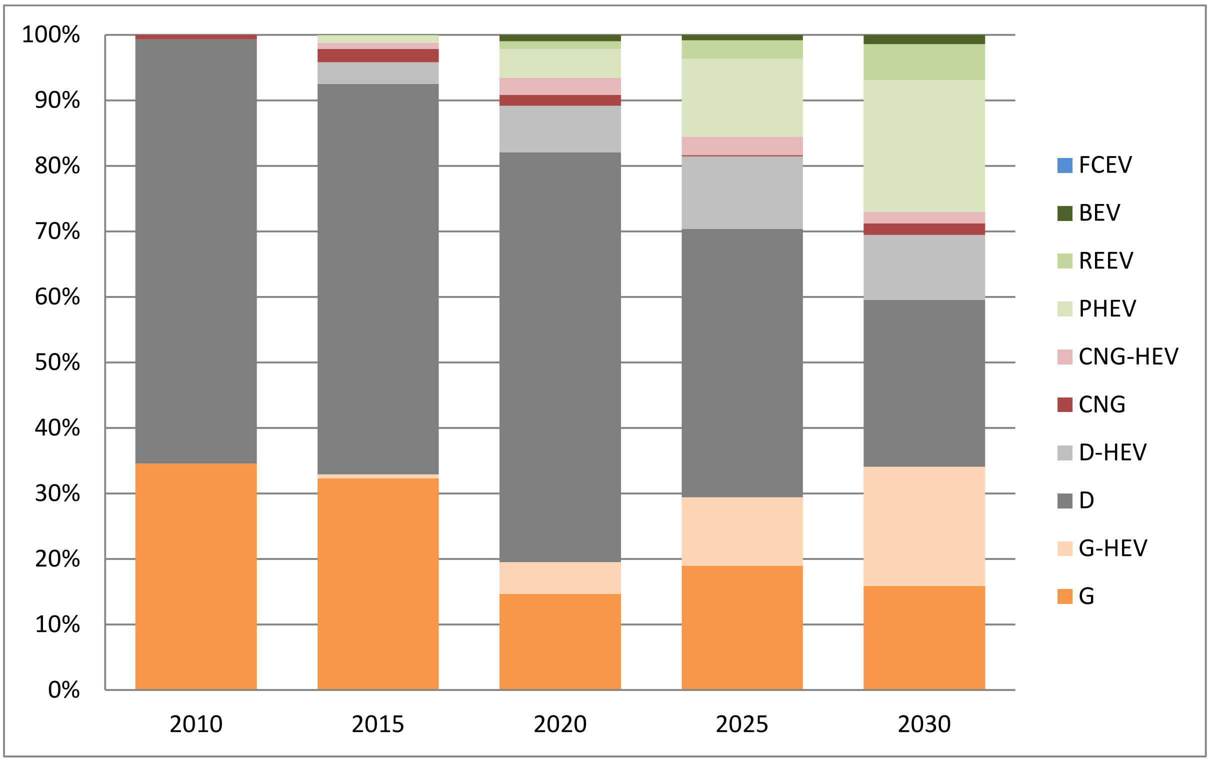


**Figure 73. TeD scenario: New vehicle sales in EU28, medium segment**

The EU28 medium segment, shown in Figure 73, reacts more sensitive to the parameter changes in the TeD scenario than the small segment. The market dominance of conventional vehicles in 2030, as it was found in BaU, is broken in the TeD simulations by an additional 10% of electrified powertrain sales in that year. Also in that year, PHEV are more frequently sold than conventional gasoline vehicles. As this segment represents the largest group of customers, the uptake of electromobility is strongly depending on medium sized vehicles.

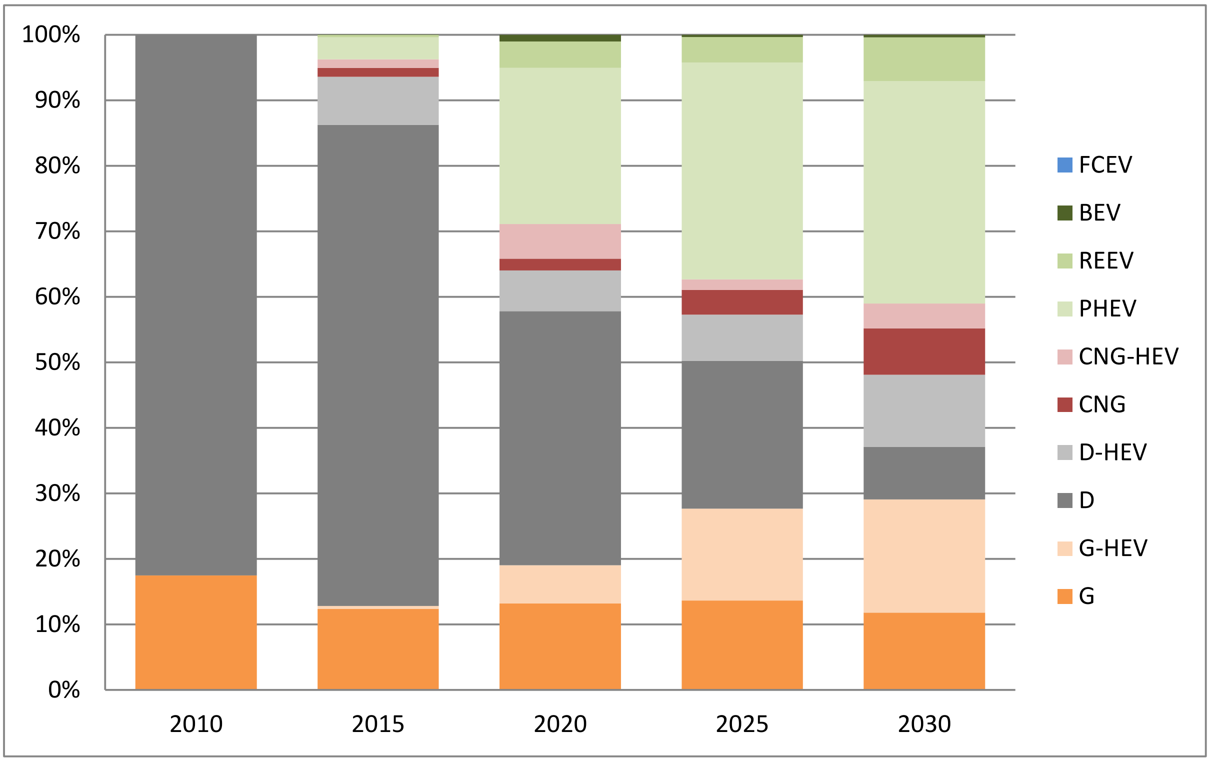


**Figure 74. TeD scenario: New vehicle sales in EU28, large segment**

The high market share of conventional diesel vehicles in 2010 (over 80%) is decreasing to 36% in 2020 and falls below 15% in 2030 in the large segment of EU28 in the TeD scenario (Figure 74). PHEV sales, in turn, profit from this drastic reduction of diesel sales much earlier than in the BaU scenario. However, the share of conventional gasoline vehicles remains constant between 17%-19% and is, similar to the market shares of conventional CNG and G-HEV, not significantly changed in comparison to BaU calculations.

### $CO_2$ targets

For the TeD scenario, the same EU $CO_2$ target curve for passenger cars was assumed as for the BaU scenario (130 g/km in 2015, 95 g/km in 2021[13], 75 g/km in 2030). In comparison to the target curve, average $CO_2$ emissions in g/km per vehicle including super credits are shown in Figure 75. In 2021 the $CO_2$ target is underrun by almost 6 g/km of $CO_2$ in the TeD scenario. Average $CO_2$ emissions are decreasing to 68 g/km in 2030, which is about 5 g/km below the BaU average in that year.

[13] While the EU $CO_2$ target for passenger cars is 95 g/km already in 2020, only 95% of each manufacturer's new passenger cars have to comply to that target; from 2021 on, this percentage is raised to 100% (Regulation (EU) No 333/2014)

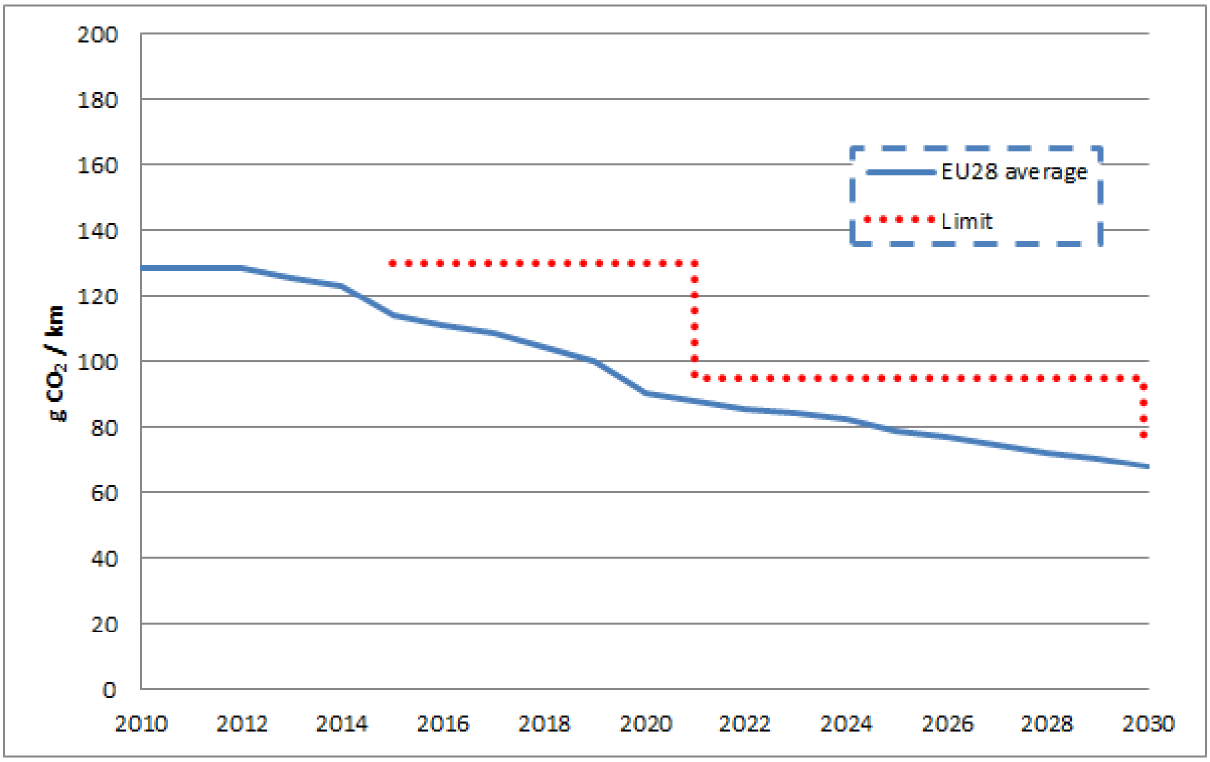


Figure 75. TED scenario: EU28 average $CO_2$ emissions (including super credits) versus $CO_2$ target

**EV component prices**

Following higher investments into traction battery research and development as assumed in the TeD scenario, a faster price decline of EV components is feasible (Figure 76). Reduced traction battery system prices lead to higher EV sales, which in turn drives the cost reduction of the battery systems even more. Due to this positive feedback loop, the assumed floor costs of 230 €/kWh are reached even before the year 2020 for the current battery system technology. Although a major technological breakthrough in battery research may lead to a technology switch and ultimately to lower floor costs, this is (from today's point of view) not an expected development and was thus not considered in the simulations.

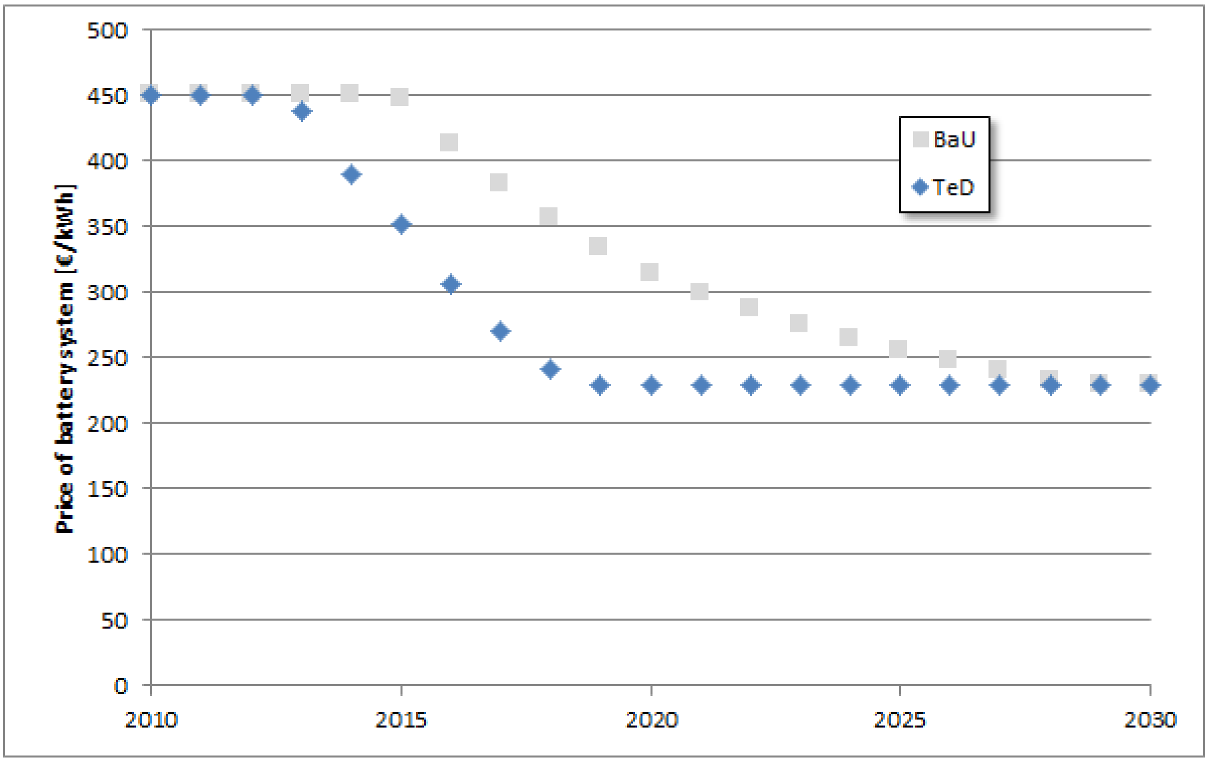


Figure 76. TeD scenario: Evolution of battery system price over time

**Stock**

The EU28 stock development resulting from the assumptions of the TeD scenario is depicted in Figure 77. With respect to the BaU scenario, a significantly larger share of electrified vehicles can be found in the TeD results: The additional percentage points of electrified vehicles in the total stock amount to 2%, 4% and 6% in the years 2020, 2025 and 2030, respectively. It must be noted that a considerable part of the vehicle electrification is caused by the markets in the UK and France.

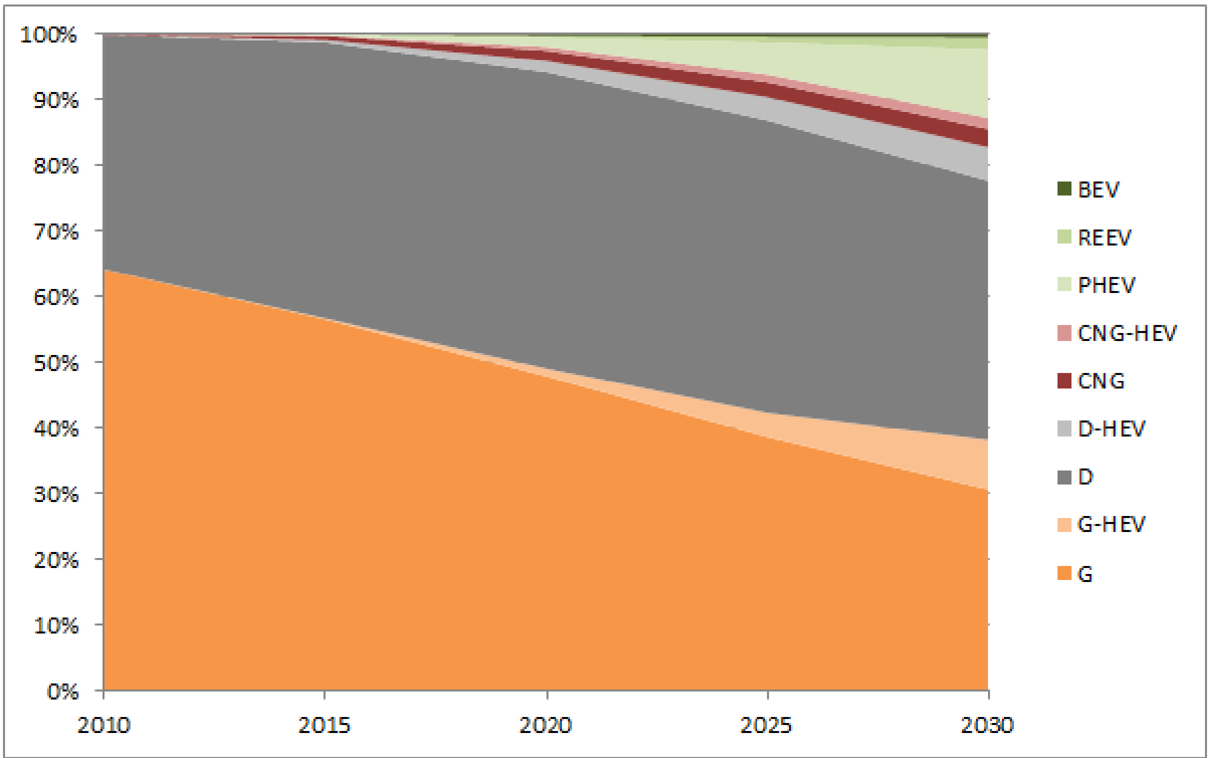


Figure 77. TeD scenario: total vehicle stock in EU28

Figure 78 shows the development of the total energy consumption of the EU28 vehicle stock under TeD scenario assumptions. In 2030 the total amount of consumed energy decreases to 74% of the value in the year 2010, although the stock size increases during that period by about 9 million passenger cars. In comparison to BaU calculations, energy consumption in the TeD scenario decreases slightly faster and is lower in 2030 by roughly 1.5 percentage points.

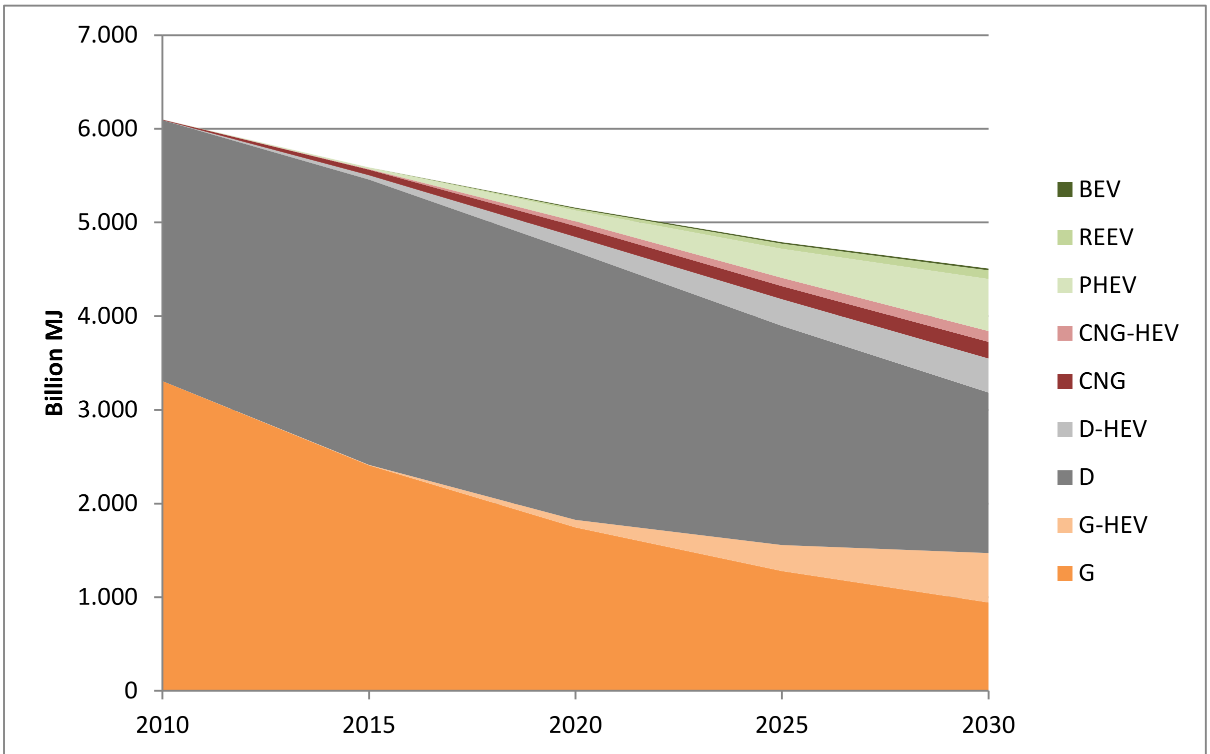


Figure 78. TeD scenario: EU28 vehicle stock annual energy consumption

As observed for the individual countries, $CO_2$ emissions are strongly correlated to the total energy consumption. Thus total Well-to-Wheel $CO_2$ emissions of vehicles in the EU28 stock in the TeD scenario, depicted in Figure 79, show qualitatively the same behaviour as the total energy consumptions shown in the preceding figure. In comparison to the reduction of $CO_2$ emissions in the BaU scenario, TeD $CO_2$ emissions are reduced by a further 1.5%, which also corresponds to the energy consumption difference between the two scenarios.

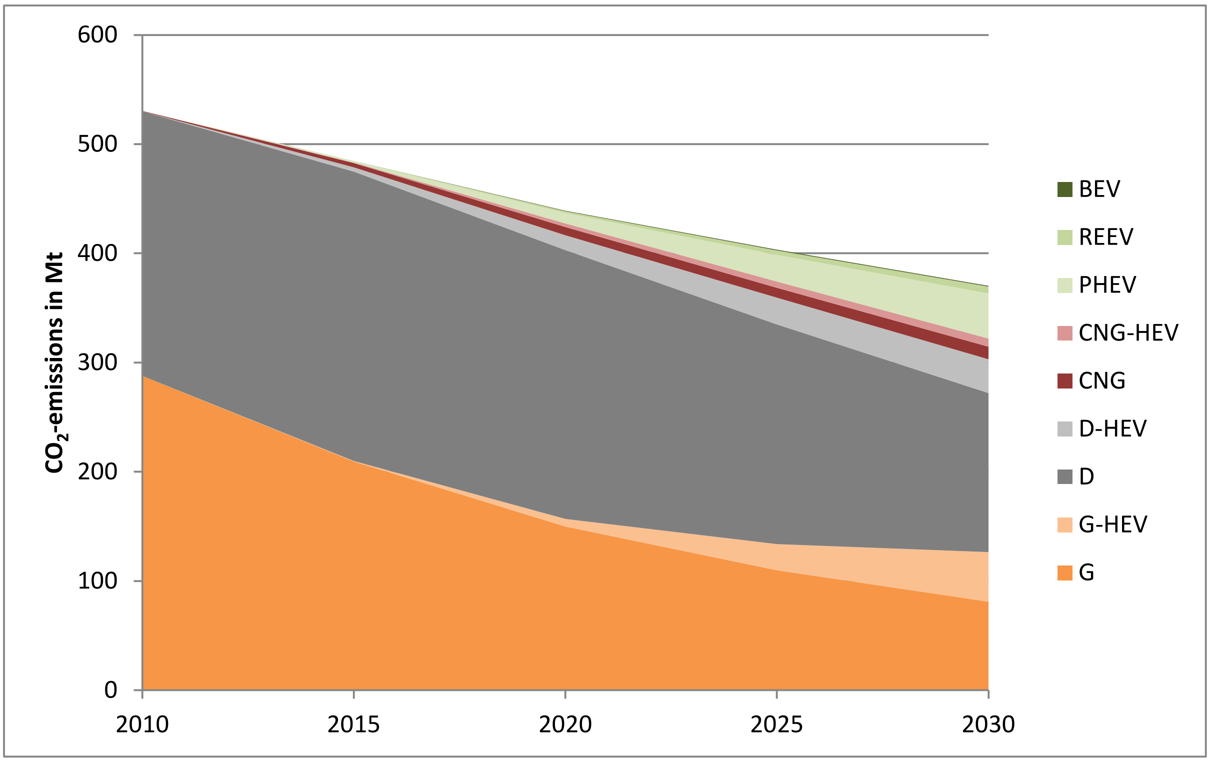


**Figure 79. TeD scenario: EU28 annual Well-to-Wheel $CO_2$ emissions of vehicles in stock**

## 4.3 TeD scenario: Conclusion

The TeD scenario with its enhanced technological development (leading to a faster decrease in battery system costs compared to the BaU scenario) is another feasible electromobility pathway. Within this framework, slightly higher shares of EV than in the BaU scenario can be found. However, significantly higher market shares of pure electric vehicles (BEV) are not reached under TeD assumptions, but higher market shares of plug-in electric vehicles (PHEV and REEV).

The weak dependency of the Finnish market shares on the exact technological development is a direct consequence of the powerful Finnish taxation model, which causes high costs for buyers and owners of conventional vehicles and thus supports the electrification of powertrains already in the BaU scenario. Similar results can be seen in France where high incentives for alternative vehicles push the market share already in the BaU scenario.

In Germany, however, taxation is less in favour for electrified vehicles and thus lower battery system prices lead to a stronger electrification of the fleet (mostly by gasoline and diesel HEV and by PHEV) in the TeD scenario. Still, the national target of one million electrified vehicles in 2020 is missed and just met in 2022 (3 years earlier than in the BaU scenario).

In contrast to that, the Polish vehicle market is almost not affected by the faster technological development in the TeD scenario. Even with strongly reduced battery prices, EV amortisation rates for the Polish customers are still very low.

For the EU28 in total in the TeD scenario, a 6% larger market share of electrified vehicles in 2020 and all subsequent years is observable. In comparison to the BaU scenario, energy consumption and well-to-wheel $CO_2$ emissions of the stock in the TeD scenario decrease slightly faster and are lower in 2030 by 1.5 percentage points.

# 5 Policy Driven scenarios (PoD)

While the BaU scenario represents a pathway under current policies and legislation, the Policy Driven scenarios (PoD) explore EU-wide (PoD-EU) and country-specific pathways where additional policies are incorporated to enhance the reduction of $CO_2$ emissions and to promote electrified vehicles.

In WP8 of the eMAP project, policy options to promote electrified vehicles are analysed, whilst their potential effectiveness are considered (see Kurte et al., 2015a). Of the whole set of those measures, those policies were chosen that can be incorporated in the VECTOR21 model setting. As VECTOR21 is not a regionally differentiated model in its current version, instruments like emission-free zones cannot be modelled adequately yet.

The EU-wide PoD-EU scenario models the effect of European climate protection policies by decreasing the EU $CO_2$ emission target for passenger cars to 60 g $CO_2$/km in 2030 (from 75 g $CO_2$/km in 2030 as assumed in the BaU scenario).

In addition, national PoD scenarios are modelled for Finland, Germany and Poland individually such that bundles of policies are solely adopted in the respective country while the other countries follow the BaU path. As those markets are interlinked in VECTOR21 (together with France, Italy and the UK), this will still have an effect on the other markets. However, as the effect tends to be small, scenario results of the other countries are not explored further in this report.

## 5.1 Political scenario parameters

### 5.1.1 Finland

Starting from the year 2018:

- Tax exemption for the powertrain-based part of the annual tax for electrified vehicles (PHEV, REEV, BEV, FCEV),
- 25% increased annual tax ($CO_2$- and powertrain-based)[14] for all vehicles.

[14] To maintain the tax revenue from cars in a manner in favour of EV, the tax being $CO_2$-based and thus lowest for EV

### 5.1.2 Germany

Starting from the year 2016:

- Lowering purchase costs by 1,500 € for electrified vehicles (PHEV, REEV, BEV, FCEV) by tax exemptions or purchase premiums for a period of 5 years (2016-2020),
- Exemption from the renewable energy levy[15] for public charging stations,
- Increasing investments (and thus coverage) in charging infrastructure by 10%[16] per year,
- Raising awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects (and thus increasing the customers' willingness-to-pay by 10%[16]).

*Willingness to pay (WTP):* This parameter represents the VECTOR21 customers' willingness to invest an extra amount of money to purchase technologically advanced and environmental friendly vehicles. Studies have shown that maximum WTP values concerning alternative powertrains are in the range of 10% (Eggers & Eggers, 2011; Nel, 2004; Carle 2003). In the frame of the PoD scenario, it is therefore assumed that by raising public awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects WTP values can be increased by 10% (in relative terms, i.e. from 10% in BaU to 11% in PoD).

*Exemption from the renewable energy levy (so-called "EEG-Umlage"):* From 2016 on, public charging stations are assumed to be excluded from the fee for renewables. The resulting electricity price is shown in Figure 80.

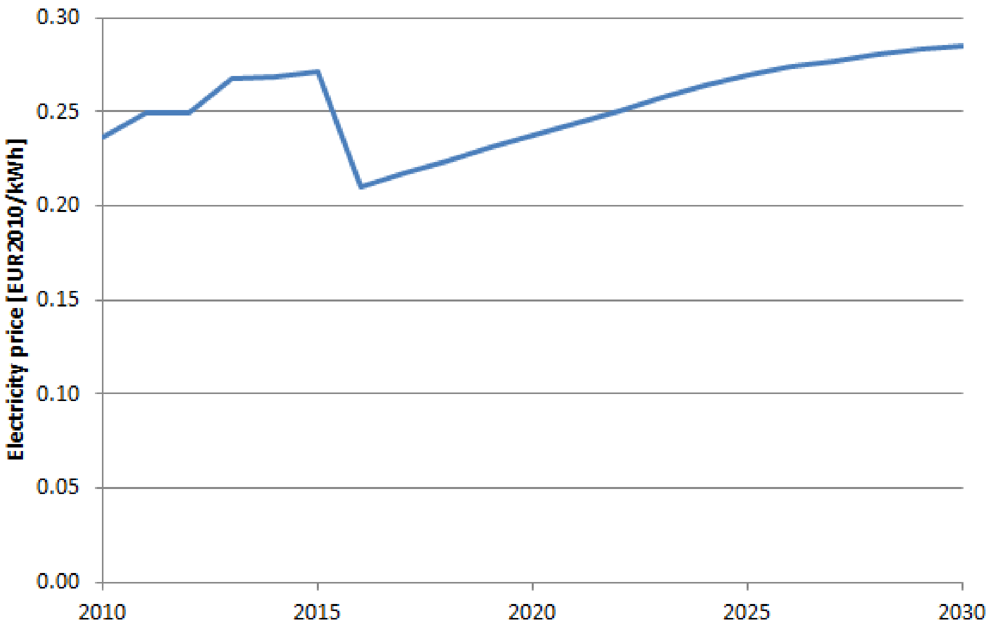


**Figure 80. German electricity prices at public charging stations in PoD scenario**

[15] So-called "EEG-Umlage", part of the electricity price, in 2015 6,17 €ct/kwh
[16] In relative terms compared to the BaU scenario

### 5.1.3 Poland

Starting from the year 2016 on:

- Lowering purchase costs by 1,050 € for electrified vehicles (PHEV, REEV, BEV, FCEV) by tax exemptions or purchase premiums,
- Raising awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects (and thus increasing the customers' willingness-to-pay by 10%[16]).

### 5.1.4 PoD-EU: EU28

The EU $CO_2$ target for passenger cars is lowered to 60 g $CO_2$/km in 2030 in the PoD-EU scenario, the target curve thus being 130 g/km in 2015, 95 g/km in 2021 and 60 g/km in 2030.

## 5.2 PoD scenario results

### 5.2.1 Finland

**Market shares**

The above described tax exemptions for electrified vehicles in the Finnish PoD scenario lead to a faster spread of electrified vehicles in the small segment (Figure 81). Market shares of BEV and REEV increase by around 50% in 2030 compared to the BaU scenario, mainly at the expense of G-HEV.

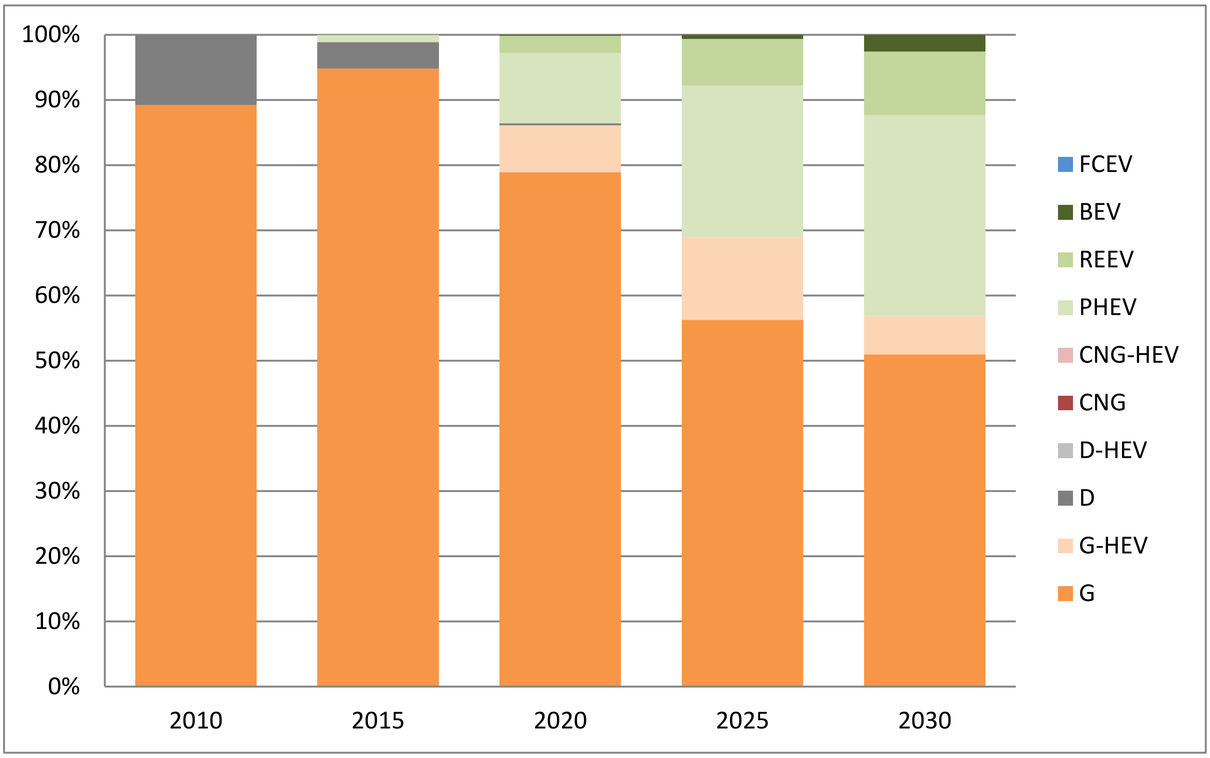


Figure 81. PoD scenario: vehicle sales in Finland, small segment

PoD market shares in the Finnish medium segment, as depicted in Figure 82, follow the same trends as in the BaU scenario. Some diesel vehicles stay in the market up to 2025, though. This is due to the fact that annual vehicle taxes are increased in the PoD scenario for all vehicles (except for the powertrain part of gasoline and electrified vehicles). As diesel is more $CO_2$ efficient than gasoline, and as fuel prices are nearly equal for diesel and gasoline (Figure 7), diesel vehicles are still attractive for a minor number of customers.

REEV and G-HEV profit from the tax exemption scheme at the expense of PHEV and gasoline vehicles.

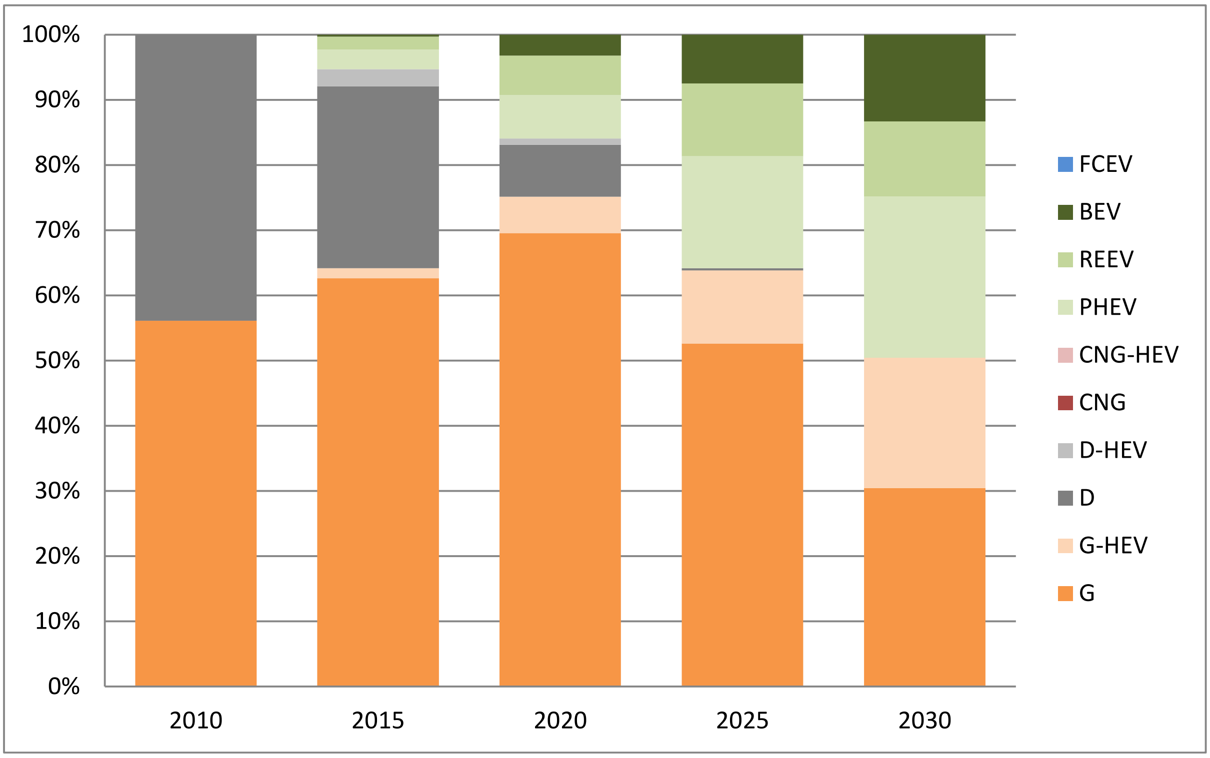


Figure 82. PoD scenario: vehicle sales in Finland, medium segment

PoD market shares in the Finnish large segment, as depicted in Figure 83 resembles the results of the BaU scenario, with the exception of BEV. At the expense of PHEV and gasoline vehicles they gain a market share of 17% in PoD compared to 14% in BaU after 2020.

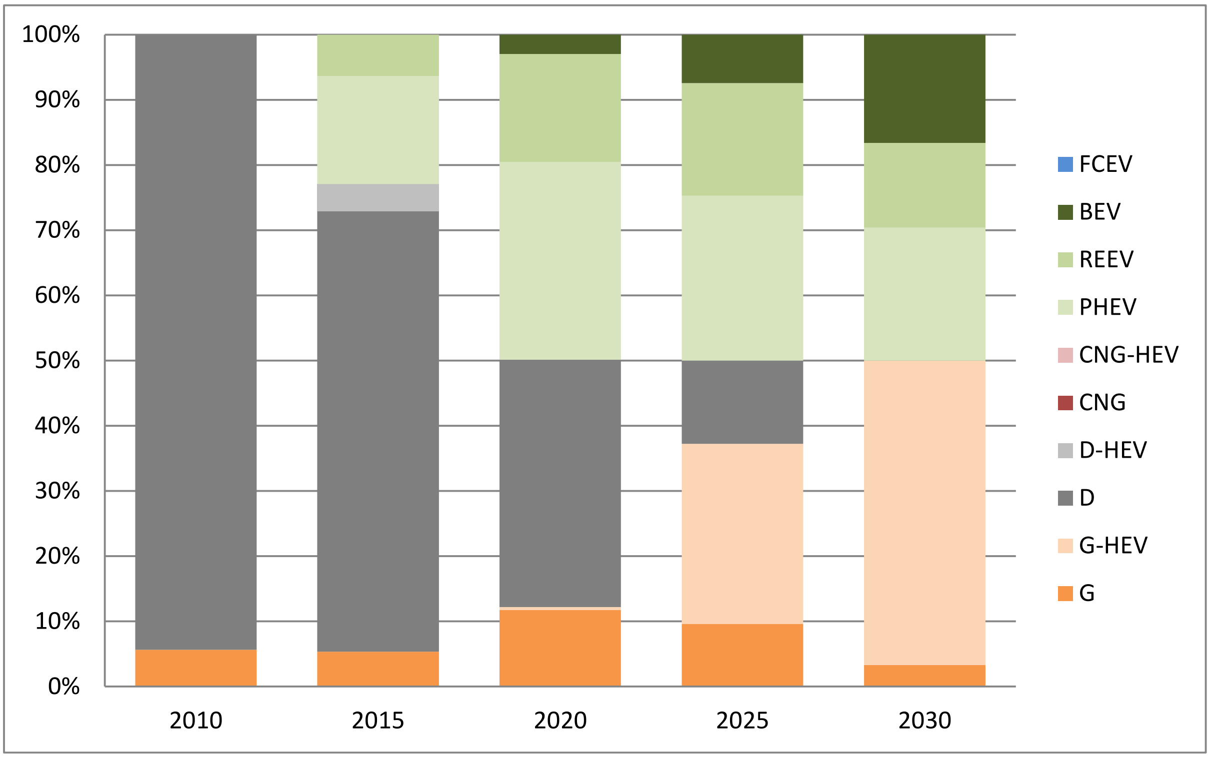


Figure 83. PoD scenario: vehicle sales in Finland, large segment

**Stock**

Results for the Finnish stock for all segments in the Finnish PoD scenario are shown in Figure 84. In comparison to the stock data of the BaU scenario, only minor differences can be seen: The share of conventional vehicles is slightly reduced in 2030, whereas the total share of BEV, PHEV und REEV in this year is about 5% larger than in the BaU scenario.

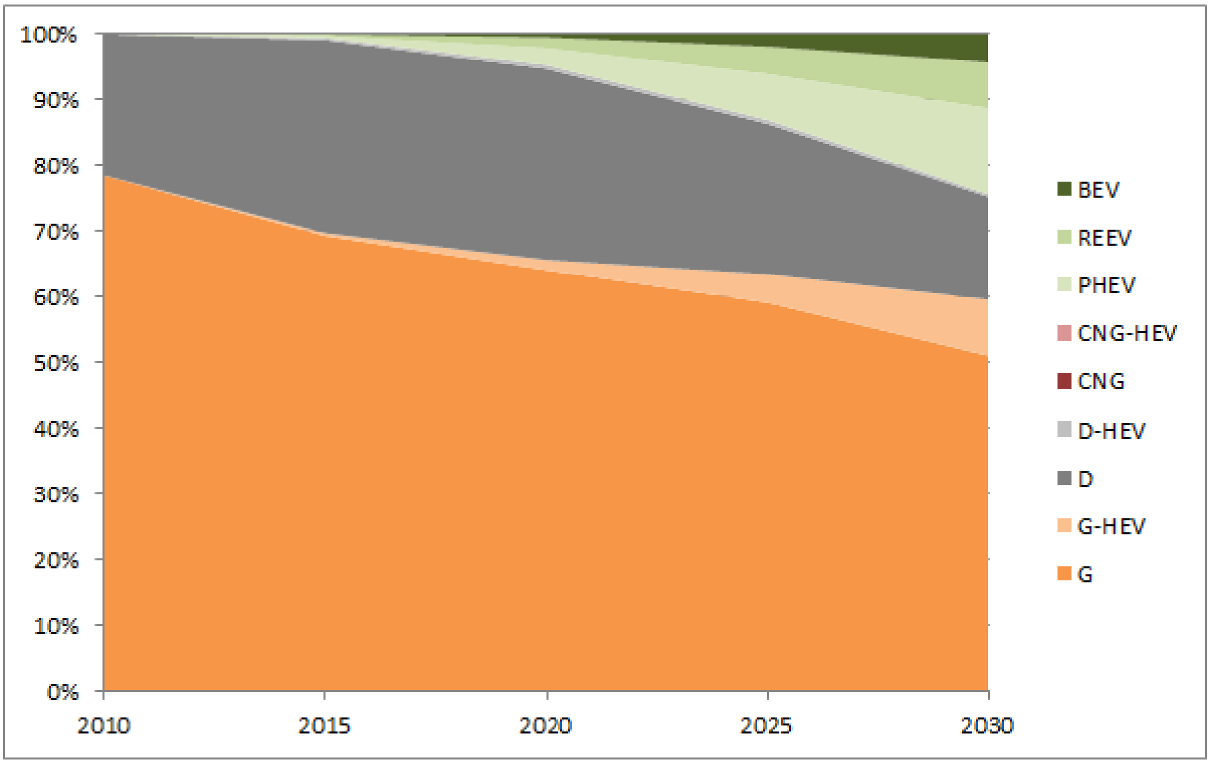


Figure 84. PoD scenario: total vehicle stock in Finland

Figure 85 shows the total energy consumption per year of the vehicle stock in Finland under Finnish PoD assumptions. Again, differences between the Finnish PoD and the BaU scenario are rather small. However, similar to the TeD calculations, total energy consumption decreases below 80 PJ in 2030, and is thus reduced by a further 1% in comparison to BaU results. A change is found in the consumption of the gasoline fleet, which is 4% smaller than in the BaU scenario in 2030 as new gasoline vehicles are sold to a lesser extend from 2025 on.

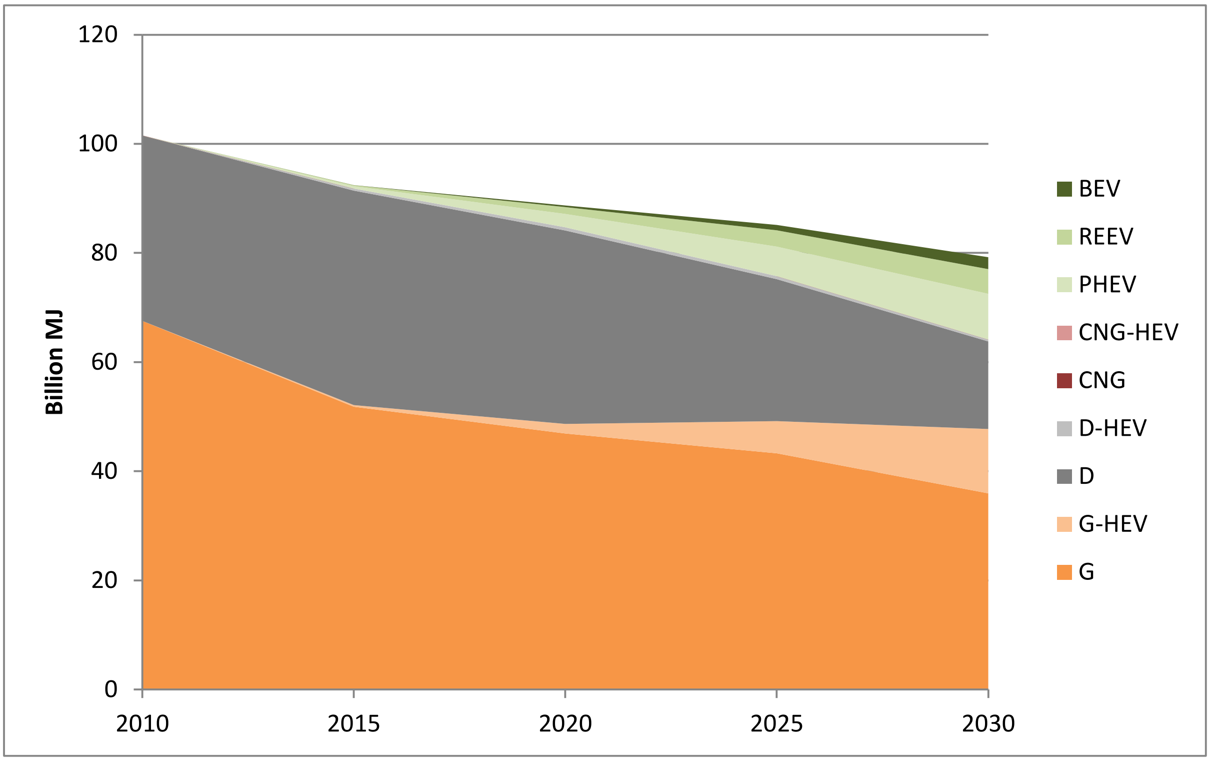


Figure 85. PoD scenario: total annual energy consumption of vehicles in Finnish stock

In accordance to energy consumption, annual WTW $CO_2$ emissions of the Finnish vehicle stock, as depicted in Figure 86, drop further in the Finnish PoD than in the BaU scenario: In 2030 $CO_2$ emissions are about 1% below those in the BaU scenario.

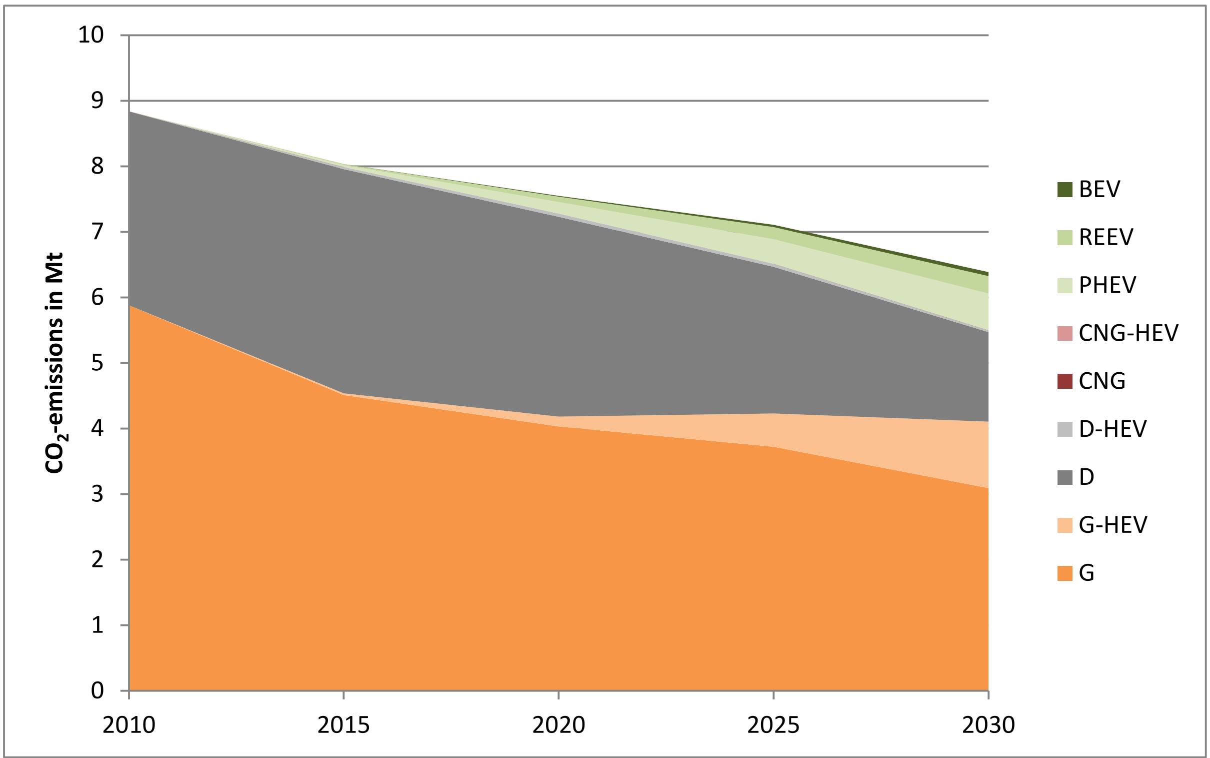


Figure 86. PoD scenario: annual Well-to-Wheel $CO_2$-emissions of the Finnish vehicle stock

### 5.2.2 Germany

**Market shares**

Due to bundles of policies to enhance the market penetration of electrified vehicles (lowering of purchase costs, exemption from the renewable energy levy, increased coverage of charging infrastructure, raised awareness for electrified vehicles, see chapter 5.1.2), market shares of electrified vehicles increase significantly (Figure 87) and electrified vehicles are able to enter the market earlier. In 2020, the small fraction of CNG vehicles sold in the BaU scenario has vanished in the German PoD scenario, since the policies chosen in the PoD scenario are not CNG-targeted. Starting just before 2020, diesel, gasoline and HEV slightly decrease their share for the benefit of PHEV, REEV and BEV. As a consequence, the sales of conventional gasoline vehicles are reduced to 12% in 2030 (compared to 20% in BaU).

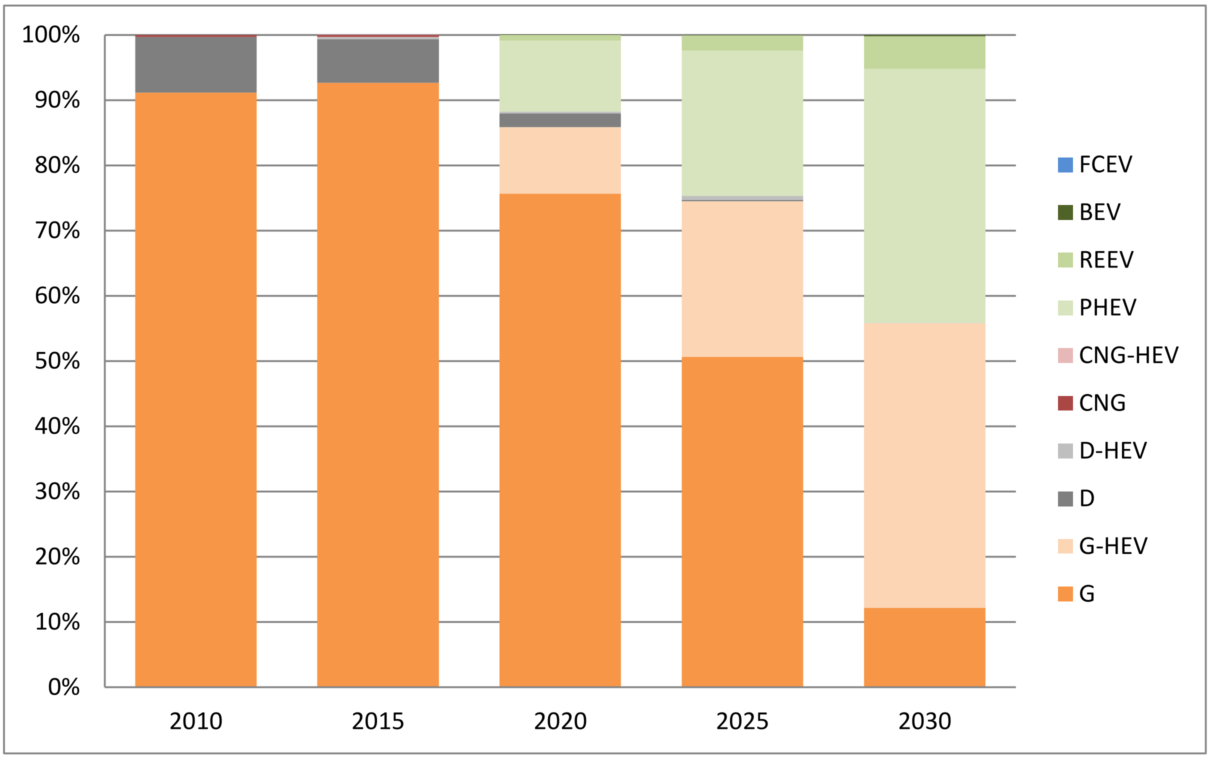


Figure 87. PoD scenario: vehicle sales in Germany, small segment

Similar to the small segment, electrified vehicles of the German medium segment enter the market earlier and are able to increase their shares in the German PoD scenario (Figure 88). Of the conventional powertrains in 2030, diesel vehicles are the ones that are mainly affected by the modelled policies – their market share decreases to 13% (20% in BaU). In the same year, PHEV, REEV and BEV are able to gain a market share of 36% compared to 23% in the BaU scenario.

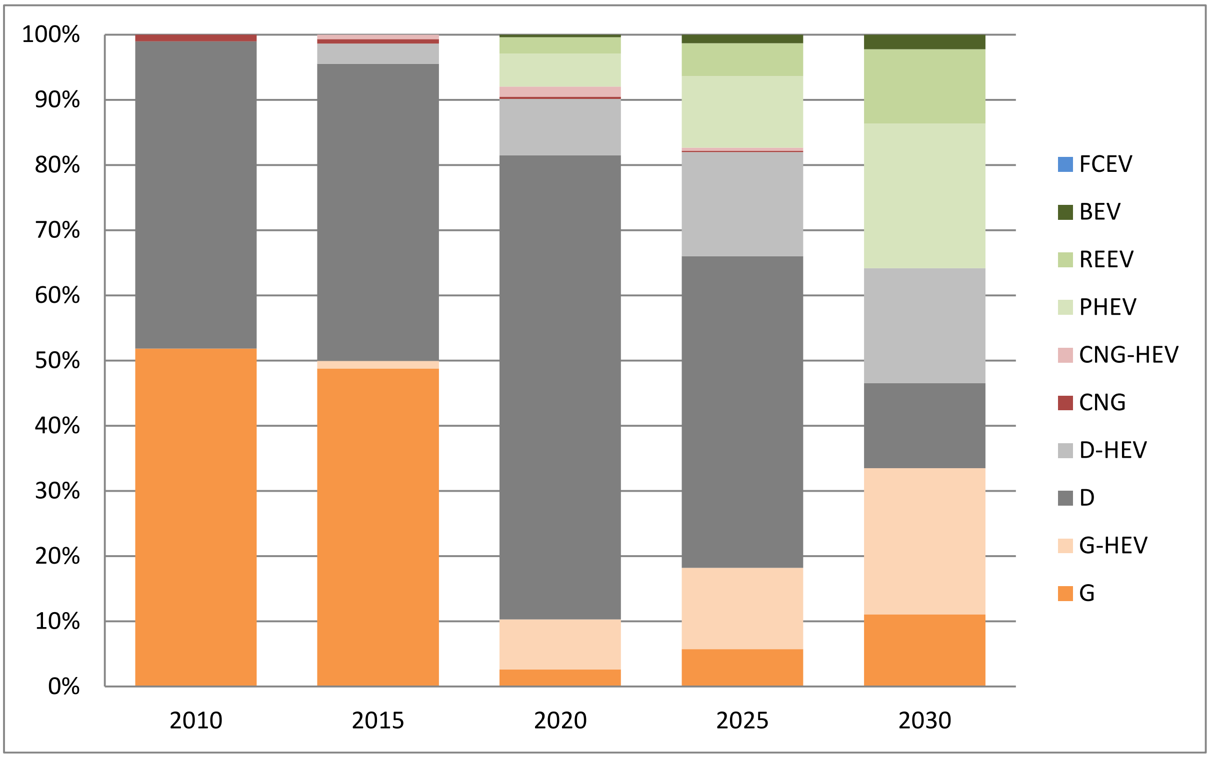


Figure 88. PoD scenario: vehicle sales in Germany, medium segment

While the German policies of the PoD scenario clearly enable an earlier market entrance and a more pronounced market share in the small as well as the medium segment, market shares of large electrified vehicles in 2030 are not significantly different from the BaU pathway (Figure 89). However, market entrance is earlier and faster, such that the accumulated number of electrified vehicles is still higher even in the large vehicle segment.

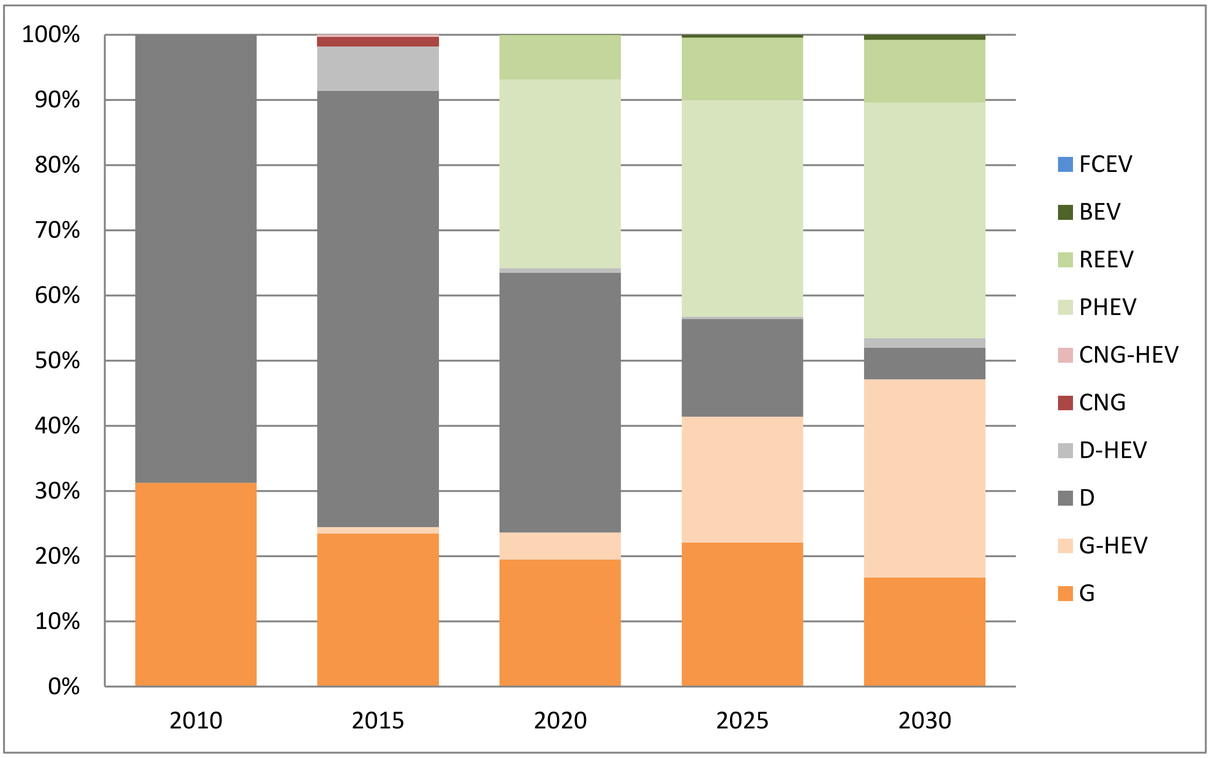


Figure 89. PoD scenario: vehicle sales in Germany, large segment

**Accumulated Sales**

In the PoD scenario for Germany, accumulated sales of electrified vehicles amount to 987,000[17] in 2020, thus almost reaching the national target of one million electric vehicles (Figure 90). By 2025, sales have reached 3.6 million and by 2030 8.7 million EV.

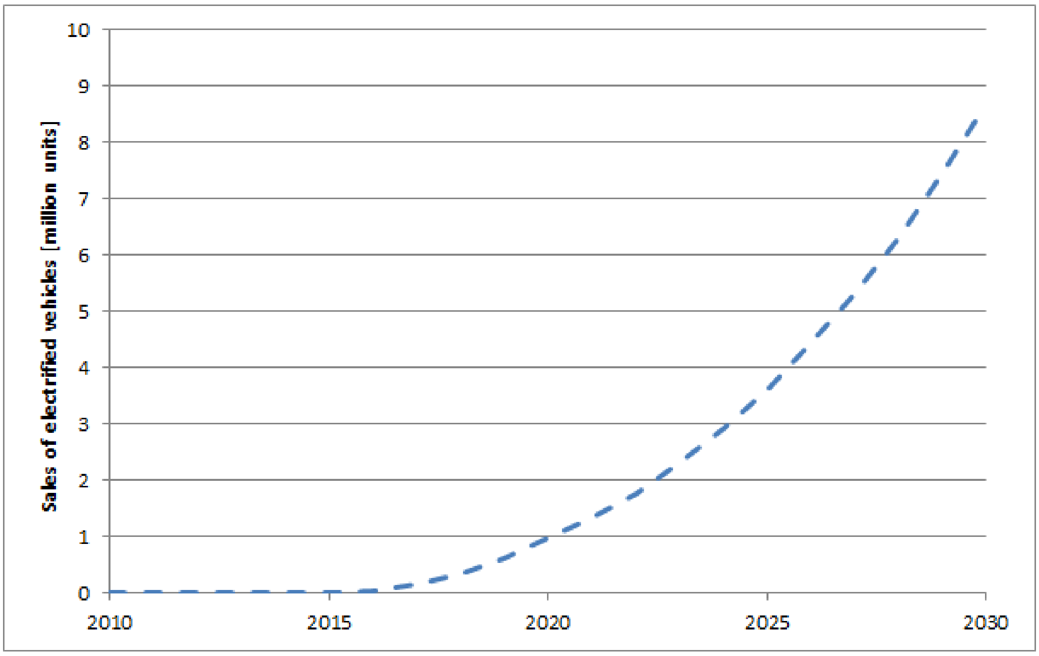


Figure 90. PoD scenario: accumulated EV sales in Germany

**Stock**

Results for the German stock for all segments under German PoD scenario assumptions are shown in Figure 91. The share of electrified vehicles in the German stock grows significantly faster and larger in the PoD than in the BaU scenario: In 2020, already 6.7% (4.9%) of the vehicles utilize electrified powertrains and in 2030, their share reaches 42% (34%) in the PoD (BaU) scenario.

[17] A limited number of EV has a shorter lifetime than average and does not remain in stock until 2020. The actual number of EV in stock as given in Kurte et al. (2015b) is therefore slightly lower than the cumulated number of sold EV.

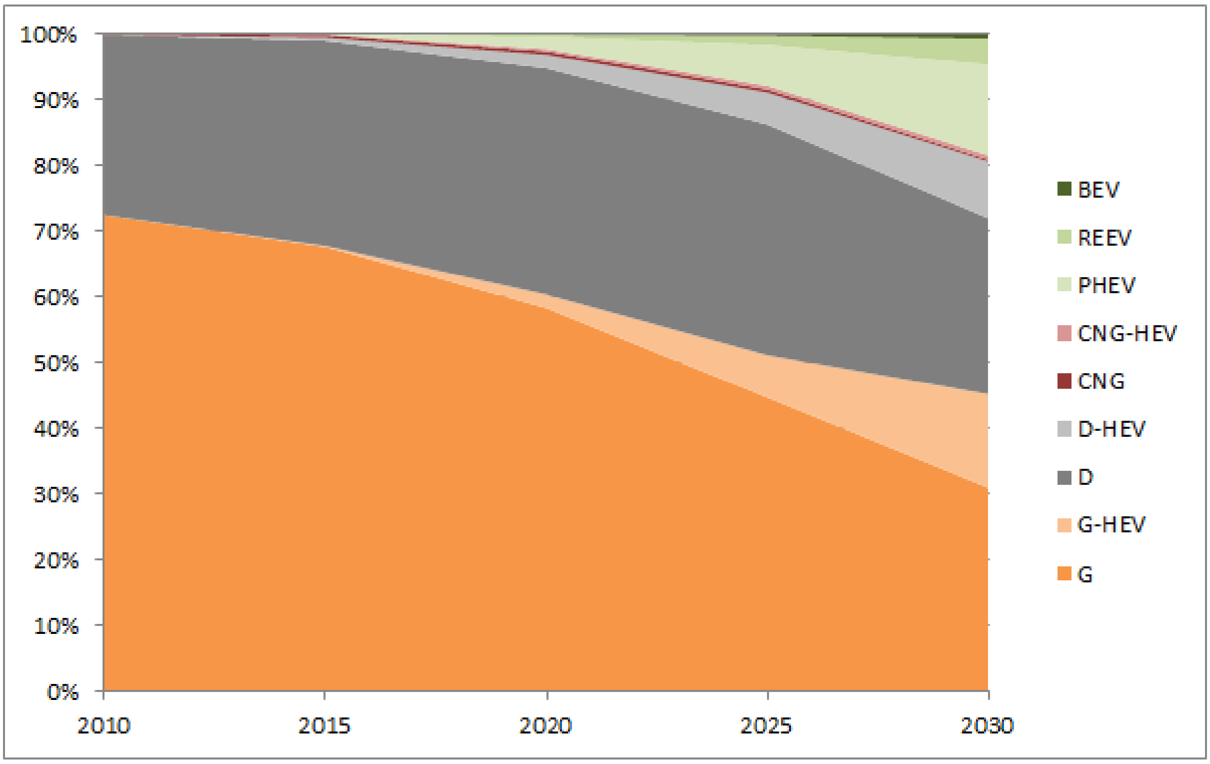

Figure 91. PoD scenario: total vehicle stock in Germany

The total annual energy consumption of German vehicles in the German PoD scenario is shown in Figure 92. Although significantly more electrified vehicles enter the German stock in the PoD scenario, their total energy consumption is not significantly decreased (about 4%) below the energy consumption found in the BaU scenario. This can be explained by the fact, that the majority of electrified vehicles in the German stock are G-HEV, D-HEV and PHEV, which are not as energy efficient as BEV. Thus their influence on the total energy consumption is limited.

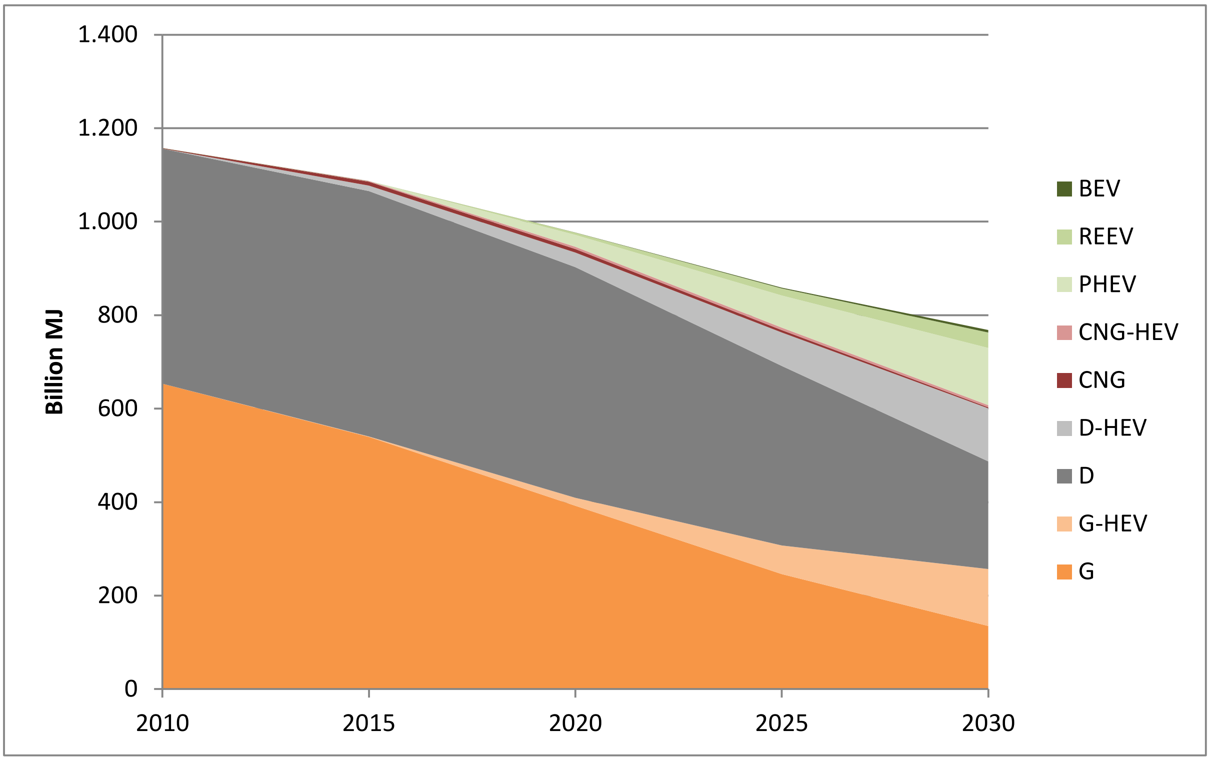


Figure 92. PoD scenario: annual energy consumption of the German vehicle stock

Figure 93 depicts the German vehicle stock WTW $CO_2$ emission development in the PoD scenario. $CO_2$ emissions are reduced by 37% in 2030 in comparison to the year 2010, thereby surpassing the BaU emission reduction in 2030 by about 3 percentage points, which corresponds to the enhanced total energy consumption reduction discussed in the previous paragraph.

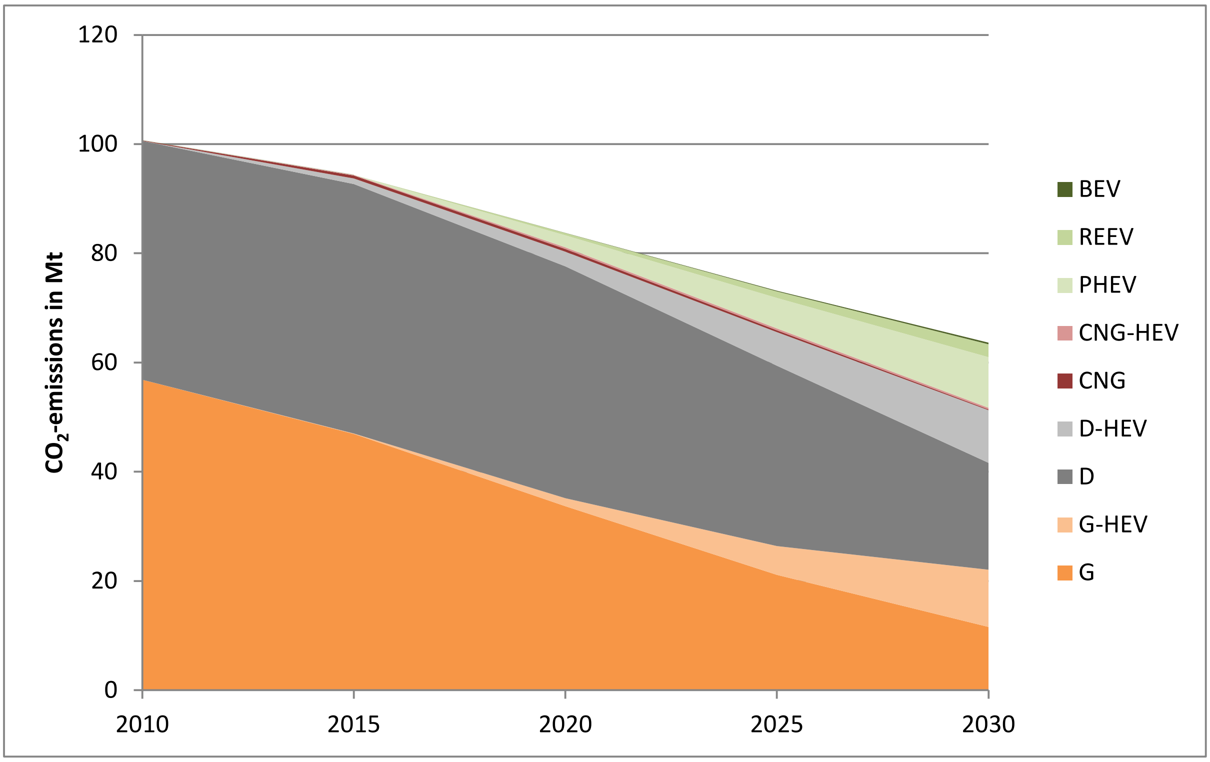


Figure 93. PoD scenario: annual Well-to-Wheel $CO_2$-emissions of the German vehicle stock

### 5.2.3 Poland

#### Market shares

Due to bundles of policies to enhance the market penetration of electrified vehicles (lowering purchase costs and raising awareness for electrified vehicles, see chapter 5.1.3), electrified vehicles are now finally able to enter the Polish market. While gasoline vehicles still dominate the small segment (Figure 94) up to 2030, their share is slightly reduced as PHEV have a market share of 4% in 2030.

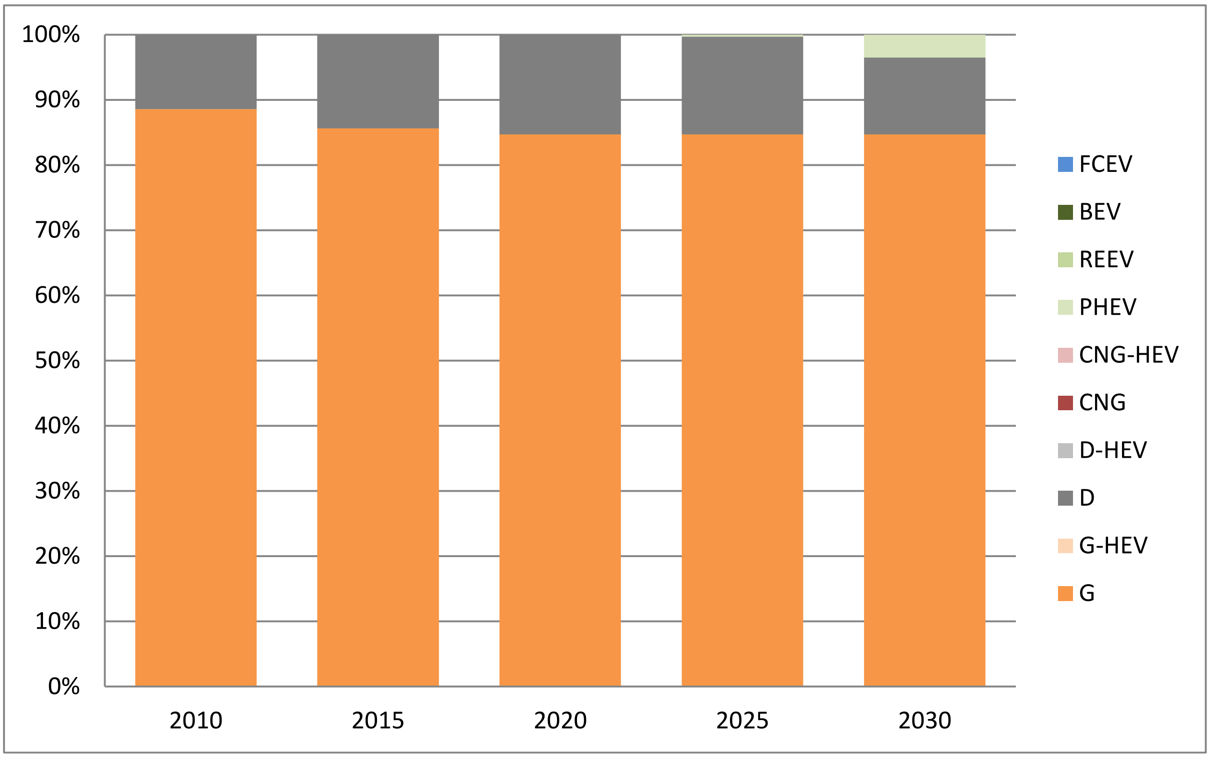


Figure 94. PoD scenario: vehicle sales in Poland, small segment

Policies promoting electrified powertrains also enable the market penetration of PHEV in the medium segment of the Polish PoD scenario (Figure 95) reaching a share of 9% in 2030. Conventional diesel and gasoline vehicles still dominate the market up to 2030 with diesel having a slightly higher share (48% in 2030). Although CNG infrastructure is not widely spread, there is a very small amount of CNG customers in the medium segment (<1%).

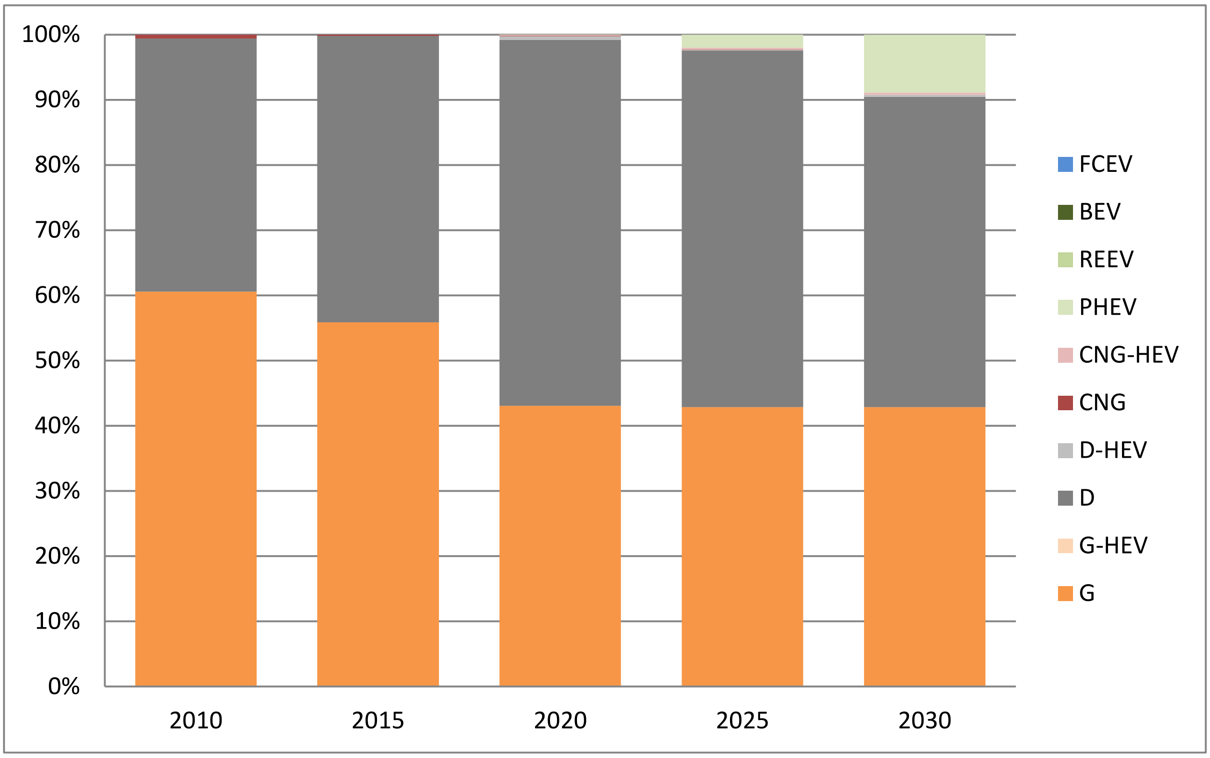


Figure 95. PoD scenario: vehicle sales in Poland, medium segment

The Polish large vehicle sales (Figure 96) are quite sensitive to the Polish PoD policy measures. Apart from the increased PHEV share in comparison to the BaU calculations, the share of G-HEV is also increased. In 2030, their combined share adds up to 21%, of which 19 percentage points correspond to PHEV. Conventional diesel and gasoline vehicles still dominate the market up to 2030 und the amount of CNG customers in the large segment is, with only about 2%, negligible.

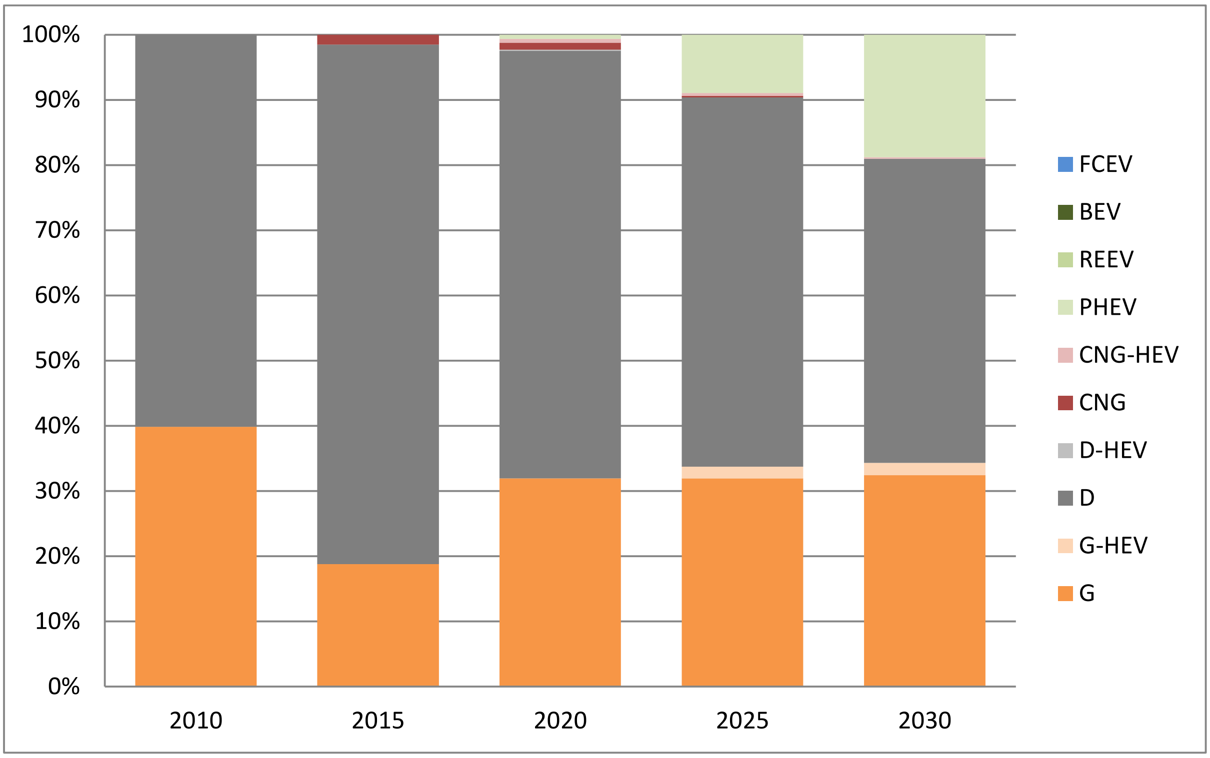


Figure 96. PoD scenario: vehicle sales in Poland, large segment

**Stock**

Polish PoD scenario results for the total stock are shown in Figure 97. As in the BaU scenario, conventional gasoline and diesel vehicles dominate the Polish stock up to 2030, whereas in the Polish PoD scenario, a small share of PHEV can be seen in the vehicle stock towards 2030.

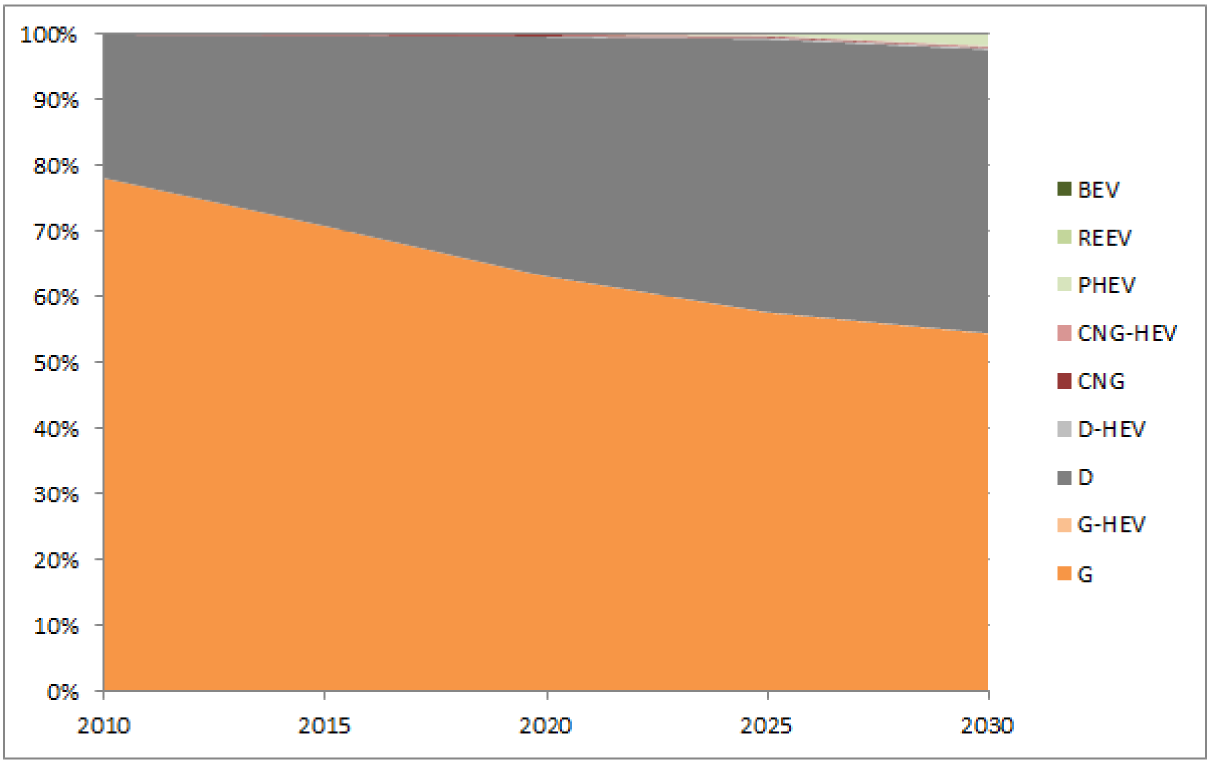


Figure 97. PoD scenario: total vehicle stock in Poland

Total energy consumption of the Polish vehicle stock in the PoD scenario is depicted in Figure 98. As market penetration of electrified powertrains (mostly PHEV) is higher than in the BaU scenario, energy consumption of the Polish fleet in 2030 is lowered by another 2%, thus resulting in a 15% decrease in energy consumption compared to 2010.

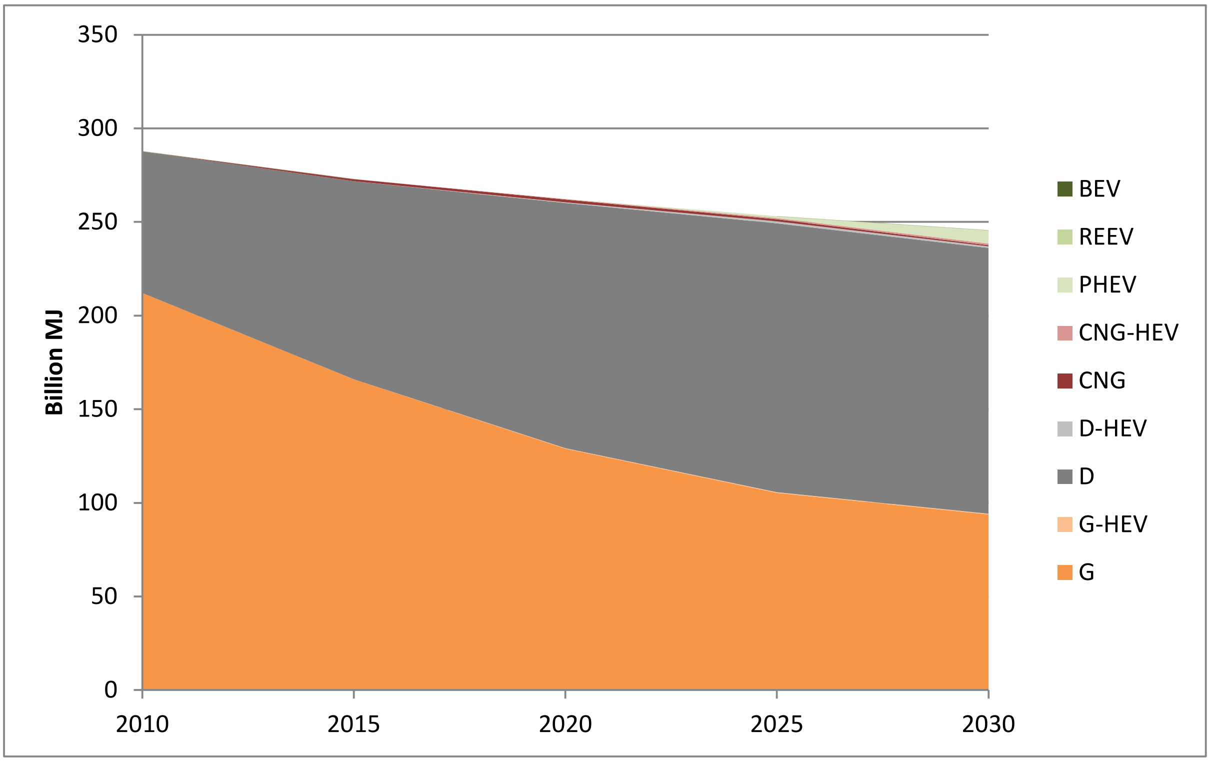


Figure 98. PoD scenario: energy consumption of the Polish vehicle stock

Following the decrease in energy consumption, well-to-wheel $CO_2$ emissions in the Polish PoD scenario are lowered by 16% in 2030 compared to 2010 (-15% in 2030 vs 2010 in the BaU scenario).

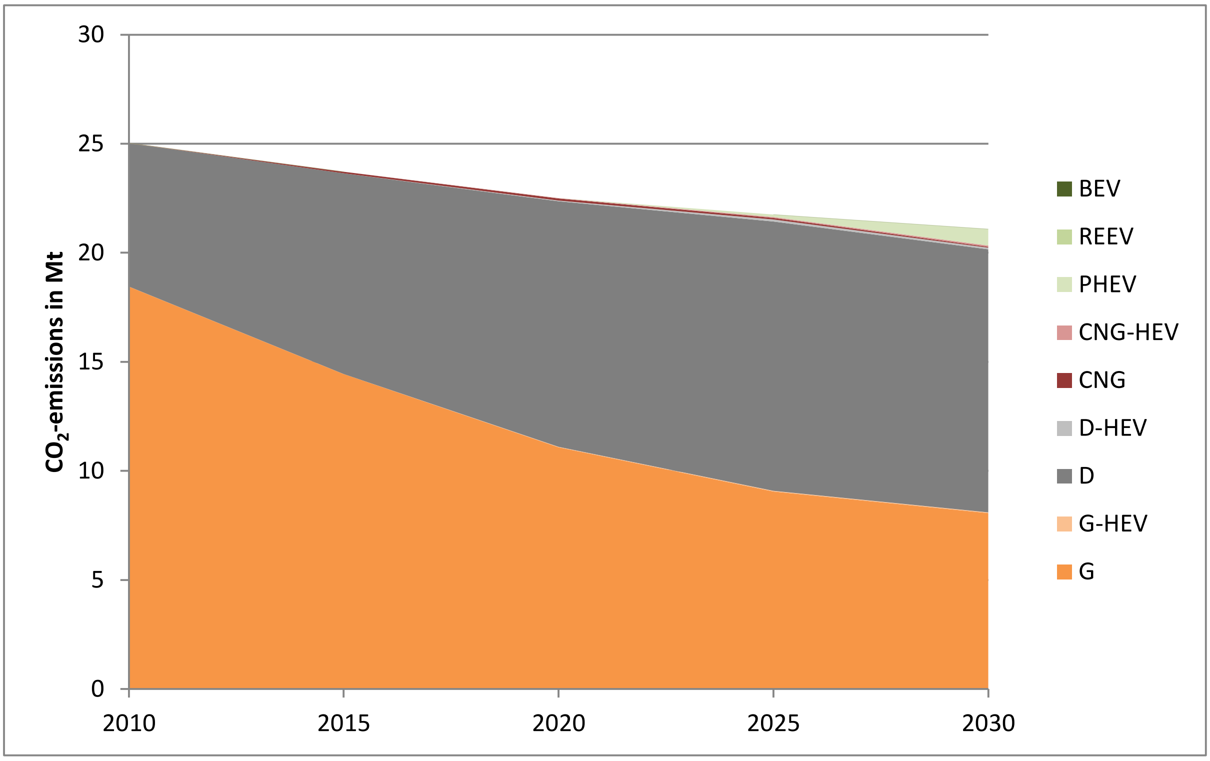


Figure 99. PoD scenario: Well-to-Wheel $CO_2$-emissions of the Polish vehicle stock

### 5.2.4 PoD-EU: EU28

**Market shares**

Following the EU climate policy path by lowering the EU $CO_2$ target for passenger cars to 60 g $CO_2$/km leads to a faster and more pronounced market penetration of electrified vehicles in EU28 after 2021 (Figure 100) compared to the BaU pathway. In 2030, electrified vehicles dominate total new vehicle sales in the EU28 markets and take up a share of 60% (of which approximately one half are plugin electric vehicles, i.e. PHEV, REEV and BEV). Compared to the BaU scenario, this is an increase of 11%. As policies enhancing CNG and hydrogen infrastructure are not considered within this PoD-EU scenario, market shares of CNG and fuel cell do not differ significantly from the BaU scenario (CNG vehicles are almost exclusively sold in Italy and to a small extend in Germany).

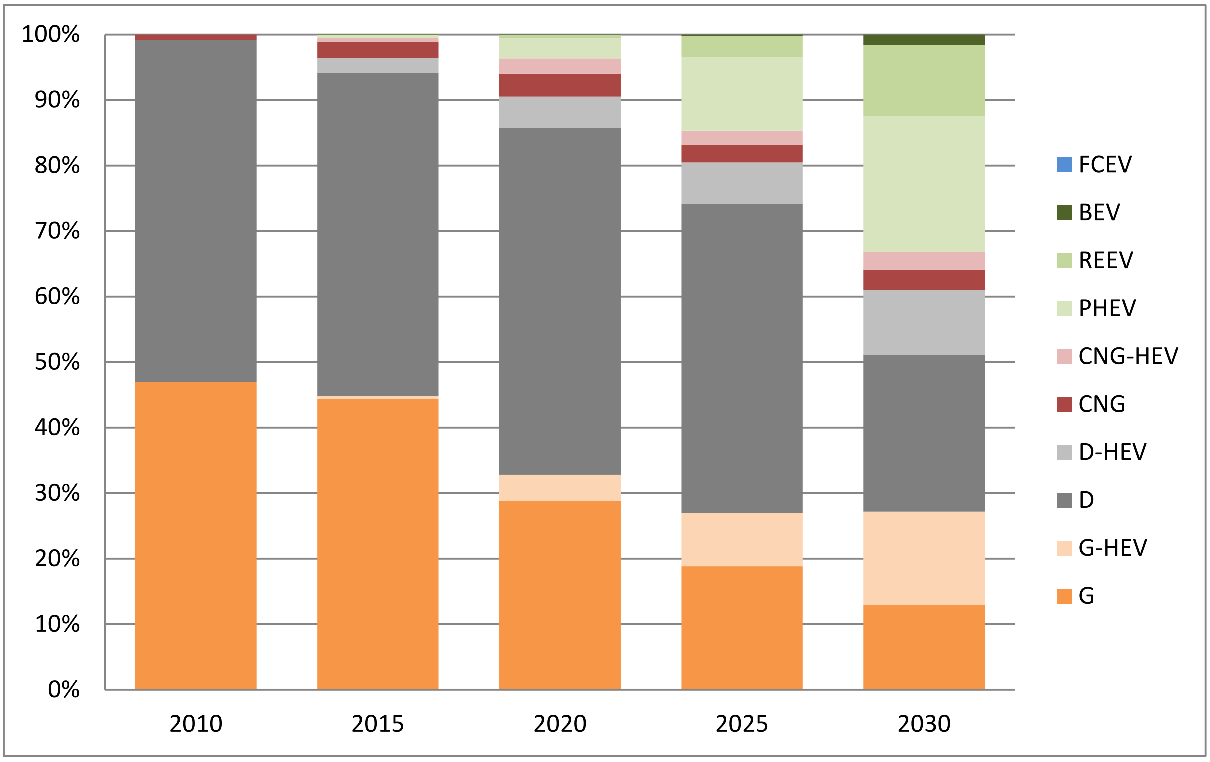


Figure 100. PoD-EU scenario: Total new vehicle sales in EU28

PoD-EU scenario results for the EU28 small segment (Figure 101) show that more stringent $CO_2$ emission targets support an increase in market shares of electrified powertrains (57% in 2030 compared to 40% in BaU). Especially REEV and BEV are able to increase their shares significantly in 2030, while conventional diesel and gasoline powered vehicles are less attractive for customers due to higher - $CO_2$ driven - purchase costs (see also chapter 3.1.1).

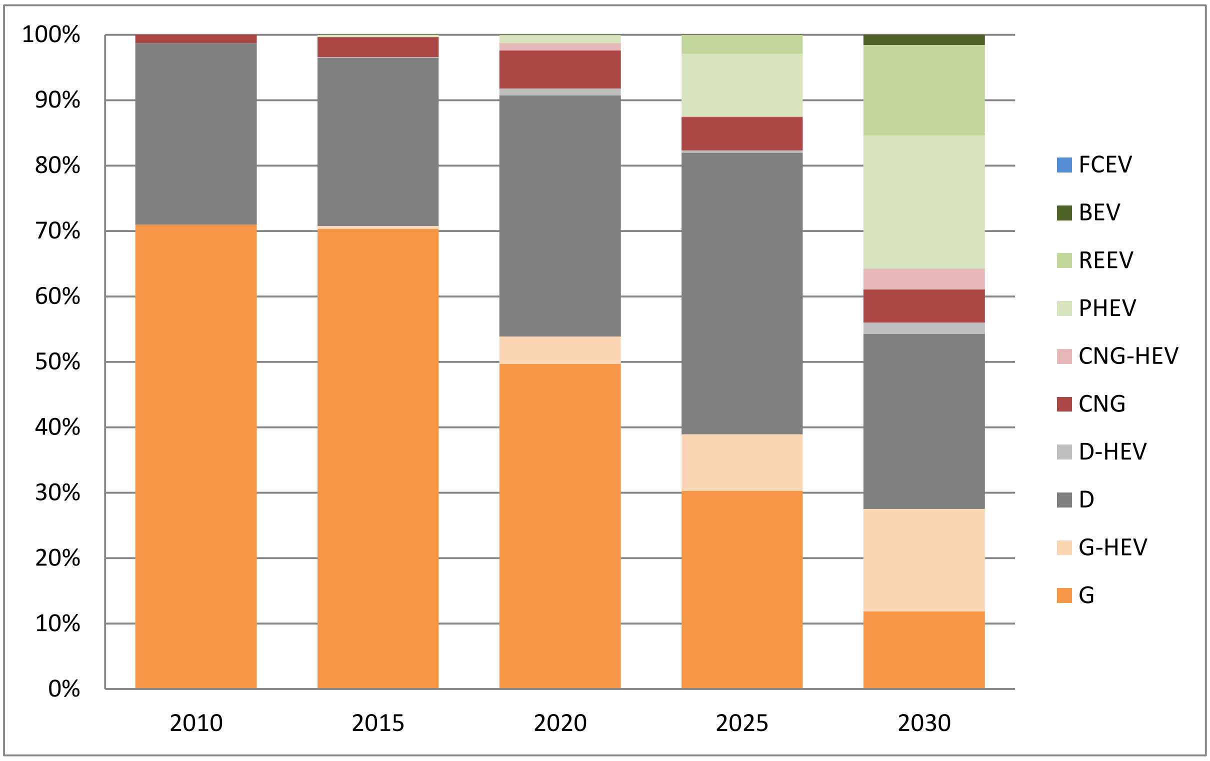


Figure 101. PoD-EU scenario: New vehicle sales in EU28, small segment

As in the small segment, medium sized electrified vehicles are able to increase their market share within EU28 countries in the PoD-EU scenario (Figure 102). PHEV, REEV and BEV make up for 28% of the market in 2030 (22% in BaU) at the expense of conventional diesel and gasoline (41% in 2030 compared to 50% in BaU).

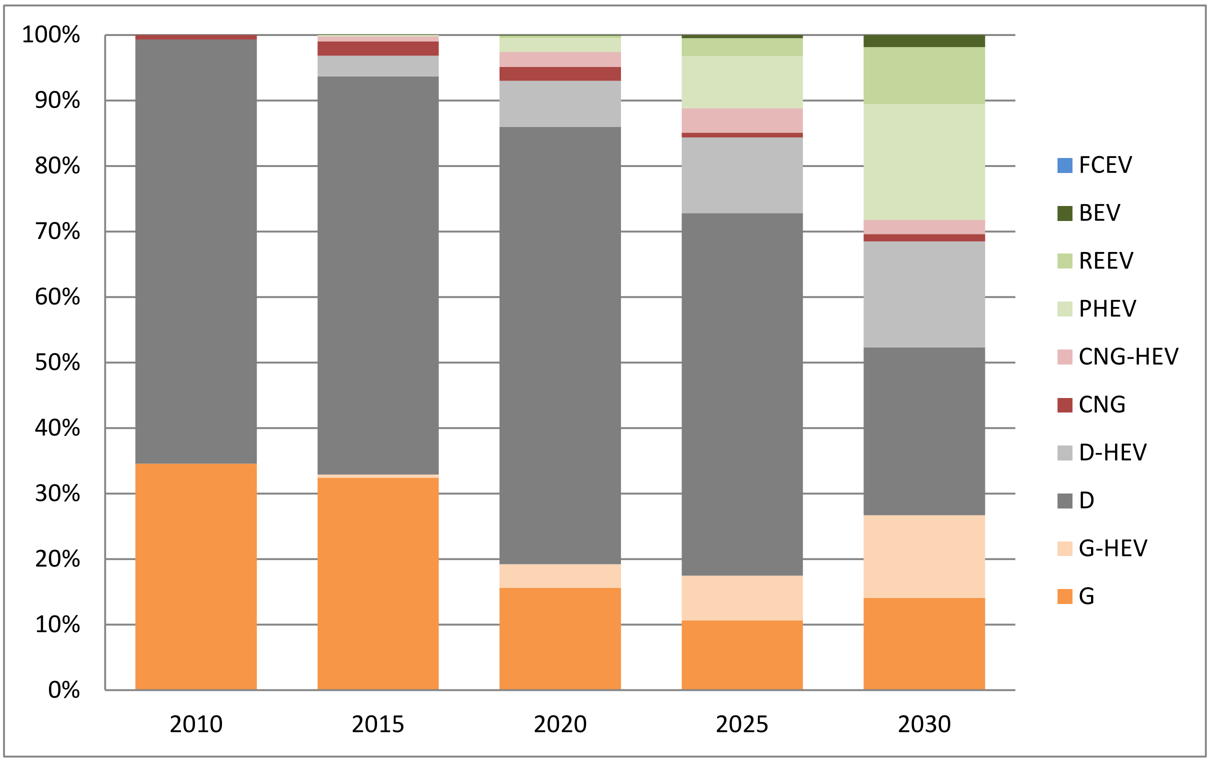


Figure 102. PoD-EU scenario: New vehicle sales in EU28, medium segment

Of all vehicle segments, the large segment is most likely to allow for an electrification of powertrains, the reason being a higher than average annual mileage and a higher energy consumption (and thus higher $CO_2$ emissions). Results of the EU PoD scenario for the large segment of EU28 countries are shown in Figure 103. Therein, PHEV, REEV and, to a small extend, BEV have a market share of 46% in 2030 (40% in BaU). In combination with HEV, the market share of electrified vehicles reaches 76% of the large segment's sales in 2030 (70% in BaU).

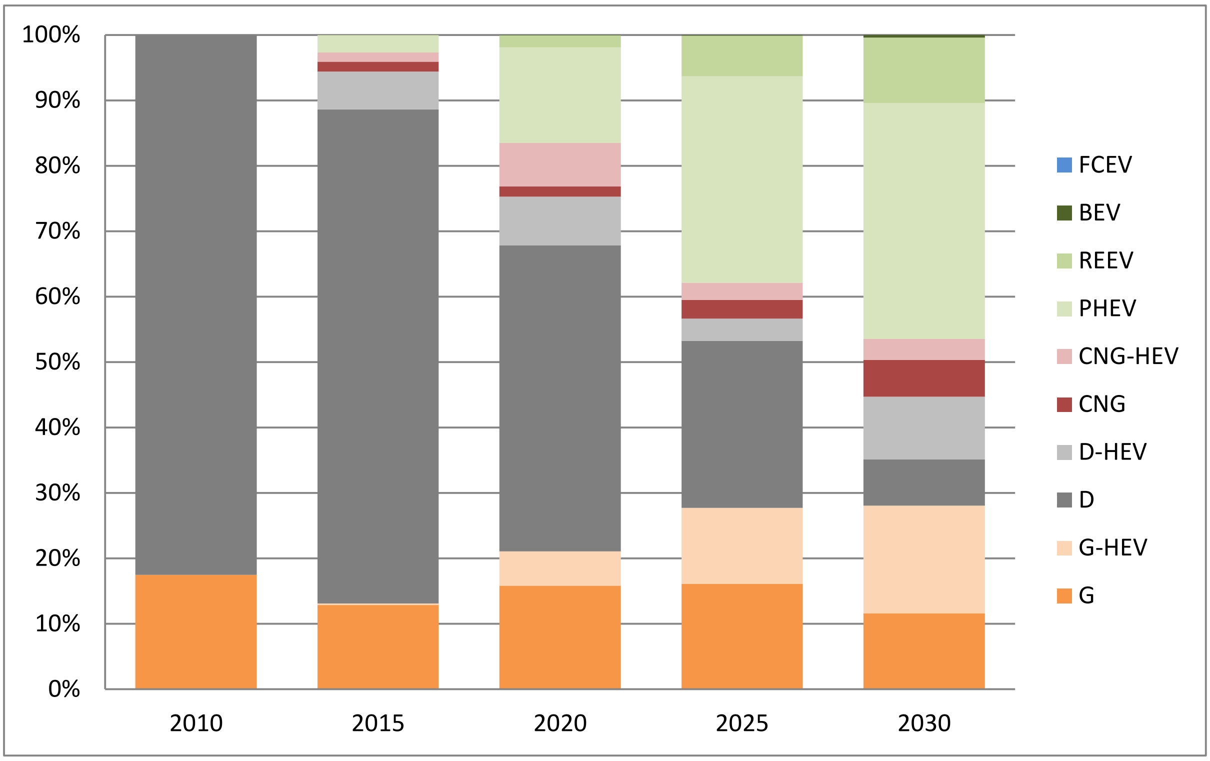


Figure 103. PoD-EU scenario: New vehicle sales in EU28, large segment

**$CO_2$ targets**

For the PoD-EU scenario, the EU $CO_2$ target for passenger cars is lowered to 60 g $CO_2$/km in 2030 (red dotted line in Figure 104). The blue line indicates average $CO_2$ emissions of new vehicles in EU28, including super credits. As in the BaU scenario, in 2021 average $CO_2$-emissions meet the target of 95 g/km. In the following years, average tank-to-wheel $CO_2$ emissions decrease steadily and almost reach 60 g $CO_2$/km in 2030, thus being less than half a gram of $CO_2$ per km above the set target value.

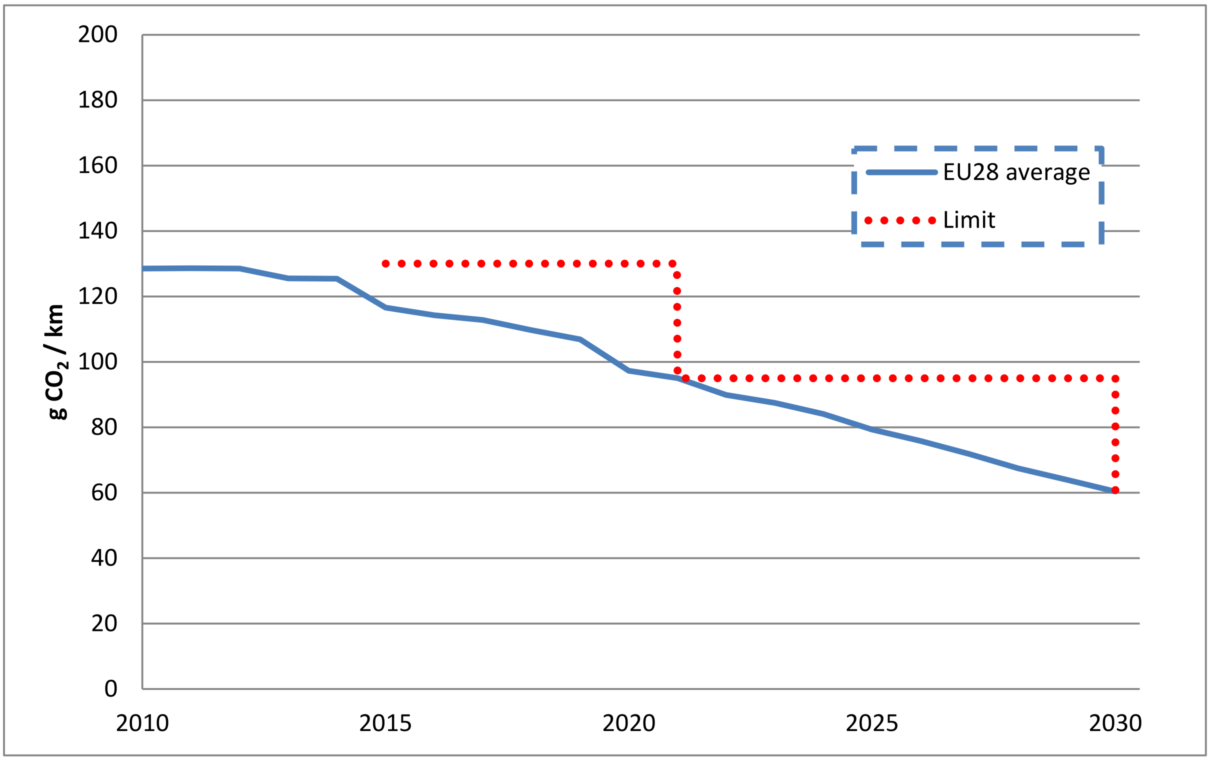


Figure 104. PoD-EU scenario: EU28 average $CO_2$ emissions (including super credits) versus $CO_2$ target

**Stock**

PoD-EU scenario results for the total stock of EU28 countries are shown in Figure 105. The share of conventional gasoline and diesel vehicles in the stock decreases to 72% in 2030 (75% in BaU). As in the BaU scenario, the share of electrified vehicles rises rapidly and reaches 12% in 2025 (11% in BaU) and 25% in 2030 (22% in BaU), although the major contributors are G-HEV, D-HEV and PHEV vehicles with an almost equal stock share in 2025 and 2030 of around 6% and 8%, respectively.

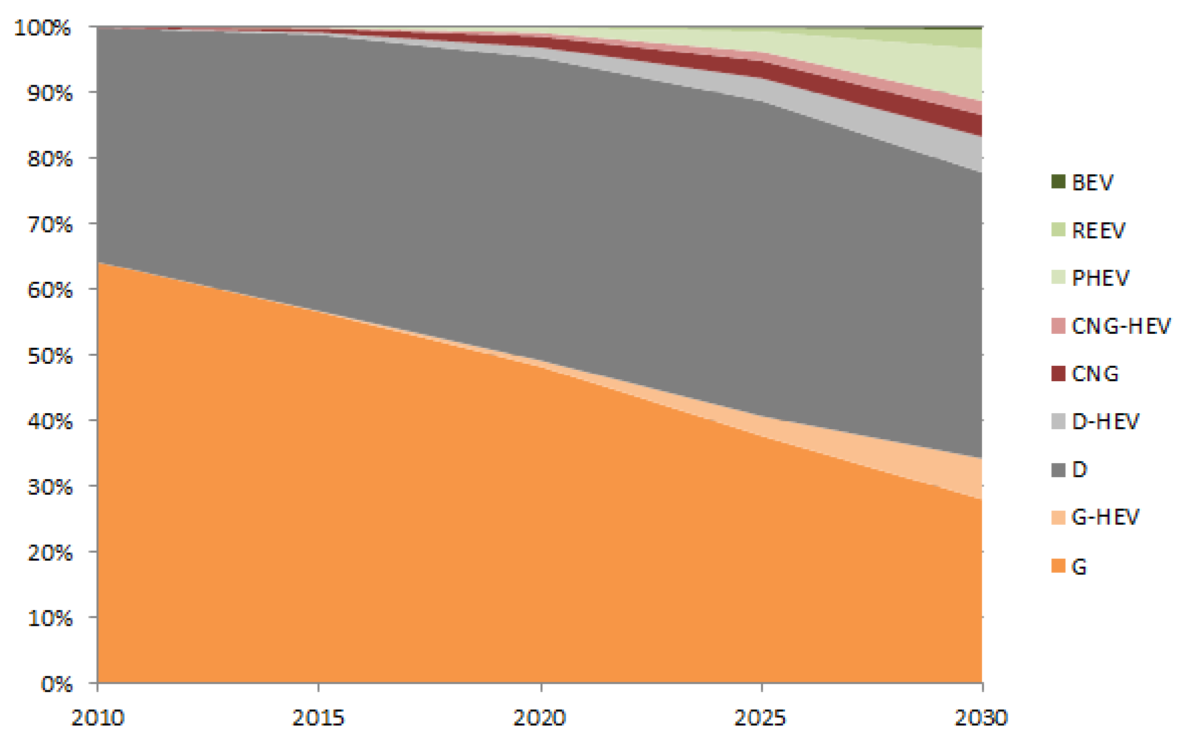


Figure 105. PoD-EU scenario: total vehicle stock in EU28

Figure 106 shows the annual energy consumption of vehicles in the stock of EU28 countries for the PoD-EU scenario. Total energy consumption decreases from 6.1 TJ to about 4.4 TJ, which corresponds to a relative reduction of 27% (25% in BaU).

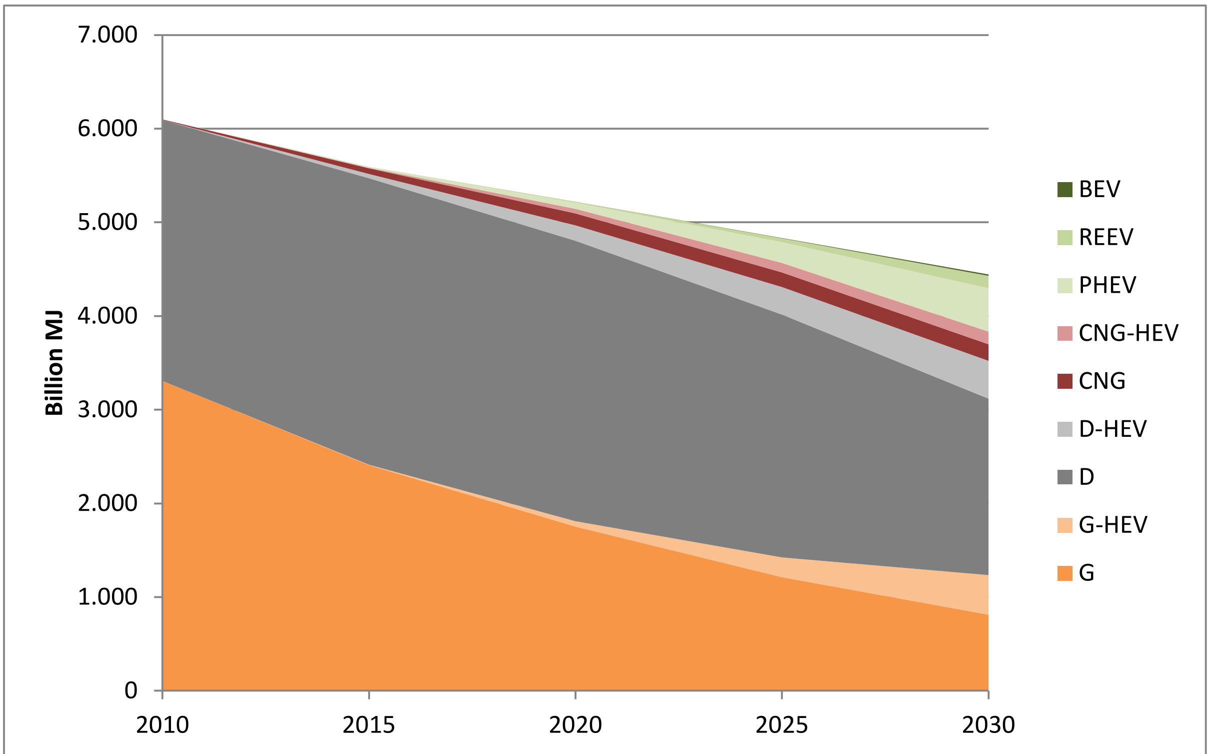


Figure 106. PoD-EU scenario: EU28 vehicle stock annual energy consumption

Corresponding total Well-to-Wheel $CO_2$ emissions of the EU28 vehicle fleet are depicted in Figure 107. In 2030, WTW $CO_2$ emissions are reduced by 31% compared to 2010 (28% in BaU).

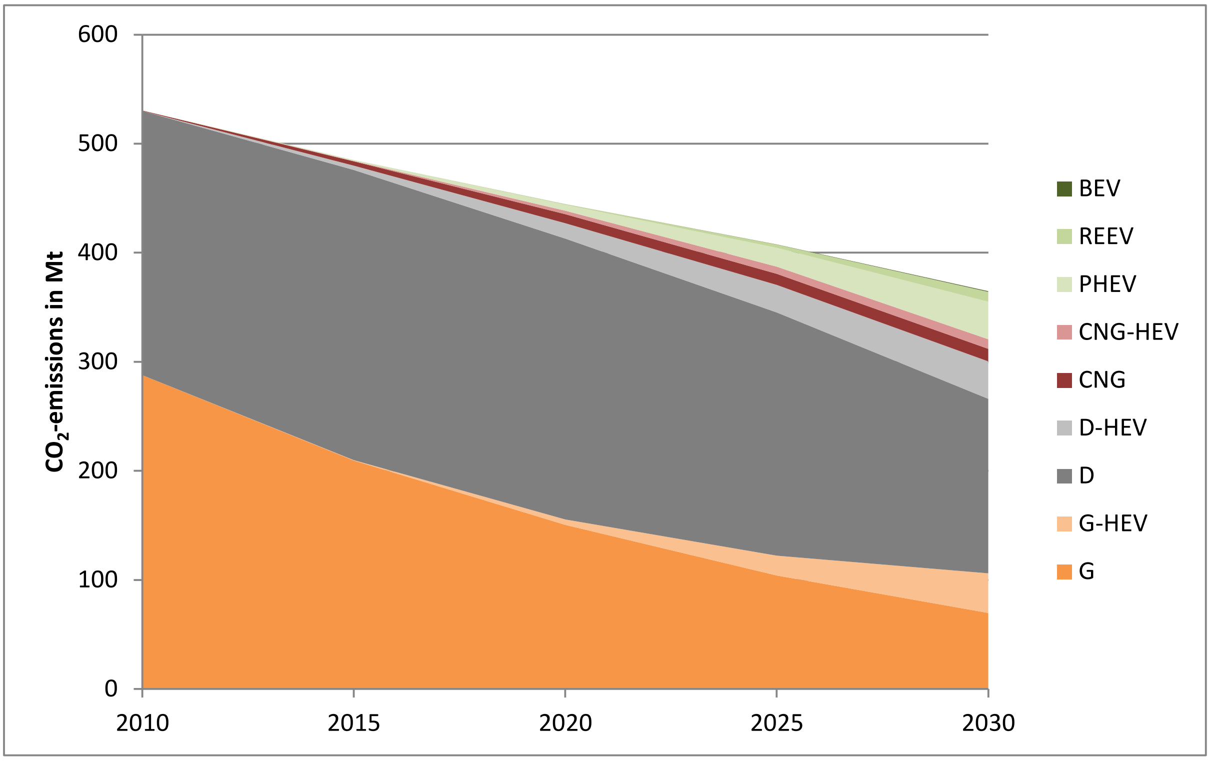


Figure 107. PoD-EU scenario: EU28 annual Well-to-Wheel $CO_2$ emissions of vehicles in stock

## 5.3 PoD scenario: Conclusion

Finland is already today favouring vehicles with low $CO_2$ emissions and thus electrified vehicles by its taxation scheme, thus further tax exemptions for electrified vehicles in the Finnish PoD scenario have a relatively small effect on vehicle sales. $CO_2$ emissions in 2030 are thus only 1 % lower than in the BaU scenario. Accumulated sales of electrified vehicles amount to 5 % higher numbers in 2030 than in the BaU case.

Model results of the PoD scenario for Germany show that those national policies promoting electrified vehicles are an effective path towards a low-carbon fleet. To make them most effective, however, a quick adoption is necessary to allow for the spread of technology and know-how within the industry and thus a decrease in costs. Within the PoD scenario for Germany, a reduction in well-to-wheel $CO_2$ emissions of 36 % in 2030 compared to 2010 is feasible, thus reducing $CO_2$ emissions of passenger cars by another 4 % compared to the BaU case. Accumulated sales of electrified vehicles amount to 987,000 in 2020, thus almost reaching the national target of one million electric vehicles.

Policies promoting electrified vehicles are also enabling the market penetration of EV in Poland within the Polish PoD scenario. Of the electrified powertrains, BEV and REEV are not able to enter the Polish market, while PHEV is the most preferred plug-in powertrain. $CO_2$ emissions of the Polish PoD scenario in 2030 are 1 % lower than in the BaU scenario and accumulated sales of electrified vehicles are one order of magnitude higher.

Lowering the EU $CO_2$ target for passenger cars to 60 g $CO_2$/km supports a faster and more pronounced market penetration of electrified vehicles in EU28 after 2021 compared to the BaU pathway. In 2030, electrified vehicles dominate the total new vehicle sales in countries of the EU28 market and take up a share of 60 %. Compared to the BaU scenario, this is an increase of 11 %. Total energy consumption drops from 6.1 TJ to about 4.4 TJ, which corresponds to a relative reduction of 27 % (24 % in BaU). Accordingly, Well-to-Wheel $CO_2$ emissions are decreased by 31 % compared to 2010 (28 % in BaU).

# 6 Summary

Three deployment paths for electrified vehicles were analysed with the agent based vehicle market model VECTOR21 within the eMAP project: Business as Usual (BaU) as a reference up to 2030, Technology Driven (TeD) with higher efficiencies of electrified vehicles and Policy Driven (PoD and PoD-EU) with a stricter EU-wide $CO_2$ regulation for passenger cars respectively a more pronounced promotion of electrified vehicles, the latter with individual measures per country.

VECTOR21 is simulating the competition between conventional and alternative powertrains for the new vehicle market, taking into account customer needs, automotive innovations and policy settings. 900 types of customers are modelled using relevant costs of ownership as a basis for their purchase decision, taking into account the political framework for $CO_2$ emission targets. Scenario results give the number of new vehicles sold per segment, powertrain, year and market. Vehicle stock in the individual markets is modelled including energy consumption and well-to-wheel $CO_2$ emission reductions in the stock over time. Within eMAP, an extended version of VECTOR21 was developed to cover Finland, France, the United Kingdom, Italy and Poland in addition to Germany, now representing three quarters of the EU28 new passenger car market and thus enabling statements on EU28 as a whole.

## 6.1 Business as Usual scenario

The BaU scenario as chosen within eMAP incorporates current policies, technologies and their respective development until 2030 anticipated from today's point of view such as a tightening of the EU $CO_2$ targets for passenger cars beyond 2020. The $CO_2$ target curve as assumed in the BaU scenario is thus 130 g $CO_2$/km in 2015, 95 g $CO_2$/km in 2021[18] and 75 g $CO_2$/km in 2030. Consequently, VECTOR21 results show a significant uptake of electrified vehicles in almost all of the modelled countries (Finland, France, Germany, Italy and the UK).

One of the markets strongly favouring electrified vehicles (EV) is Finland where relatively low electricity prices, a comparatively high mileage and Finnish tax regulations are supporting EV already today. Under the assumptions of the BaU scenario, plug-in electric vehicles (PHEV), range-extended electric vehicles (REEV) and battery electric vehicles (BEV) reach a share of around 20% in new vehicle sales in 2020, increasing to almost 50% in 2030. In contrast to other markets, where electricity prices are higher and customer's mileages are lower, a significant amount of pure battery electric vehicles is chosen by Finnish customers: about 10% in 2030, mostly in the medium segment.

In Germany, under the taxation system as of today, customers are less encouraged to purchase electrified vehicles. In combination with higher electricity prices, market penetration of EV starts later (after 2020 in the BaU scenario), market shares are lower (around 30% in 2030) and medium electrified powertrains (PHEV) are dominant. The share of BEV stays low.

[18] While the EU $CO_2$ target for passenger cars is 95 g/km already in 2020, only 95% of each manufacturer's new passenger cars have to comply to that target; from 2021 on, this percentage is raised to 100% (Regulation (EU) No 333/2014)

In Poland, drivers have a comparatively low average mileage and tax regulations are not in favour of EV. From the customer's economics perspective, the initially more expensive EV, although more fuel-efficient than conventional cars, are not within their budget: conventional diesel and gasoline powertrains dominate the market up until 2030.

In France, under the assumptions of the BaU scenario, the solely $CO_2$ emission-based Bonus-Malus system results in a dominance of diesel-based powertrains up to 2030 and a 22% market share of medium and higher electrified powertrains (of which around 80% are PHEV, 20% REEV and less than 5% BEV).

Conventional gasoline powertrains have a comparatively high market share in the United Kingdom up to 2030 as diesel fuel is slightly more expensive than gasoline. However, $CO_2$ emissions of gasoline powertrains are higher. With the boundary conditions given by EU $CO_2$ targets, electrified powertrains have thus an earlier and more pronounced market entrance compared to other markets, with PHEV, REEV and BEV gaining around 30% share in 2030.

Upscaled to EU28, conventional powertrains (diesel, gasoline and CNG) keep their market dominance up to the year 2025. Electrified vehicles slowly enter the market from 2020 on. The most preferred electrified powertrains are PHEV, followed by gasoline and diesel HEV. Due to high initial costs and infrastructure requirements, REEV and BEV are not able to gain a significant market share. CNG vehicles are not entering new markets but are sold almost exclusively in Italy with its well-developed refuelling infrastructure and relatively low CNG prices and, to a small extend, in Germany. In combination with decreasing Well-to-Tank $CO_2$ emissions of e.g. electricity production, total energy consumption of the EU passenger car stock decreases from 6.1 TJ in 2010 to 4.6 TJ in 2030, which corresponds to a reduction in Well-to-Wheel $CO_2$ emissions of about 29 %.

## 6.2 Technology Driven scenario

The additional impact of a faster technological development was modelled in the TeD scenario on the assumption that higher investments into traction battery R&D would lead to a faster uptake of corresponding production capabilities, a faster price decline for EV technologies and slightly improved vehicle efficiencies. For this TeD scenario, a relatively moderate technological development path was chosen: technology switches resulting in lower floor costs of battery systems, increasing electric ranges and increasing electric driving shares were not included. Bearing this in mind, the TeD scenario does not lead to significantly higher market shares of pure electric vehicles (BEV). However, in markets like Germany, which initially do not favour electrified vehicles, lower battery system prices enable an earlier and stronger market penetration of EV. Here, electrified powertrains (mostly PHEV and to a lesser extend REEV) make up for a third of the sales in 2030.

Compared to the BaU scenario, the slightly faster uptake of EV in EU28 in the TeD scenario leads to a slightly stronger electrification of the passenger car stock with slightly lower well-to-wheel $CO_2$ emissions in 2030.

## 6.3 Policy Driven scenarios

The impact of alternative policies was modelled in national and EU-wide PoD scenarios. Depending on the reference situation, VECTOR21 results showed that national policies promoting electrified vehicles or more stringent EU $CO_2$ targets (60 g $CO_2$/km in 2030) can support a further electrification of national car fleets. Accordingly, well-to-wheel $CO_2$ emissions of the fleet in EU28 countries in the PoD-EU scenario are reduced by 31 % in 2030 compared to 2010. The impact of the PoD-EU scenario on national level differs (Figure 108). While the influence, compared to the BaU scenario, in the markets in Germany and die United Kingdom is low, significant changes can be found in Italy and Poland after 2025. In Finland, no changes at all can be observed. This comes from the difference in fulfilling the $CO_2$-targets in the BaU scenario. Finland already fulfils the requirements of the PoD-EU scenario under the conditions of the BaU scenario, while Poland for example clearly exceeds the limits. Hence, the impact of stricter $CO_2$-regulations is bigger.

In Finland, legislative and economic conditions are already favourable for EV in the BaU scenario and the further political measures of the PoD scenario do not have a noticeable impact. In contrast to that, in Germany and to a lesser extend in Poland, national policies towards lowering purchase costs by tax exemptions or purchase premiums as well as lowering electricity prices have proven to be effective in the PoD scenarios. In Germany, they enable an earlier market entrance and a more pronounced market share of EV, resulting in around 40% PHEV, REEV and BEV in 2030 (compared to 30% in the BaU scenario). The share of pure electric vehicles (BEV) in 2030 in the German PoD scenario is, however, still very low with less than 5%.

In all VECTOR21 scenarios and markets, the large vehicle segment is the most progressive in terms of the uptake of electrified powertrains. Customers in this segment typically have a higher average mileage than customers of the small and medium vehicle segment. From an economic point of view, their focus is then shifted from purchasing costs towards fuel costs where an EV is more cost-competitive than a conventional car.

# 7 Conclusion

Within the collaborative project eMAP, feasible deployment paths of electrified vehicles (EV) were analysed up to 2030 with the vehicle market model VECTOR21 for Finland, France, Germany, Italy, Poland, the UK and EU28 as a whole. Three different scenario storylines were developed following research questions on the timing and dimension of EV market penetration under current policies (BaU scenario), on the influence of an enhanced technological development (TeD) and on the influence of additional national and EU-wide policies (PoD).

One of the main drivers in all three scenarios and markets is the EU regulation on $CO_2$ targets for passenger cars. A tightening to 75 g $CO_2$/km in 2030 (as assumed in the BaU and TeD scenario) results in a significant market penetration of EV in Finland, France, Germany, Italy, the UK and in EU28. However, individual market shares and the timing of market penetration strongly depend on the national legislative and economic framework, namely national taxation schemes and electricity prices. A further tightening to 60 g $CO_2$/km in 2030 (as assumed in the PoD scenario) results in a faster and more pronounced market penetration of electrified vehicles in EU28 after 2021. In 2030, electrified vehicles take up a share of 60 % of the new vehicle sales, an increase of 11 % compared to BaU. Accordingly, well-to-wheel $CO_2$ emissions of the fleet in EU28 countries are reduced by 31 % in 2030 compared to 2010.

The TeD scenario shows that moderately improving EV technologies by e.g. higher investments into traction battery R&D can enable an earlier and stronger market penetration of EV. However, this is effective mostly in markets like Germany which initially do not favour electrified vehicles by fiscal means (see also Figure 108).

The analysis of PoD scenarios for Finland, Germany and Poland indicates that national policies promoting electrified vehicles can support a further electrification of national car fleets. However, the timing of political instruments is crucial for an effective market penetration: a quick adoption is necessary to allow for the spread of technology and know-how within the industry and thus a decrease in costs.

Summarising the range of feasible pathways of the different scenarios, the cumulated number of EV sold per scenario in each of the six markets is plotted in Figure 108. In Finland, the national taxation scheme strongly supports a high EV penetration already in the BaU scenario and shows that Finnish policy and legislation is positive for electromobility. In Poland, in contrast to that, additional national and EU-wide climate policies in favour of EV are needed to bring EV into the market in a significant amount. This is in parts also true for Germany. Here, more stringent EU $CO_2$ targets (PoD-EU), an enhanced technological development of EV (TeD scenario) and, especially introducing additional national policies represent different pathways to support an earlier and more pronounced market penetration of EV. In the case of the national PoD scenario, model results show that a doubling of the number of EV sold in 2030 compared to the BaU scenario is feasible. Assuming a continuation of the Bonus-Malus-System as of today (BaU), the penetration rate of EV is relatively moderate in France. Decreasing battery costs (TeD) and the tightening of EU $CO_2$ targets for passenger cars (PoD-EU) are feasible means to enhance EV sales. In the United Kingdom, gasoline powertrains have a relatively high market share as diesel fuel is more expensive than gasoline. Under given and extrapolated $CO_2$ targets this fact allows for a comparatively high penetration rate of EV already in the BaU scenario as electrified powertrains are then more cost-competitive. Here, enhancing the technological development of EV and thus decreasing battery system costs proves to be an effective pathway (TeD scenario). With its well-developed refuelling infrastructure and relatively low CNG prices, EV are initially not very attractive in Italy in the BaU scenario. However, the analysis of the TeD and the PoD scenario shows that feasible electromobility pathways for that market exist.

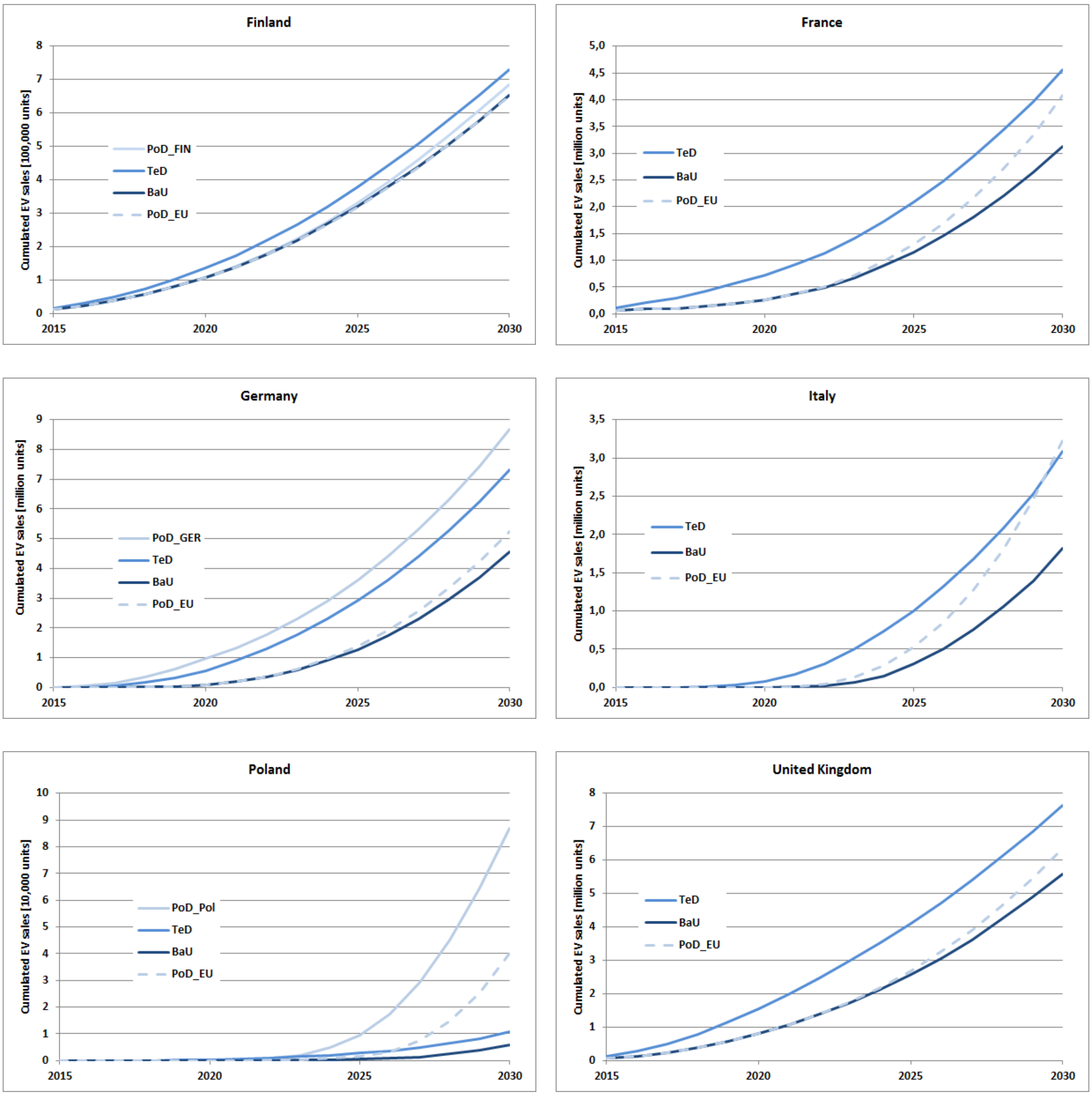


**Figure 108. Cumulated EV sales in all scenarios[19] and markets**

[19] BAU: Business as Usual; TeD: Technology Driven; PoD_EU: Policy Driven with EU policies; PoD_Country: Policy Driven with national policies

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