



Climate Protection in the Transport Sector – The Key Role of Alternative Fuels

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Abstract:

The targets for the reduction of greenhouse gases in the transport sector are ambitious at both German and European level. However, the potential of important measures suitable for this purpose is in danger of being lost due to a lack of technological neutrality. Political regulatory framework conditions strongly favour the ramp-up of electric mobility. The German Climate Protection Programme 2030 focuses on electric mobility through excessive financial support and is accompanied by other legal measures such as the non-inclusion of the standard DIN EN 15940 in the new BImSchV, which means that paraffinic renewable fuels are strongly discouraged. At European level, this includes especially the fleet regulation system for CO₂ emissions, in which battery electric vehicles are counted with zero emission, but renewable fuels do not count at all. These regulations need urgent correction considering well-to-wheel emissions. An analysis shows that renewable fuels will be by far the most important climate protection measure in transport.

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1 Introduction

The German government is preparing a climate protection law for the period until 2030. In this context, the transport sector is a challenging one due to still increasing tendency in greenhouse gas (GHG) emissions. One result of the supporting working groups in the national platform future of mobility (NPM, 2019) is that the climate targets for the transport sector are not achievable in time with electric mobility alone. In particular, alternative fuels including advanced biofuels will play a key role in reducing greenhouse gas emissions for both the existing car fleet and the areas difficult to electrify such as heavy-duty transport, aviation, marine shipping and numerous special applications. In addition, hybrid cars will need liquid fuels in the long term. Thus, the demand for alternative fuels will rise sharply within the next decade.

2 Mathematics of Climate Protection

The mathematics of climate protection in general is mainly based on the following two factors: Carbon dioxide (CO_2) budget and CO_2 emission level. The CO_2 budget is the maximum amount of CO_2 that can still be released into the atmosphere if a certain level of warming is not to be exceeded. The CO_2 emission level is the CO_2 emission per time.

According to the IPCC special report of Oct. 2018 (IPCC, 2018) related to the 1.5-degree target, the global CO_2 budget based on the beginning of 2018 was 420 gigatonnes (Gt) CO_2 for a 66% probability of limiting warming to 1.5°C . The current global annual CO_2 net emission level is about 40 Gt CO_2 (IPCC, 2018). Thus, the global CO_2 budget is shrinking by 40 Gt CO_2 every year, resulting in a remaining **global budget** of just **340 Gt CO_2** from the beginning of 2020.

According to this simple mathematics of climate protection, the CO_2 budget will be exhausted in about 8.5 years if no action is taken. As an example, for correct action, the CO_2 budget could be kept, if the CO_2 emission level is reduced linearly to zero within 17 years until the beginning of 2037. These two scenarios are shown in Fig. 1. The respective consumption of the CO_2 budget is the integral (area) under each line. The horizontal red line in Fig. 1 represents the “no-action” scenario, while the linear falling green line stands for the “correct-action” scenario. As calculated from the beginning of 2020, the integral (area) under each line is representing the same CO_2 budget value of 340 Gt CO_2 .

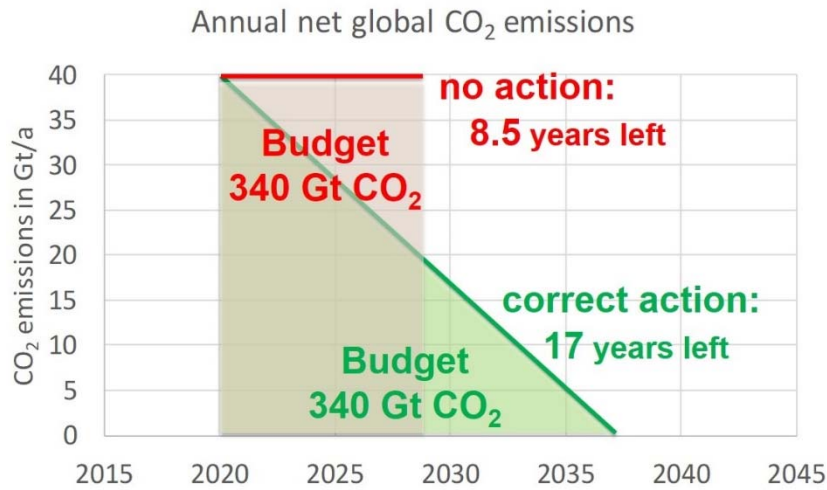


Figure 1: No-action and correct-action scenario for global CO₂ emissions

The linear reduction scenario as an example for correct action in Fig. 1 should be taken as a minimum action roadmap not only for the world, but also for every single country or every single sector. Assuming that the world would agree on this roadmap, the respective CO₂ budget for each country or each sector in the world could be calculated by Formula (1).

$$B_i = \frac{E_i}{E_g} \cdot B_g \quad (1)$$

With: B_i = CO₂ budget of the respective country or sector

B_g = global CO₂ budget (340 Gt at the beginning of 2020)

E_i = CO₂ emission per time of the respective country or sector

E_g = global CO₂ emission per time (currently 40 Gt/a)

An advantage of Formula (1) compared to other more complex calculation methods might be that it can be easily understood, applied and adjusted to the shrinking global CO₂ budget.

The following two examples calculate German CO₂ budgets from the beginning of 2020 according to Formula (1), which should set the framework for political climate protection programmes in Germany. These calculations can be transferred accordingly to any other country or sector:

1. The total German CO₂ emission level is about 0.8 Gt/a (UBA, 2019). Thus, **the CO₂ budget of Germany is $(0.8 / 40) \cdot 340 \text{ Gt CO}_2 = 6.8 \text{ Gt CO}_2$.**
2. The German transport sector CO₂ emission level is about 0.168 Gt/a (UBA, 2019). Thus, **the CO₂ budget of the German transport sector is $(0.168 / 40) \cdot 340 \text{ Gt CO}_2 = 1.4 \text{ Gt CO}_2$.**

According to the linear CO₂ mitigation scenario of Fig. 1, **the CO₂ emissions must be reduced annually by about 5.9% every year** or, as an example, by about 59%

during the next decade until 2030, respectively based on the today's emission level. **In that case, the remaining time is just 17 years until the beginning of 2037.** Some more time could only be achieved by faster CO₂ emission reduction in the meantime. Conversely in case of slower CO₂ emission reduction in the first years, the remaining time for reduction to zero emission would be even shorter.

Realistically speaking, the zero-emission target year 2050 of both the German Climate Roadmap and the "Green Deal" of the European Commission is now far outside the range for the 1.5-degree target. We have already lost too much time doing nearly nothing for effective climate protection.

According to Willner (Willner, 2019) the key messages that emerge for policymakers are:

- *Significant global GHG reduction must start immediately in every single country of the world.*
- *Long-term goals must be set, but that is not enough.*
- *In addition, annual milestones are needed, based on the linear GHG emission reduction roadmap as shown in Fig. 1 for the example of CO₂ emissions.*
- *All technical options must be involved.*

Thus, following the mathematics of climate protection, measures to reduce GHG emissions must meet the following criteria as far as possible:

- **"No delay"**: *Measures must be effective immediately.*
- **"No GHG export"**: *Measures for GHG reduction in one country or sector must not lead to GHG increases in other countries or sectors.*
- **"Fast roll-out"**: *It must be possible to implement the measures quickly world-wide.*

These recommendations apply to all sectors of the economy, including the transport sector, which is discussed in this paper.

3 CO₂ Emission Reduction in the Transport Section by Alternative Fuels

In Germany, the final energy demand of transport in 2017 was almost 2.8 exajoule (EJ), with a share of 98% liquid fuels (BMVI, 2018). According to the UBA (Umweltbundesamt), the German transport sector accounts for about 30% of the total final energy demand and for about 20% of the GHG emissions (UBA, 2019). In 2017, the GHG emissions of transport were 168 megatonnes (Mt) CO₂eq (UBA, 2019). This represents an increase of 4 Mt CO₂eq compared to 1990 (UBA, 2019).

In view of the overwhelming share of combustion engines in the transport sector, **an accelerated implementation of alternative fuels is obviously the only way for fast**

GHG emission reduction in the transport sector including both the huge existing fleet and areas difficult to electrify such as aviation, shipping, heavy road transport as well as special applications (e.g. farming, forestry, construction, civil protection, police, fire brigade, military and others).

3.1 Alternative Fuels

Alternative fuels mean renewable fuels or fuels based on renewable resources. They include both liquid and gaseous fuels. The terms “alternative fuels” and “renewable fuels” are used synonymously throughout the text. To avoid a widespread misunderstanding, it should be mentioned that alternative fuels concern not only biofuels, but also any kind of non-fossil fuels.

Examples for alternative fuels are:

- BtX, BtL, BtG fuels = biofuels
 - 1st generation biofuels (1G biofuels) = conventional biofuels based on agricultural crops
 - 2nd generation biofuels (2G biofuels) = advanced biofuels based on biomass waste and residues or lignocellulosic energy crops
 - 3rd generation biofuels (3G biofuels) = advanced biofuels based on algae or comparable resources
- WtX, WtL, WtG fuels = advanced alternative fuels based on waste mixtures with a high share of non-biogenic waste such as plastic waste, automotive shredder residue, municipal solid waste etc.
- PtX, PtL, PtG fuels = e-fuels = advanced alternative fuels based on renewable electric power (e.g. via electrolysis of water for hydrogen production and further processing) and, if necessary, based on a non-fossil gaseous carbon source (e.g. CO₂, CO).
- Hybrids such as B/PtX fuels or SynBioPtX fuels (combination of BtX and PtX fuels) or W/PtX (combination of WtX and PtX fuels) = fuels based on biomass or waste, upgraded by renewable hydrogen.

With: BtX fuels = biomass to liquid or gaseous fuels, BtL fuels = biomass to liquid fuels, BtG fuels = biomass to gaseous fuels, WtX fuels = waste to liquid or gaseous fuels, WtL fuels = waste to liquid fuels, WtG fuels = waste to gaseous fuels, PtX fuels = power to liquid or gaseous fuels, PtL fuels = power to liquid fuels, PtG fuels = waste to gaseous fuels, e-fuels = fuels based on renewable electric power

The term “**synthetic fuels**” is usually used when synthesis gases occur as an intermediate stage in the respective production process line. Examples for synthesis gases are

mixtures of hydrogen (H_2) with carbon monoxide (CO) or carbon dioxide (CO_2). Synthesis gases can occur in multiple production lines and they are not limited to any group of the alternative fuels (BtX, WtX, PtX and hybrids) mentioned above.

Due to the high share of 98% liquid fuels in the German fuel market, as mentioned above, it is obvious that **liquid alternative fuels will play the major role in the alternative fuel area**. A comprehensive description of current developments and technologies for the production of advanced liquid alternative fuels including their technology readiness levels and their synergy potentials is given in a position paper of ProcessNet, a joint initiative of DECHEMA and VDI-GVC (ProcessNet, 2018).

From the chemical point of view, typical examples for **liquid alternative fuels** are:

- FAME (fatty acid methyl esters), e.g. biodiesel
- liquid hydrocarbons: e.g. paraffinic fuels, Fischer-Tropsch-fuels, HVO (hydrotreated vegetable oils) or HEFA (hydroprocessed esters and fatty acids)
- alcohols: e.g. ethanol, methanol, butanol etc.
- ethers: e.g. OME (oxymethylene ethers), DME (dimethyl ether) etc.

But alternative fuels also include gaseous fuels. Typical examples for **gaseous alternative fuels** are:

- H_2 (hydrogen)
- CH_4 (methane)
- NH_3 (ammonia)

The importance of gaseous alternative fuels is expected to increase due to their high potential for the reduction for GHG emissions. One large area here is the H_2 -driven fuel cell technology. Another one is the application of biomethane or synthetic methane (CH_4) for CNG (compressed natural gas) cars, LNG (liquified natural gas) trucks or LNG ships. In those cases, the methane of the natural gas is replaced by biomethane or synthetic methane. “Biomethane” means that the carbon source is biomass. This can be biogas, for example. “Synthetic methane” is a synthetic fuel, produced by synthesis from H_2 and CO_2 , independent from the source of the CO_2 . Just in case the CO_2 is biogenic, e.g. derived from biogas, then the synthetic methane is a biomethane at the same time. Finally, ammonia should also be mentioned. Ammonia as an energy carrier is a quite new idea. For example, it could be applied as a hydrogen source for fuel cell technology approaches.

3.2 The German Situation in the European Context

Starting with the discussion of the status quo, the current share of biofuels already in the German market is about 3.4 Mt or 112 petajoule (PJ), based on 2017 (MWV, 2018). These biofuels, mainly biodiesel and bioethanol, are already making

a significant contribution to reducing transport CO₂ emissions. In 2017, emissions savings from biofuels amounted to 7.7 Mt of CO₂eq (BLE, 2019), which is equivalent to 4.54% emission reduction resulting in 161.8 Mt CO₂eq emissions for UBA (UBA, 2019), calculation see below Table 2. The tendency is increasing due to 8.2 Mt CO₂eq emission reduction in 2018, related to the same base value for fossil fuels of 83.8 g CO₂eq/MJ (BLE, 2019).

Thus, current biofuels are already performing significantly better than the legal requirement of 4% GHG emission reduction for the years 2017, 2018 and 2019 by German law (BImSchG, 2014). According to the same law, the emission reduction by biofuels has to be 6% from 2020. This increase should be possible due to further potential and improving GHG emission reduction efficiency of biofuels.

The average efficiency of biofuels for GHG emission reduction reached a high level of 83.8% by 2018 (BLE, 2019). One reason for this excellent performance is an increasing share of waste based biofuels. As an example, in 2018, 40% of the biodiesel in Germany was produced from waste, such as used cooking oil (UCO) (BLE, 2019). Correspondingly, there are already both kinds of biofuels in the market, 1G biofuels based on agricultural crops and 2G biofuels based on waste and residues.

According to the recast of the Renewable Energy Directive of the European Union (RED II), 1G biofuels with high indirect land-use change-risk (ILUC-risk), already limited to the respective level of 2019 as a maximum, shall be gradually reduced to zero from beginning of 2024 until end of 2030 at the latest (EU, 2018).

But obviously unexpectedly, phasing out 1G biofuels according to RED II and replacing them by 2G biofuels would have an adverse effect on GHG emission reduction. Much better would be retaining the current level of 1G biofuels and realization of further GHG emission reduction by additional implementation of 2G biofuels. This was clearly shown by a study of the Hamburg University of Technology (Buchspies and Kaltschmitt, 2018). The main reason of the negative effect of phasing out 1G biofuels is their coupling with feed, as 1G biofuels are by-products of feed production. In case of phasing out 1G biofuels, the feed provision needs to be additionally covered.

According to the considerable and indispensable performance of existing biofuels for GHG reduction in the transport sector, an important recommendation for action to policymakers must be:

- *Phasing out 1G biofuels according to RED II would be a big mistake in climate policy. On this point, RED II urgently needs to be revised.*

- *Thus, 1G biofuels must be retained at the current level. Further GHG emission reduction should be realized by additional measures such as the implementation of 2G biofuels, waste-based fuels, e-fuels and others.*

4 The CO₂ Emission Reduction Potential of Different Measures

In the Climate Protection Programme (CPP) 2030 of the German Government, published as a key issues paper on 20 Sept. 2019 (Bund, 2019a) and published as a detailed working plan on 9 Oct. 2019 (Bund, 2019b), there are different measures listed for the reduction of GHG emissions until 2030 within the framework of the Climate Protection Plan 2050.

The German 2030 target for the transport sector is the reduction of CO₂ emissions by 40 to 42% compared to 1990 (Bund, 2019a+b). The German CPP 2030 assumes 163 Mt CO₂eq for 1990 (Bund, 2019a+b) in small deviation to the UBA data giving 164.3 Mt CO₂eq for 1990 (UBA, 2019). **The target corridor for the emissions in 2030 shall be between 98 and 95 Mt CO₂eq (Bund, 2019a+b).**

In 2017 the transport sector emitted 168 Mt CO₂eq (UBA, 2019). **Hence, the annual quantity emitted must be reduced by 70 to 73 Mt CO₂eq by 2030 compared to 2017.** This represents a reduction by 47 to 48% compared to 2017 being a major challenge.

With all these data related to the transport sector, it must be noted that the German share of both international aviation and shipping is not included (UBA, 2019). Thus, measures for the CO₂ emission reduction in these two areas are not covered by the national CPP 2030.

Related to the transport sector, the following measures are listed in the key issues paper (Bund 2019a):

- Measure 14: Expansion of the charging point infrastructure for electric mobility
- Measure 15: Promotion of the changeover to electric cars
- Measure 16: Fuel mix and development of advanced biofuels
- Measure 17: Increasing the attractiveness of public transport
- Measure 18: Expansion of cycle paths
- Measure 19: Increasing the attractiveness of rail passenger transport
- Measure 20: Strengthening rail freight transport
- Measure 21: Capital increase in the company Deutsche Bahn
- Measure 22: Putting low-CO₂ trucks on the road
- Measure 23: Modernisation of inland waterway transport and use of shore-side electricity in ports
- Measure 24: Development of electricity-based fuels (e-fuels)
- Measure 25: Digitalisation of the mobility

- Measure 26: Consistent CO₂-related reform of the motor vehicle tax
- Measure 27: Making rail travel cheaper, flying more expensive
- Measure 28: Model projects for annual public transport tickets

In the detailed working plan (Bund 2019b) the measures listed above are assigned to the following political fields of action:

- Public transport, cycle and foot traffic (measures 15, 17, 18, 19, 21, 27 and 28)
- Alternative fuels (measures 16 and 24)
- Freight transport (measures 20 and 23)
- Passenger cars (measures 14, 15, 26)
- Commercial vehicles (measure 22)
- Digitalisation (measure 25)
- Annual Tax Act 2019 (measure 15)

Related to the transport sector, the German CPP 2030 is neither balanced nor technology-neutral. There is a clear focus on electric mobility. Five of the seven political fields of action (public transport, passenger cars, commercial vehicles, digitalisation and Annual Tax Act 2019) are predominantly dedicated to electric mobility (measures 14, 15, 22, 25 and 26). The following concrete targets and measures illustrate this (Bund, 2019a+b):

- Setting a specific target number corridor of 7 to 10 million electric vehicles until 2030.
- Exemption from vehicle tax for electric cars, including plug-in hybrids, to be extended until 2030.
- Reduction of company car tax for electric cars, including plug-in hybrids, to be extended to 2030.
- Extension of the purchase premium for electric and fuel cell cars beyond 2021 and its increase for cars below 40,000 €.

However, there is no corresponding programme for alternative fuels. Only two measures (measure 16 and 24) have been attributed to alternative fuels, addressing just two types of them, biofuels and e-fuels (PtX fuels). Important variants, such as waste-based fuels (WtX fuels) and hybrids according to the list above, are missing. The information on the promotion of alternative fuels remains vague. The only concrete information is negative, as 1G biofuels are not to be additionally supported. Moreover, there is no plan for the ramp-up of alternative fuels. Regarding target shares of advanced biofuels there are vague references to the subquotas of RED II.

It must be noted that the RED II subquotas for advanced biofuels are nearly irrelevant due to the low level of 0.2% in 2022, 1% in 2025 and 3.5% in 2030, respectively based on the energy consumption in the transport sector (EU, 2018).

The potential of German biomass sustainably available for bioenergy is given by a range of 1,000 to 1,200 PJ/a (Bund, 2019a+b). Taking a sustainable import potential into account, the total biomass potential exceeds 1,500 PJ/a (Bonaldo, 2019). But no potential for biofuels is derived from this in the CPP 2030. A cautious estimate could be 500 PJ/a biofuels by 2030. To get a feeling for the magnitude, one may compare this level with the current German biofuel consumption of 112 PJ/a and the final energy consumption for transport of 2,805 PJ/a in 2017 (MWV, 2018).

This imbalance and lack of technology neutrality in the German Climate Protection Programme (CPP) 2030 regarding the transport sector in favour of electric mobility seems to be a big mistake. Policymakers should note that the following problems could be caused:

- *Important options for GHG emission reduction remain unused*
- *Jobs are lost unnecessarily*
- *Unnecessary costs are incurred*
- *Resource bottlenecks threaten*

As will be shown below, the focus of the German CPP 2030 regarding the transport sector has obviously been prematurely placed on electric mobility without having sufficiently examined its effectiveness for climate protection and its economic, social and financial consequences.

4.1 Economic, Social and Financial Issues

The **economic and social** consequences indicated by considerable **job losses** as a result of the exaggerated focus on electric mobility are already evident today. This affects above all the medium-sized suppliers in the automotive industry. The leading automotive supplier Bosch has already started to cut jobs, for example (Manager-Magazin, 2019a+b). According to a study of the BUND (Bund für Umwelt und Naturschutz Deutschland) by Rudi Kurz, a professor of economics in Pforzheim, 360,000 jobs threaten to be lost in the next ten years in Germany's automotive industry (Spiegel, 2019). An advisory committee of the German Government sees even 410,000 jobs at risk (Handelsblatt, 2020). New jobs in electromobility depend in particular on whether it is possible to quickly establish a leading battery production industry in Germany. However, this is questionable in view of Asia's technological lead in this area. And even if these efforts were successful, these new jobs would not be able to compensate for the massive loss of jobs in the conventional supply industry. Moreover, the global market opportunities for battery electric mobility are unclear since China has started a strategy switch from battery electric mobility to hydrogen fuel cell mobility and synthetic fuels (Focus, 2019). This change in China's strategy

could become a major problem for the German automotive industry in the medium term, if it is going to focus solely on electric mobility in the future.

The detailed working plan of the CPP 2030 (Bund, 2019b) admits that **employment effects** in the transport sector are not yet adequately analysed. The paper notes that, with regard to the transport sector, needed results of both the working group 4 of the national platform future of mobility (NPM, 2019) and the German Concerted Action on Mobility are still missing (Bund, 2019b).

A further aspect of **economic and social** consequences are issues in other countries, where raw materials such as lithium and cobalt are extracted for battery production. One point is the critically high water demand for the lithium extraction in the Andes Mountains of South America. Another point could be the inhumane working conditions in copper mining for cobalt production in the Democratic Republic of Congo. Furthermore, the resources of cobalt are very limited. Therefore, cobalt counts as a critical raw material and is likely to become a **resource bottleneck** for future battery production. (EU, 2017)

The next critical point focusing on electric mobility only is the **financial** cost situation. In view of the above listed measures for supporting electric cars planned by the German Government, such as exemption from vehicle tax, reduction of company car tax as well as extension of the purchase premium, combined with incentives for the ramp-up of renewable power generation, it is clear that an enormous financial burden will be imposed on Germany. As one example, the purchase premium for electric cars including plug-in hybrids illustrate the magnitude. The German Government and the automotive companies will pay up to 6,000 € (each 50%) purchase premium per electric car (Bund, 2020). For an assumed number of about 700,000 electric cars until 2025 there are 2.1 billion € allocated by the Government. But this is far away from the target corridor of 7 to 10 million electric cars in 2030. This would cost the Government up to **30 billion €**.

The absurd amount of this subsidy becomes clear when compared with a CO₂ price for diesel fuel assuming the following boundary conditions:

- CO₂ price of 30 €/t representing roughly an average between 2021 and 2030 according to the German CPP 2030 (Bund, 2019a+b)
- 2,64 kg CO₂ emission per litre resulting from the emission factor of 3.167 kg CO₂ per kg for fossil diesel fuel (UBA, 2016) and the standard diesel density of 0,833 kg/litre
- 6 litre diesel per 100 km as an average fuel consumption of the car
- resulting in 0.158 kg CO₂ emission per km for pure fossil diesel fuel

Hence, the 6,000 € purchase premium subsidy for an electric vehicle corresponding to the price for 200 t of CO₂ would represent the full CO₂ price for about 1.3 million km car driving with pure fossil diesel fuel. This is much more than a normal diesel car can reach in his operation life time.

Much more costs come on top for transport electrification by car tax reductions, renewable power extension, building up the charging infrastructure and so on. An analysis of costs for different scenarios is given by a BDI study (BDI, 2018), for example. A study of Economic Trends Research (ETR) has analysed the financial support of a battery-electric vehicles (BEVs) compared to a car with a combustion engine, using the example of a Golf type car from Volkswagen (VW) (ETR, 2019). Based on this study, the German Association of the Mineral Oil Industry (MWV) has calculated the loss of revenue for the German state. The MWV comes to the result that the support measures already adopted alone would cost the German state reduced revenues of around 13,000 € for one BEV or **130 billion €** for 10 million BEVs (MWV, 2020).

The ETR study has identified even **further cost-relevant measures** that favour BEVs and burden cars with combustion engines. The most important measure is the EU fleet regulation for CO₂ emissions (EU, 2019). From 2020, the average CO₂ emissions of a manufacturer's vehicles may only be 95 g CO₂ per kilometer and vehicle (fleet limit value). For every additional g of CO₂ per km, the manufacturer must pay a fine of 95 € per new vehicle sold. BEVs are counted with zero CO₂ emission, but renewable fuels do not count at all. This is a very strong and completely unjustified discrimination of renewable fuels in favour of electric mobility. As will be shown in the following sections, on the one hand renewable fuels are an indispensable option for action in climate protection (see section 4.2). On the other hand, the assumption "zero CO₂ emission" for BEVs is far from reality. A well-to-wheel (WTW) consideration should be taken into account here (see section 5).

Adding up all the benefits for BEVs and costs for cars with combustion engines, the ETR study comes to a difference between these car variants of more than **27,000 € per vehicle in favour of BEVs**. With this amount, **renewable fuels could be promoted with up to more than 4 € per litre** over a 12-year operation period for example assuming a Golf class gasoline car with 11,000 km/a and 4.8 liters/100 km resulting in 6,336 liters (ETR, 2019; MWV, 2020). Such a promotion of renewable fuels would even make the production of expensive variants such as e-fuels economically viable. In a study by Prognos and others (Prognos et al., 2018), various scenarios for the development of e-fuels are also presented. According to these scenarios, the production costs will decrease significantly in the future. In 2030, these could be between 1 € and 1.75 € per litre.

As a note for policymakers, it becomes clear that the electrification of the transport sector is socially, ecologically and financially highly questionable. Furthermore, it is an economically risky approach in view of the threat of resource bottlenecks, and it is also an extremely expensive scenario. It would be much cheaper to make full use of the existing infrastructure by introducing alternative fuels. Liquid alternative fuels would also bring the major advantage of integrating the large existing fleet into immediate CO₂ emission reduction. At European level, a correction of the fleet limit value system appears to be a priority. There is an urgent need to allow the crediting of renewable fuels so that this important potential of suitable technologies for effective climate protection in the transport sector is not lost.

4.2 Climate Protection Issues

An additionally very important point is the check of the **GHG emission reduction performance** of the intended measures of the Government. It would be tragic if costly measures with negative financial, economic and social consequences were to be taken, with poor performance in the end. Therefore, the real GHG mitigation performance of the intended measures is to be investigated.

Regarding measure 25 “**Digitalisation**” the GHG mitigation performance is very questionable. This measure means the digital networking of electric vehicles in order to optimise the traffic flow. On the one hand, this might reduce the energy demand of electric vehicles a little bit due to some enhancement of the traffic efficiency. But on the other hand, it will increase the amount of data to be processed tremendously. Accordingly, the power consumption for the necessary server services and the associated CO₂ emissions will increase strongly. Due to calculations of Tilman Santarius, two million autonomous driving cars alone would generate the same amount of data as half of the world population today (Stern, 2018).

For the sake of clarity, the analysis of further measures will be summarised in groups. According to the above mentioned BDI study (BDI, 2018), the **GHG emission reduction in the transport sector can be based on the following four pillars:**

- Pillar 1: Shift of transport from road and air to rail and water
- Pillar 2: Reduction of energy consumption by increasing the efficiency of the drive systems
- Pillar 3: Introduction of new drive systems
- Pillar 4: Increasing the share of renewable fuels in the fuel mix

Pillar 1 “Transport shift” is related to eight measures and thus most of the above listed measures of the German CPP 2030: measures 17, 18, 19, 20, 21, 23, 27 and 28. There is no doubt about the positive GHG mitigation effect of pillar 1 “Transport shift” and the related measures of the German CPP 2030. But unfortunately, the effect

of this transport shift is expected to be very limited. The BDI study calculates reductions just by **7 Mt CO₂ for pillar 1** (BDI, 2018). The theoretical potential of this pillar is much higher. If it were possible to shift heavy freight traffic alone from road to rail, savings of more than 20 Mt CO₂ could be achieved (BDI, 2018). Other measures such as increasing cycling in urban areas can help here.

Pillar 2 “Efficiency” is not related to the measures of the German CPP 2030, perhaps with the exception of measure 25 “Digitalisation”. But as discussed above, digitalisation cannot really be expected to contribute significantly to CO₂ mitigation. **Moreover, the effectiveness of efficiency enhancement (pillar 2) may be doubted in principle because of underestimated rebound effects** (Santarius, 2014). Without considering rebound effects, the BDI study optimistically calculates reductions by **15 Mt CO₂ for pillar 2** (BDI, 2018).

Another aspect of efficiency should be addressed here. It is often cited as an argument for electric mobility and against renewable fuels that the electricity requirement for BEV driving is lower than for the production of e-fuels. The first point is, that there are a lot of other variants of renewable fuels, such as BtX and WtX as well as hybrid-PtX (see section 3.1), which need much less electric power for their production than BEV driving. The second point is, that Germany is an energy-importing country and will remain so in the future. In this respect, future imported energy should be renewable, for example in form of renewable fuels such as hydrogen or e-fuels produced in countries with an excess supply of renewable energy. In this case, it would be much more efficient to use these imported renewable fuels directly in fuel-cell cars or cars with combustion engines than to convert these fuels into electric power in order to drive BEVs.

Pillar 3 “New drive systems” is related to five measures of the German CPP 2030: measures 14, 15, 22, 25 and 26. In the German CPP 2030, almost only electric mobility is addressed as “new drive systems”. In contrast to the BDI study (BDI, 2018), in this paper pillar 3 is assigned to electric vehicles alone, since mobility based on hydrogen as a gaseous renewable fuel is treated in pillar 4 “renewable fuels“. In the following model calculation, only BEVs as passenger cars are considered for pillar 3. Deviations from this simplified model calculation due to effects of other electrification options such as plug-in hybrid electric vehicles (PHEVs) instead of BEVs or electrification of road freight transport are expected to be minor. On the one hand, PHEVs instead of BEVs would just correspond to a less-electrification scenario. Electrification of road freight transport, on the other hand, for example by electric overhead lines on the motorway, could improve the situation somewhat. But this has not been considered in detail here, because a significant electrification of road freight transport would be neither likely nor purposeful. It would be far better to shift road

freight transport to rail. In this sense, such an electrification of the road freight transport would just reduce the potential of pillar 1 “transport shift”.

According to international agreement, for the calculation of the CO₂ emission reduction in the transport sector, BEVs are counted with zero CO₂ emission. But as shown in section 5 below, this approach is far away from reality due to high CO₂ emissions for the construction of batteries and for the production of the electric power mix. **That means, other sectors such as the industry sector for the battery production and the power sector for the power mix production have to bear the CO₂ burden caused by electric mobility in the transport sector. Hence, the GHG export of measures in pillar 3 would be high (see section 5).**

Regardless of this, the CO₂ saving potential of electric mobility for pillar 3 is initially calculated according to the official regulation with zero CO₂ emissions, the so-called **sectoral approach**:

Then, the target corridor of 7 to 10 million electric cars in 2030 would replace 7 to 10 million conventional cars. The average annual CO₂ emission of one conventional car in 2017 was 2.44 t CO₂, according to the sectoral approach (calculation see Tab. 1 and 2). Hence, 7 to 10 million electric cars counted with zero emission for the transport sector would save around **17 to 24 Mt CO₂ for pillar 3** by imputation. The real burden of CO₂ emissions by electric cars to be exported to other sectors is calculated in section 5 below.

Fuel	Fuel consumption of passenger cars in m ³ in 2017 (BMVI, 2018)	Standard density in t/m ³	Fuel consumption of passenger cars in t in 2017	Combustion factor in t CO ₂ per t fossil fuel (UBA, 2016)	CO ₂ emissions of passenger cars in t for fossil fuels in 2017
Gasoline	25.8 million	0.748	19.3 million	3.171	61.2 million
Diesel	21.1 million	0.833	17.6 million	3.167	55.7 million
Sum					116.9 million

Table 1: Calculation of the average annual CO₂ emissions of conventional passenger cars for fossil fuels in 2017 according to the sectoral approach

CO ₂ emissions of passenger cars in t for fossil fuels in 2017	Relative CO ₂ savings by biofuels in 2017 (calculation see below)	CO ₂ emissions of passenger cars in t for real fuels in 2017	Number of passenger cars in 2017 (BMVI, 2018)	Average CO ₂ emission of one passenger car in t for real fuels in 2017
116.9 million	4.54%	111.6 million	45.8 million	2.44

Table 2: Continuation of Table 1: Calculation of the average annual CO₂ emission of one conventional passenger car for real fuels including biofuels in 2017 according to the sectoral approach

With: Relative CO₂ savings by biofuels in 2017 = reduced amount of CO₂ / CO₂ emissions of fossil fuels for road transport = reduced amount of CO₂ / (CO₂ em. of real fuels for road transp. + reduced amount of CO₂) = 7.69 Mt CO₂ (BLE, 2019) / (161.8 Mt CO₂ (UBA, 2019) + 7.69 Mt CO₂) = 0.0454 = 4.54%

Pillar 4 “Renewable fuels” (liquids and gases) is related to just two measures of the German CPP 2030: measures 16 and 24. Thus, pillar 4 is underrepresented in this programme, in spite of being the most important pillar according to this work. As with electric mobility according to the sectoral approach applied here, renewable fuels are counted with zero CO₂ emission in the transport sector. But unlike battery electric mobility, the real CO₂ savings from renewable fuels are actually not that far away from 100%. Already today, the average CO₂ saving of biofuels on the market is 83.8% and for purely waste-based biofuels well above 90% (BLE, 2019). The sustainable potential of renewable fuels by 2030 has been recently calculated for Germany by a study of the DBFZ (Deutsches Biomasseforschungszentrum) (DBFZ, 2019). The ramp-up scenario according to this study is shown in Fig. 2.

The status quo for biofuels in Fig. 2 is in the range of 110 PJ, which fits well with the above mentioned 112 PJ according to MWV, based on 2017 (MWV, 2018). As indicated in Fig. 2 the potential of **renewable fuels** reaches nearly 650 PJ **by 2030**, hence, **about 540 PJ more than 2017**. According to UBA for the sectoral approach, the CO₂ emission factor is 73.1 t CO₂/terajoule (TJ) for fossil gasoline and 74.0 t CO₂/TJ for fossil diesel fuel (UBA, 2016). Taking a share of 766 PJ gasoline and 1620 PJ diesel fuel in 2017 into account (MWV, 2018), the average CO₂ emission factor of fossil road transport fuels in 2017 was about 73.7 t CO₂/TJ.

Hence, **the 540 PJ additional renewable fuels in 2030 represent a saving of about 40 Mt CO₂**, if counted with zero emission like electric mobility according to the sectoral approach.

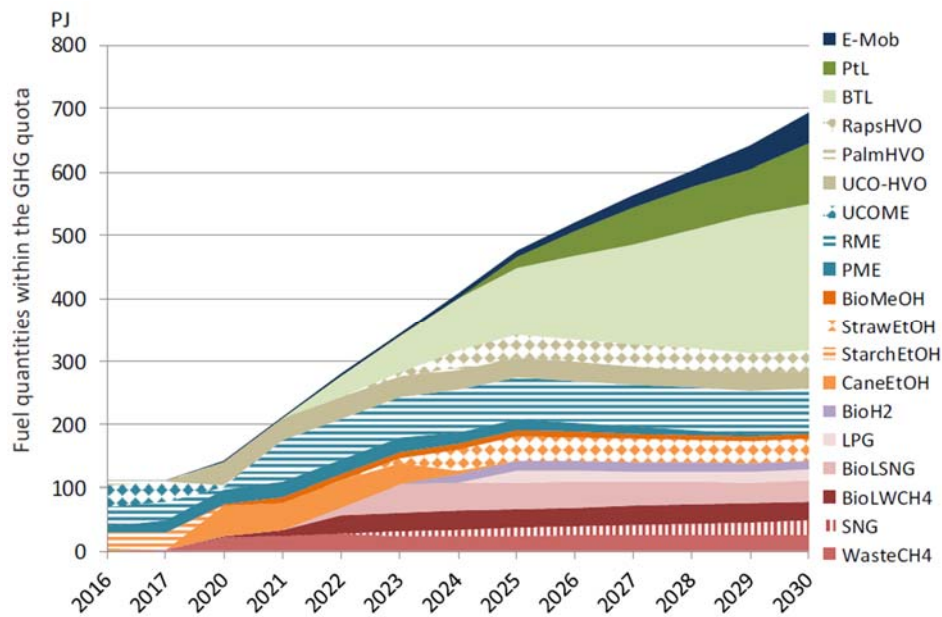


Figure 2: Ramp-up scenario for renewable transport options until 2030 (DBFZ, 2019)

According to surveys at European and international level, the raw material potential for Germany is sufficiently available to sustainably realise a ramp-up of renewable fuels, as shown in Fig. 2, even beyond 2030, if an appropriate import potential is used (IRENA, 2016; S2Biom, 2016; SGAB, 2017; BDI, 2018; Prognos et al., 2018; DBFZ, 2019; UFOP, 2020). The associated technologies are available (ProcessNet, 2018). However, scaling the technologies takes time and needs substantial financial support. Reliable and incentive-creating boundary conditions from the political side are urgently needed for this.

Table 3 summarises the results for the CO₂ saving potential of the four pillars in the German transport sector. Accordingly, **it could be possible to save 79 to 86 Mt CO₂eq in the German transport sector by 2030, compared to 2017**. It should be noted that, in contrast to the BDI study (BDI, 2018), here “renewable fuels” include both liquids and gases, the latter including hydrogen and methane.

This CO₂ saving potential has to be compared with the CO₂ saving target according to the German CPP 2030. As discussed above, the annual German transport CO₂ emissions must be reduced by 70 to 73 Mt down to a level of 98 to 95 Mt in 2030 compared to 2017. In orientation to the BDI study (BDI, 2018), **for further calculation a saving of 71 Mt CO₂ down to a target level of 97 Mt CO₂ in 2030 is assumed, based on 2017**.

Pillar	CO ₂ saving in t by 2030	Source
Pillar 1 “Transport shift”	7 million	(BDI, 2018)
Pillar 2 “Efficiency”	15 million	(BDI, 2018)
Pillar 3 „New drive systems“ (electric vehicles)	17 to 24 million	This work
Pillar 4 “Renewable fuels” (liquids and gases)	40 million	This work
Sum	79 to 86 million	

Table 3: CO₂ saving potential of the four pillars of CO₂ mitigation in the transport sector by 2030 according to the sectoral approach

With pillar 3 values: 17 million t CO₂ saving for 7 million electric cars by 2030
or 24 million t CO₂ saving for 10 million electric cars by 2030

However, further increases in traffic, especially in freight transport, must be considered additionally. For the decade 2020 to 2030, the BDI study assumes a traffic increase of 15 Mt CO₂ compared to 2015 (BDI, 2018) or 8 Mt CO₂ compared to 2017. Hence, this results in **total savings in CO₂ emissions of $71 + 8 = \underline{79 \text{ Mt CO}_2}$ between 2017 and 2030.**

According to Tab. 3, these required 79 Mt CO₂ could be saved by 2030 for both the 7 million electric cars scenario and the 10 million electric cars scenario. **Here, the scenario with as few electric cars as possible is preferable, since the actual CO₂ reduction performance of electric mobility is much worse than that of renewable fuels, as shown in section 5 below.** Therefore, the 7 million electric cars scenario is preferred and illustrated in Fig. 3. But even the unfavourable 10 million electric cars scenario would not change the picture significantly with minus 24 Mt CO₂ by electric vehicles and minus 33 Mt CO₂ by renewable fuels. **In any case, renewable fuels must bear the main burden of CO₂ savings in the transport sector.**

Thus, as results for policymakers, pillar 4 “Renewable fuels” will be the most important pillar for the CO₂ reduction measures of the transport sector. In order to relieve both pillar 3 “Electric vehicles” and pillar 4 “Renewable fuels”, it would be highly desirable to achieve a significant increase in the savings of pillar 1 “Transport shift” towards 20 Mt CO₂. Unfortunately, the benefit of pillar 2 “Efficiency” is very uncertain because rebound effects are to be expected. Finally, in this context it should be noted that the measure “Digitalisation” cannot really be regarded as a climate protection measure for the transport sector, as it would very likely increase CO₂ emissions by increasing power demand for big data processing.

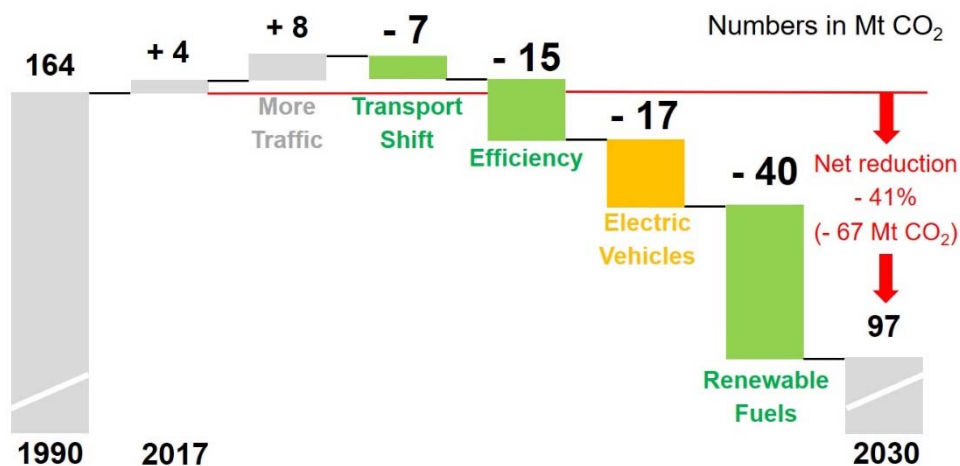


Figure 3: CO₂ reduction potential of different measures in the German transport sector

With: “Renewable fuels” including both liquids and gases; Mt = megatonnes = million tonnes; green coloured columns = measures with no or low GHG export to other sectors or countries; orange coloured column = measures with high GHG export to other sectors or countries

5 The Real CO₂ Emission Reduction Performance of BEVs

Based on the examination of various climate protection measures in section 4, it turns out that the electrification of road transport by BEVs could be the most critical option. Therefore, this extra section is dedicated to it, in particular to investigate its real performance for CO₂ reduction in more detail. Real performance means the WTW performance considering the CO₂ emissions of the upstream chains.

Different studies have calculated the WTW CO₂ emissions of BEVs including the battery production and the power mix generation in comparison with other mobility options. Recently published examples are a study of the Joanneum Research in Graz (JR, 2019; ADAC, 2019a+b) and a study of the Fraunhofer Institute for Solar Energy Systems ISE (Fraunhofer-ISE, 2019).

The Joanneum Research study (JR, 2019; ADAC, 2019a+b) compares vehicles of the Golf class, i.e. vehicles of the size of a Golf type car from VW. With respect to the diesel car, the study considers 7 vol% of biofuels in the diesel fuel. Regarding the electric power for the BEV, the study assumes the official CO₂ emission factor of the German power mix for the starting year 2019 of 580 g CO₂eq/kWh electric power (Bund, 2018). The study further assumes increasing shares of renewable energy in the future power mix, resulting in an optimistic lower CO₂ emission factor of 435 g CO₂eq/kWh by 2030, for example. It should be noted, that the Joanneum Research study does not consider increasing shares of biofuels in the diesel fuel, even ignoring the current legal increase in the proportion of biofuels from 4% to 6% GHG

savings from the beginning of 2020 (BImSchG, 2014). Under these boundary conditions in favour of BEVs the Joanneum Research study concludes that the BEV emits more CO₂ than a diesel vehicle up to a distance of 219,000 km. Only above 219,000 km does the BEV drive more climate-friendly than a diesel vehicle.

The Fraunhofer-ISE study (Fraunhofer-ISE, 2019) comes to a very similar result to the Joanneum Research study. In this case the study compares vehicles of a Hyundai Nexo SUV (Sport Utility Vehicle) size. Concerning a diesel car, the study assumes purely fossil diesel without any biofuel share throughout the whole operation period, which makes the diesel worse than it is today. Regarding the electric power for the BEV, the study assumes a very optimistic average CO₂ emission factor of 421 g CO₂eq/kWh for the decade 2020 to 2030. Thus, the assumptions of the Fraunhofer-ISE study are even more in favour of BEVs compared to the Joanneum Research study. Accordingly, the distance in the Fraunhofer-ISE study is somewhat shorter but still long at almost 160,000 km, until the BEV undercuts the diesel vehicle in CO₂ emissions. Another interesting result of the Fraunhofer-ISE study is that the use of hydrogen as an alternative fuel for operating fuel cell electric vehicles (FCEV) would produce slightly better results regarding CO₂ mitigation than a BEV during the next decade.

Despite these assumptions favouring BEVs (increasing renewable share over time on the power side, but not on the fuel side) in both studies, these very poor results regarding the CO₂ savings by BEVs come out.

Now these results are considered on the time line:

To convert these results from distance in km to time in years, an assumption has to be made about the average annual mileage. The average annual mileage of a German gasoline vehicle is currently about 10,900 km (BMVI, 2018). It can be assumed that BEVs provide less mileage because they are not suitable for long distances. If 10,000 km per year are calculated for an average BEV, then the results of the Fraunhofer-ISE study or the Joanneum Research study mean that it would take more than 16 or 21 years before a BEV even begins to save CO₂ emissions compared to a fossil diesel vehicle or to the status quo of a diesel vehicle respectively. The picture does not change that much, if even very optimistically more mileage for the BEV is assumed. Joanneum Research for example assumes 15,000 km per year (JR, 2018). But even then, it would take more than 14 years for a BEV to compensate for the additional CO₂ emissions for its production compared to a status quo diesel vehicle.

This enormous delay of more than 14 to 21 years in climate protection caused by BEVs corresponds to a “no-action” scenario lasting over more than 14 to 21 years. Such a delay contradicts the mathematics of climate protection. It is not

acceptable in view of the short time available for GHG reduction to zero. Accordingly, a BEV scenario for the transport sector is even worse than an 8.5 years “no-action” scenario (compare Fig. 1). This is illustrated in Fig. 4.

Measures with a delay effect beyond this period of 8.5 years should in principle be ruled out. **Under these boundary conditions the BEV measure would therefore no longer be suitable as an effective climate protection measure.** It would be too late for that.

Quite apart from this, such a period of 14 to 21 years would come to the limits of the lifetime of cars and batteries, especially against the background of the increasing use of rapid charging points, which place a particular strain on batteries. Moreover, the optimistic assumption of both studies that the renewable share in electricity will increase steadily until 2030 is by no means a matter of course for Germany. Realistically, one would even have to assume a deterioration in the German electricity mix in the next few years, as nuclear power plants are being shut down and will have to be replaced by fossil gas-fired power plants. The expansion of renewable electricity is not keeping pace with the planned increase in demand.

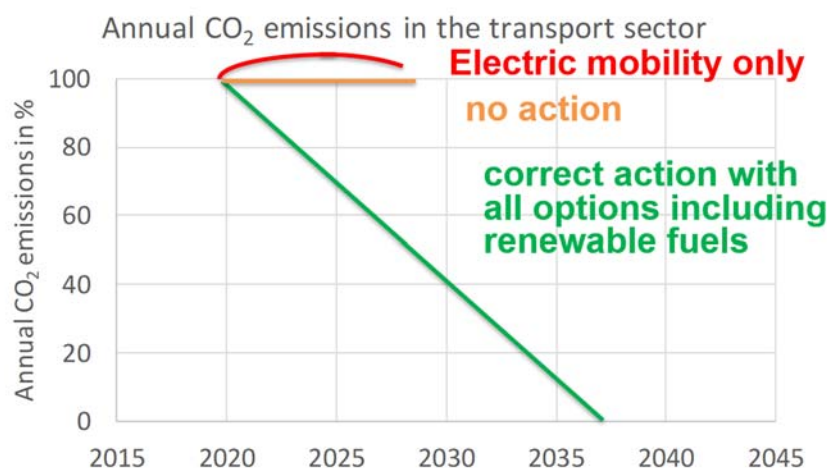


Figure 4: Scenarios “electric mobility only”, “no action” and “correct action” for CO₂ emissions in the German transport sector, according to a WTW analysis

Because of the importance and scope of the conclusions drawn from the results of the two studies of Joanneum Research and Fraunhofer-ISE, the following simple model calculation is intended to make the possibly much-doubted results of these studies plausible:

Two small cars, an Opel Corsa diesel vehicle and a Renault Zoe BEV, the currently best-selling BEV in Germany, shall be compared in the model calculation as examples.

The WLTP (Worldwide harmonized Light vehicles Test Procedure) fuel consumption of an Opel Corsa 1.5 Diesel Edition is 4.0 litres per 100 km (ADAC, 2020). Assuming pure fossil diesel fuel, the official emission factor of 95.1 g CO₂eq/MJ including upstream production chains (BLE, 2019) corresponds to an emission factor of 3.36 kg CO₂eq/litre at 25 C. the resulting **emission of the Opel diesel car** would be **134 g CO₂eq/km with pure fossil diesel fuel**.

For comparison the BEV is calculated: The power consumption of a Renault Zoe LIFE Z.E. 40, with a battery capacity of 41 kWh, is 20.3 kWh per 100 km including charging losses, according to an ADAC test (ADAC, 2018). With the official emission factor of 580 g CO₂eq/kWh for the German power mix in 2019 (Bund, 2018), the resulting **emission of the Renault BEV** would be **118 g CO₂eq/km without considering CO₂ emissions for the battery production, the so-called “battery rucksack”, coming on top**.

That means, **even without taking the CO₂ emission of the battery production into account, the CO₂ saving factor of the BEV is poor at 12%** compared to the fossil diesel car. In contrast, **the CO₂ saving factors of average biofuels are already much higher at 83.8% in 2018** with increasing tendency (BLE, 2019). Even assuming a very optimistic emission factor for electric power of about 400 g CO₂eq/kWh by 2030, the emission saving factor of the calculated BEV would not be better than 40% compared to a fossil diesel car. Thus, the CO₂ mitigation performance of renewable fuels will be much better than that of electric mobility in the long run.

Now, the additional CO₂ emissions for battery production of the BEV have to be considered. What counts is the difference of the CO₂ emissions between a BEV and a combustion car. According to the calculations of Joanneum Research (JR, 2019; ADAC, 2019) the production of a BEV with a battery capacity of 35 kWh emits around 5 t more CO₂eq than the production of a combustion car, based on a Golf-class. The Renault Zoe from this model calculation example has a battery with a slightly higher capacity of 41 kWh. In favour of the BEV, the same difference of 5 t CO₂ load is assumed for this calculation example. Thus, considering the difference of CO₂ emissions by driving being (134 – 118) g CO₂eq/km = 16 g CO₂eq/km, around 300,000 km would have to be driven to compensate for this additional load of the BEV battery rucksack compared to a pure fossil diesel car, if neither the power mix nor the fuel mix is changed over time. If increasing shares of renewable power in the next decade are assumed considering a CO₂ emission factor of 508 g CO₂eq/kWh as an average between 580 g CO₂eq/kWh for 2019 and 435 g CO₂eq/kWh for 2030 according to Joanneum Research (JR, 2019), then around 160,000 km or 210,000 km would be necessary to compensate the BEV battery rucksack compared to a car with fossil diesel fuel or with biofuel-diesel blend, the latter

with 6% less GHG emissions according to German law (BImSchG, 2014). These results of the simple model calculation show that the results of the above discussed studies by Joanneum Research and Fraunhofer-ISE are comprehensible, based on the given boundary conditions. This also supports the conclusion discussed above that BEVs can no longer be considered an effective climate protection measure for Germany.

Proponents of electric mobility, who could argue that battery construction emits less CO₂ than assumed by Joanneum Research and Fraunhofer-ISE, should note that even a very optimistic assumption of only half of the 5 t additional CO₂ emissions for the construction of a BEV compared to a diesel vehicle would not fundamentally change the picture. Then the delay effect of BEVs would still be in the range of unacceptable 7 to 11 years before the first CO₂ savings compared to the status quo would start. Even a delay of 4 years, for example, would be in contradiction to the mathematics of climate protection. Furthermore, the unilateral promotion of electric mobility would not include the large existing fleet in climate protection, which would again contradict the mathematics of climate protection. Finally, it should be noted that BEVs not only fail to meet the "no delay" criterion. The other two criteria essential for climate protection, "no GHG export" and "fast roll-out", could not be met in time either. Regarding the former criterion, the BEV concept would export significant CO₂ emissions both to the industrial sector or to other countries for battery construction and to the energy sector for electricity production. As far as the latter criterion is concerned, the BEV concept is basically not suitable for a fast roll-out throughout the world because, on the one hand, most countries lack the necessary infrastructure and renewable electricity and, on the other hand, raw material limitations such as cobalt and other rare elements stand in the way. The BEV concept is also fundamentally unsuitable for countries with large areas and long distances outside cities.

As results for policymakers it should be noted, that BEVs cannot be regarded as a climate protection measure in the transport sector at least during the next decade. More than the calculated CO₂ emissions saved in the transport sector according to the sectoral approach described in section 4 are exported to other sectors or countries where the batteries are built and the electricity is produced. The situation might get better, with increasing shares of renewable energy in the power mix. But the expected speed of expansion of renewable energy in the power sector is not keeping pace with the planned expansion of electric mobility. In view of the shutdown of nuclear power plants in Germany over the next three years, the situation will probably even worsen in the meantime, because the remaining coal-fired power plants will have to bear a heavier burden or new fossil fuel power plants in the form of gas-fired power stations must also be used.

6 Conclusion

The mathematics of climate protection shows that there is little time left to reduce greenhouse gases. In the case of a no-action scenario, the CO₂ budget for the 1.5-degree target will be exhausted in 8.5 years. In the case of a linear CO₂ reduction to zero, referred to as “correct-action” scenario, there are 17 years left. Therefore, humanity must not allow itself to make mistakes in the choice of measures for climate protection. The measures should at least meet the criteria “no delay”, “no GHG export” and “fast roll-out” as far as possible, as discussed in section 2.

A closer look at the regulatory framework and climate protection programmes in the transport sector reveals a lack of technological neutrality both at German and European level. There is thus an acute risk that the potential of important appropriate measures will be lost. A strong focus on electric mobility can be observed. For example, in Germany exorbitant financial resources are already planned to support the purchase of electric cars. On the other hand, there is no dedicated allocation of funds to support the introduction of renewable fuels. Rather, there are already legal frameworks that hinder the introduction of renewable fuels. These include the non-inclusion of the standard DIN EN 15940 in the new BImSchV (BImSchV, 2019), which means that paraffinic renewable fuels are strongly discouraged. On the European level the most critical measure is the EU fleet regulation for CO₂ emissions or the EU fleet limit value system (EU, 2019), where BEVs are counted with zero emission, but renewable fuels are not considered at all.

These rules in Germany and Europe need to be corrected urgently. In this respect, WTW data with the CO₂ emissions of the upstream chains should be considered.

A detailed analysis of the CO₂ reduction potential of various measures shows that renewable fuels will have to bear by far the greatest burden. It would be desirable if traffic shift from road to rail and water could also assume a larger share of CO₂ savings. Therefore, both renewable fuels and traffic shift should be promoted by political framework and regulations with particular intensity.

However, the effectiveness of some measures is doubtful. These include the digitalisation of traffic, which is likely to increase the power consumption for processing big data, but also improvements in drive system efficiency, which could possibly be neutralised by underestimated rebound effects.

A WTW analysis of the CO₂ reduction performance leads to the conclusion that battery electric vehicles (BEVs) fail as a climate protection measure due to a delay in real CO₂ savings of far too many years. Therefore, the delay stretches the duration of the no-action period too far and misses the “no delay” criterion. BEVs also miss the

“no GHG export” criterion by exporting more CO₂ emissions to other sectors or countries for the construction of the batteries and the production of the used electric power than is mathematically saved in the transport sector, according to the sectoral approach. Finally, a unilateral BEV concept also fails to meet the criterion “fast roll-out” because it ignores the different requirements and conditions of many countries, resource limitations and the participation of the large existing fleets. Accordingly, BEVs can no longer be considered an appropriate climate protection measure at least during the next decade in the context discussed.

It should be underlined that this analysis is not generally directed against electric mobility. It may have several advantages in urban areas, for example, which will not be denied here. This analysis is primarily concerned with performance in climate protection. In order to bring out the advantages of electric mobility without having to accept critical disadvantages, electric cars should in future be subject to the same strict sustainability criteria as renewable fuels are already today.

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