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Transportation Research Procedia 72 (2023) 2784–2791

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Decarbonizing the German transport sector: Why the 2030 sector targets are likely to be missed

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Abstract

In order to meet its 2030 climate sector target, the German transport sector must experience a trend reversal and reduce its greenhouse gas emissions drastically. Envisioned technological solutions vary between different modes of transport and technological readiness. By making use of an integrated model chain we examine possible short-run emission reductions for different technology pathways. Through fleet and transport demand modeling we provide final energy demand and CO_2 emissions of the sector at five-year intervals. Modeling results show short-run emission reductions mainly in passenger car traffic. However, all technology pathways overshoot the 2030 sector target considerably. Consequently, ambitious measures that induce an avoidance and shifting of trips must complement the rapid ramp up of electric powertrains to meet the sector target.

Keywords: Decarbonizing the transport sector; German 2030 sector target; CO_2 emissions; zero emission powertrains

1. Introduction

While Germany reduced its total greenhouse gas emissions (GHG emissions) by 35 percent between 1990 and 2019, the German transport sector did not record any emission savings. The stagnating emissions of the sector in this period result from two opposing trends. On the one hand, efficiency gains of vehicles have reduced specific emissions, i.e. CO_2 emissions per vehicle kilometer. On the other hand, transport demand, i.e. passenger kilometers and tonne kilometers, have increased significantly. As a result, GHG emissions of the sector have increased by 0.4 percent between 1990 and 2019 (German Environment Agency, 2022a).

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10.1016/j.trpro.2023.11.821

Compared to the pre-Corona year 2019, the sector's GHG emissions dropped by 11 percent in 2020 due to pandemic mitigation measures. Reductions varied widely between individual emitters. GHG emissions from domestic aviation dropped by 53 percent, domestic navigation by 11 percent, road transport by 10 percent, and rail transport by 6 percent (German Environment Agency, 2022a). Road transport is by far the sector's biggest emitter, accounting for 98 percent of total GHG emissions. Accordingly, final energy and GHG emissions of the transport sector are driven by road transport.

In 2021, GHG emissions increased by 2 percent as the sector was still influenced by measures to contain the pandemic. Evidence by both fuel sales figures and traffic counts suggests that the sector's reduced GHG emissions are mostly due to still significantly less passenger car traffic (German Environment Agency, 2022b).

Germany's Federal Climate Change Act (KSG) requires the transport sector to reduce its GHG emissions by around 48 percent until 2030 compared to the 1990 level. The sector's emissions must then not exceed 85 Mt CO_2 equivalents (German Bundestag, 2019). Against the background of the stagnant development of GHG emissions over the past 30 years, a halving of those emissions in less than ten years represents a challenging trend reversal. In 2021, the sector missed its KSG sector target which puts pressure on the government to set up an immediate climate action program.

Within the Kopernikus-project Ariadne, we analyzed technology pathways that bring the sector's GHG emissions down and reach zero direct GHG emissions in 2045 (Luderer et al., 2021). Through fleet and transport demand modeling, we project GHG emissions at five-year intervals for four technology pathways. This way, we are able to make statements about possible short-run emission reductions until 2030. The technology pathways include measures that accelerate the diffusion of new technologies, e.g. EU CO_2 emission standards, ambitious CO_2 prices, or purchase premiums. Measures that foster an avoidance or shifting of trips to other modes of transport are implemented only to a small extent, as the focus of the projection analysis is on technology pathways.

Considered technology pathways comprise key technologies whose role in the decarbonization of the transport sector is being discussed at the moment. Firstly, the direct use of electricity through battery electric vehicles (BEVs). Secondly, the use of electricity to produce green hydrogen which powers fuel cell electric vehicles (FCEVs). And thirdly, the use of electricity to produce green hydrogen which, together with CO_2, is used to produce e-fuels that power internal combustion engine vehicles (ICEVs). Technology pathways are defined such that a specific technology is pushed primarily through implemented measures or assumptions on technology costs or infrastructure availability. A technology mix scenario offers a less pronounced push towards one specific technology but promotes a bundle of technologies. The four technology push pathways are defined as "mix", "direct electrification", "H_2", and "e-fuel".

2. Methodology

We make use of an integrated model chain that combines agent-based simulations of fleet composition and transport demand in order to calculate final energy demand and CO_2 emissions of the German transport sector at five-year intervals.

Future vehicle fleets are modeled by the Vehicle Technology Scenario Model (VECTOR21). VECTOR21 considers vehicles with different technical-economic characteristics, differentiated by powertrain configuration and vehicle segment. On the demand side, VECTOR21 maps driving behavior and preferences for different buyer groups (e.g., availability of charging infrastructure and acceleration behavior of vehicles). In addition, developments of external factors of the vehicle market are included, such as EU CO_2 emission standards, availability of charging and refueling infrastructure, vehicle technology costs as well as fuel and electricity costs. The main output of VECTOR21 is the projection of market shares of different powertrains (diesel, gasoline, plug-in hybrid electric vehicles (PHEVs), BEVs and FCEVs) and different vehicle segments (small, medium and large) from now until 2050.

Transport demand is modeled using the German national transport model Deutschlandmodell (DEMO) consisting of several submodels. For passenger transport we apply a spatially fine-grained, macroscopic transport model (Winkler and Mocanu, 2017). Trip generation (resulting in the number of trips), trip distribution (destination choice resulting in the distance of trips), and mode choice (resulting in the mode shares) are modeled. Two submodels differentiate between short- and long-distance trips and consider all relevant modes of transport, including non-motorized transport. Different trip purposes are also differentiated. For freight transport, transport demand is determined using a time series model based on observed chain-linked transport demand together with observed and projected German gross domestic product (GDP). An exception is waterway-bound freight traffic, whose transport service is assumed to be constant in view of the reduced infrastructure expansions. The main outputs from transport demand modeling are total passenger, tonne and vehicle kilometers by mode.

Fleet and transport demand modeling results are combined with real driving energy consumptions of the respective powertrains to calculate final energy demand. Emission factors of the respective energy sources are used to determine tank-to-wheel CO_2 emissions of the sector.

Model assumptions differ between the four technology pathways considered. This way, we operationalize the technology push towards one of the technologies considered. Key model inputs and technology pathway assumptions are listed in the appendix.

3. Results

In this section, we present results along the modelling chain. Based on modeled fleet composition and transport demand final energy demand and CO_2 emissions are illustrated for the four technology pathways considered. Due to their dominating relevance for final energy demand and CO_2 emissions, fleet composition results are displayed for passenger cars and trucks only.

3.1. Fleet composition

3.1.1. Passenger cars

Following the steady trend of previous years, the size of the passenger car fleet in Germany continues to increase in all technology pathways. This is due to continuing income growth and its effect on car ownership, especially within the age groups above 40 years, as well as to the absence of strong measures that promote lower car ownership.

BEVs and PHEVs gain stock shares in all technology pathways pushing back ICEVs. BEVs are the dominant powertrain technology steadily gaining stock shares while PHEV shares increase more slowly and reach their maximum in 2035. In the direct electrification pathway, stock shares of BEVs and PHEVs increase most quickly. They account for 62 percent of new sales in 2025 with a BEV share of 45 percent. FCEVs play a role only in the H_2 pathway and only after 2040. In the e-fuel pathway, BEVs and PHEVs gain smaller stock shares implying a slower pushing back of ICEVs. In 2030, BEVs make up between 19 percent (H_2) and 25 percent (direct electrification) and PHEVs 10 percent of the passenger car stock. Figure 1 illustrates the composition of the passenger car stocks for all technology pathways.

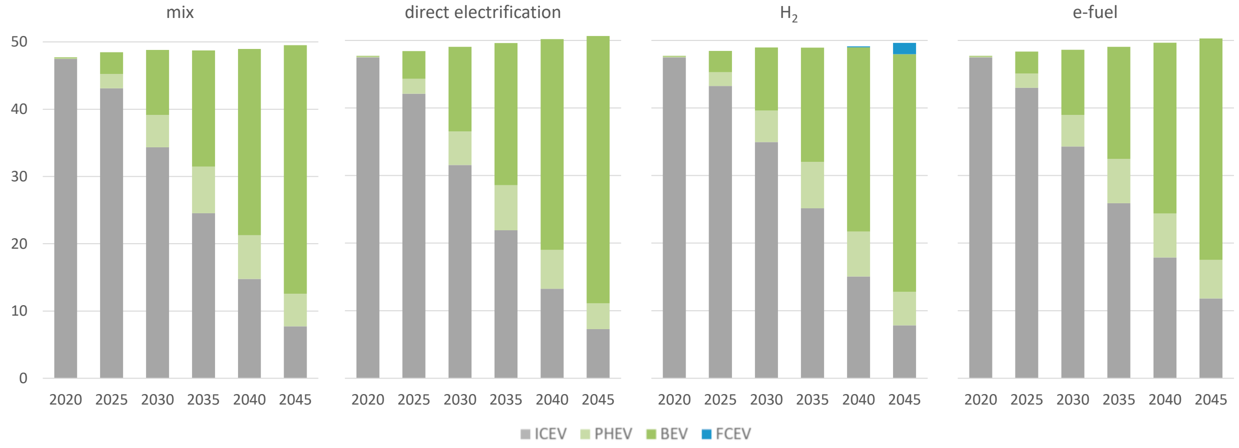

Figure 1: Passenger car stocks by powertrain and technology pathway [million]

3.1.2. Trucks

By 2045, the number of trucks in use increases significantly as freight transport performance increases. Modeling results show a much more prominent role of indirect electrification (hydrogen and e-fuels) compared to passenger transport across technology pathways. The long-term diffusion of FCEVs is more pronounced and faster than in the passenger car segment. This is due to comparative cost advantages and shorter durations that trucks stay in the fleet. Direct electrification primarily affects smaller or lighter trucks (up to and including 7.5 t), which account for a total share of around 78 percent of the truck fleet. However, the diffusion of alternative powertrains in the truck stock starts later compared to passenger cars. In 2030, BEVs and FCEVs combined represent only 3 to 5 percent of the truck stock. The e-fuel scenario shows high market potentials for ICEVs running solely on e-fuels under the scenario assumption that these are considered zero-emission vehicles under the EU CO_2 fleet targets starting from 2030. Figure 2 illustrates the composition of the truck stocks for all technology pathways.

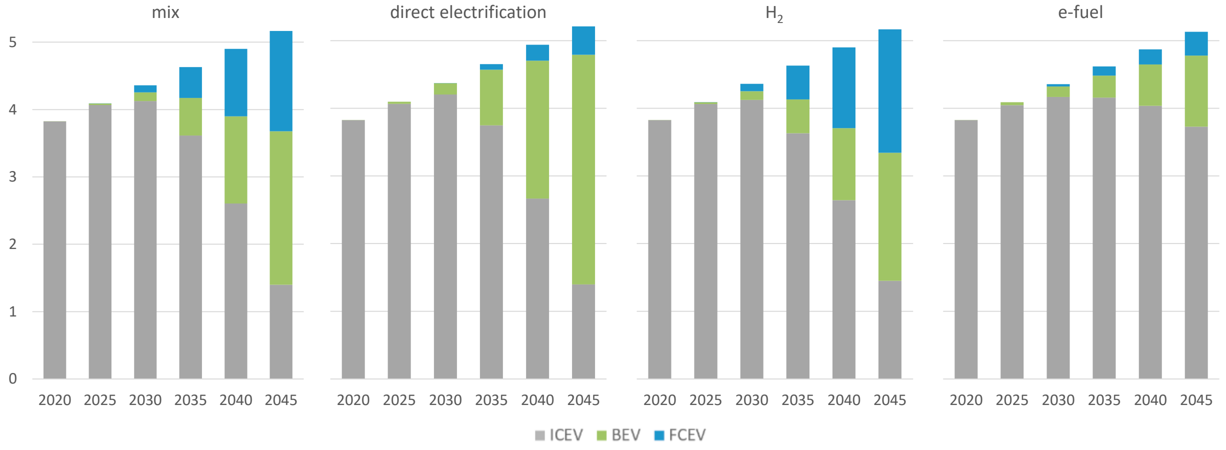

Figure 2: Truck stocks by powertrain and technology pathway [million]

3.2. Transport demand

3.2.1. Passenger transport demand

DEMO forecasts an increasing passenger transport demand. The key driver stipulating transport demand is the growing gross domestic product (GDP). Until 2045, passenger transport demand increases by about 10 percent across all technology pathways. Due to the absence of strong measures promoting a modal shift, passenger transport mode shares are predicted to remain similar to the current situation.

However, road transport demand slightly decreases until 2030. This is due to higher energy prices evoked by the sharp increase of the CO_2 price affecting a large share of the ICEVs in the stock. As ICEV stock shares decrease, the CO_2 price loses its effect on energy prices and, consequently, road transport demand. Figure 3 illustrates yearly passenger transport demand by transport mode and technology pathways.

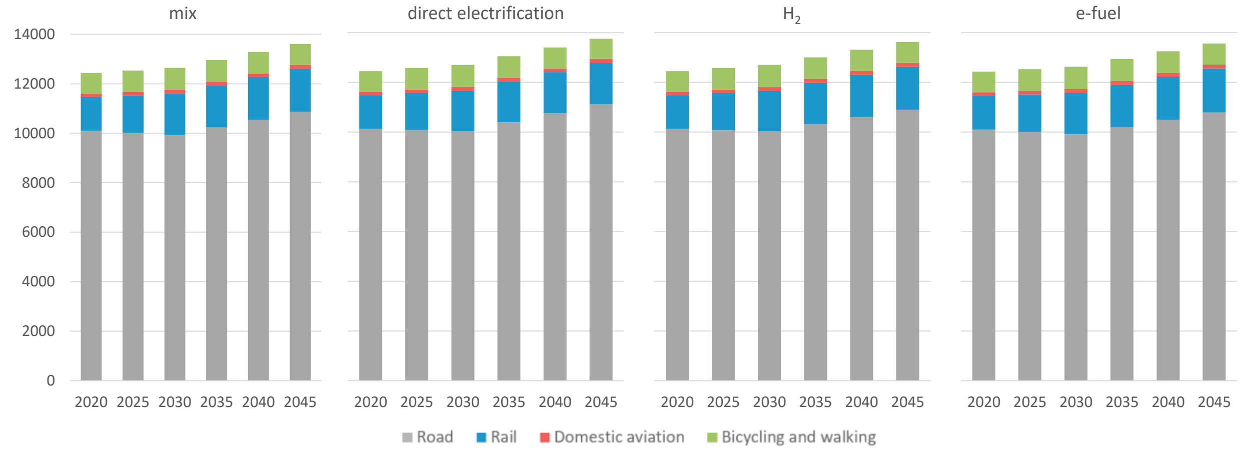

Figure 3: Passenger transport demand by transport mode and technology pathway [billion passenger kilometers p.a.]

3.2.2. Freight transport demand

Freight transport demand is projected to increase significantly. As historic data on freight transport demand and GDP are highly correlated, this increase can be explained by the expected GDP growth. Until 2045, freight transport demand increases by about 30 percent across all technology pathways. Increasing real transport costs on the road are predicted to lead to a moderate modal shift to rail.

Until 2030, freight transport demand increases by about 10 percent across all technology pathways. Figure 4 visualizes yearly freight transport demand by transport mode and technology pathways. An effect that can be observed in the mix, H_2, and e-fuel pathway is that a significant modal shift takes place from road to rail in 2035. This results from the assumption that the prices of hydrogen and e-fuel are higher than those of diesel.

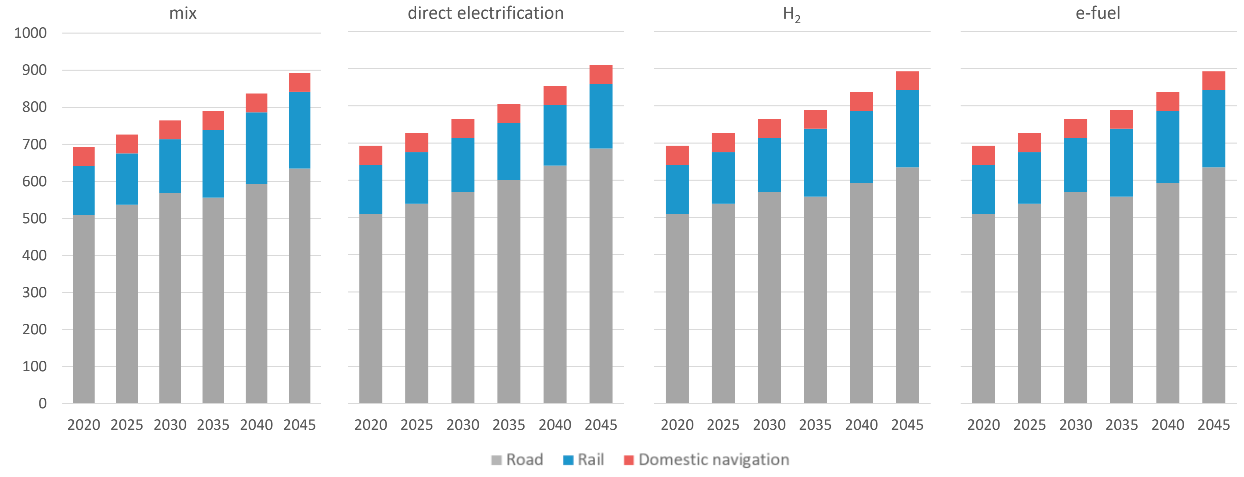

Figure 4: Freight transport demand by transport mode and technology pathway [billion tonne kilometers p.a.]

3.3. Final energy demand

Despite the increase of transport demand both in passenger and freight transport, final energy demand of the sector drops substantially across all technology pathways. This is mainly due to the lower energy consumption of electric powertrains compared to internal combustion engines.

Until 2045, final energy demand decreases by an average of 46 percent to 359 terawatt hours (TWh) per year. With the highest diffusion of electric powertrains, the lowest energy demand is projected in the direct electrification pathway (341 TWh) and the highest in the e-fuel pathway. This difference does not include the energy demand that incurs in the production of e-fuels.

Final energy demand shifts away from liquids to electricity in all technology pathways. In 2045, final energy demand for electricity lies between 177 and 223 TWh. Liquids remain an important energy source even in 2045 with a demand of 100 to 175 TWh equaling the demand for CO_2 neutral fuels. Demand for green hydrogen is projected to vary between 15 and 75 TWh. Figure 5 illustrates final energy demand of the sector by energy source and technology pathway.

Until 2030, final energy demand decreases by 18 (H_2) to 22 percent (direct electrification). This is mainly due to the diffusion of electric powertrains and, consequently, efficiency gains of passenger cars. Due to the later diffusion of electric powertrains in trucks, final energy demand of trucks does not fall until 2030. Therefore, high demand for liquids combined with the low availability of e-fuels implies a high dependence of the sector on fossil fuels in 2030.

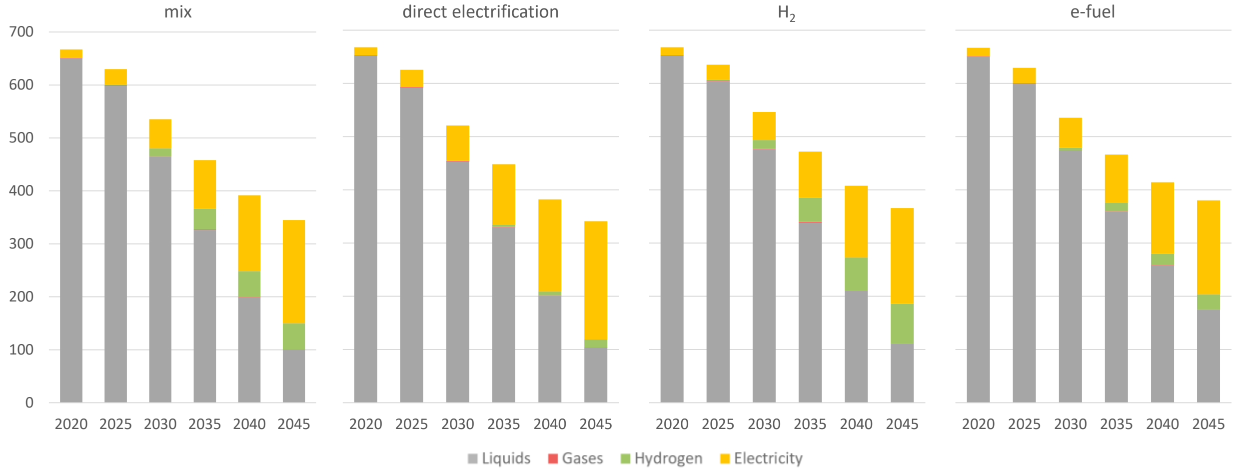

Figure 5: Final energy demand by energy source and technology pathway [TWh p.a.]

3.4. CO_2 emissions

As they represent 99 percent of GHG emissions of the transport sector, we focus on CO_2 emissions in this subsection (German Environment Agency, 2022b). In the long-run, all technology pathways achieve, by scenario definition, complete decarbonization of the transport sector in 2045. This is achieved through the diffusion of electric powertrains and a supply of CO_2 neutral liquids that power the remaining ICEVs.

However, high short- and medium-run dependency on fossil fuels implies a slow decrease of CO_2 emissions until 2030. The 2030 KSG sector target is missed by all technology pathways. The target is overrun by 23 Mt CO_2 or 27 percent on average. CO_2 emissions of the sector amount to between 103 (e-fuel) and 114 Mt CO_2 (H_2) Due to the highest assumed blending of e-fuels CO_2 emissions are the lowest in the e-fuel pathway.

Similar to final energy demand, emissions decrease by 2030 especially in passenger car traffic. Emissions from trucks continue to increase in the short-run before trucks start to contribute to emission reductions of the sector from 2030 on. Emissions from buses, rail, domestic aviation and domestic navigation are of low relevance to the sector's total emissions and, consequently, their leverage for achieving the 2030 sector target is low. Figure 6 shows yearly CO_2 emissions by transport mode and technology pathway.

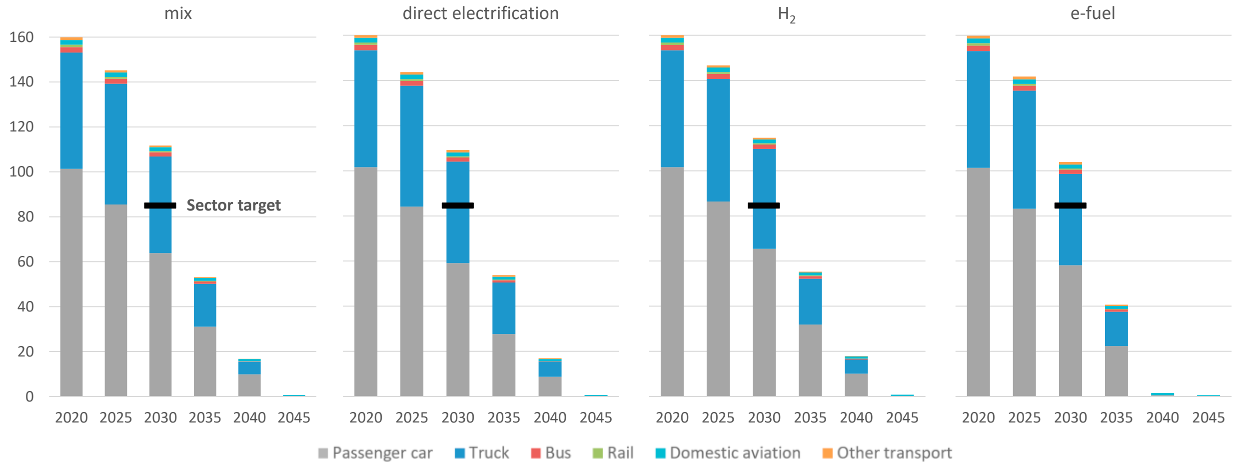

Figure 6: CO_2 emissions by transport mode and technology pathway [Mt CO_2 p.a.]

3.5. Robustness of the results

Within the Ariadne project (Luderer et al., 2021), three energy system models (REMIND, REMod, TIMES) supplement our technology pathway projections (DLR) presented above. They provide comparative data for the development of the transport sector through strategic optimization models that calculate optimal investment paths for all sectors from a macroeconomic perspective considering a CO_2 budget available. They do not simulate any change in explicit transport policy framework conditions.

Results of the optimization models identify similar reduction curves for the transport sector. 20 out of 22 total model runs overshoot the 2030 sector target. Two exceptions are model runs with a much higher number of electric vehicles and with a higher availability of e-fuels in 2030. Figure 7 depicts projected CO_2 emissions of the transport sector for all scenarios (line colors) by all models (line types). KSG new depicts the current sector target, KSG depicts the old target before the law's amendment in 2021.

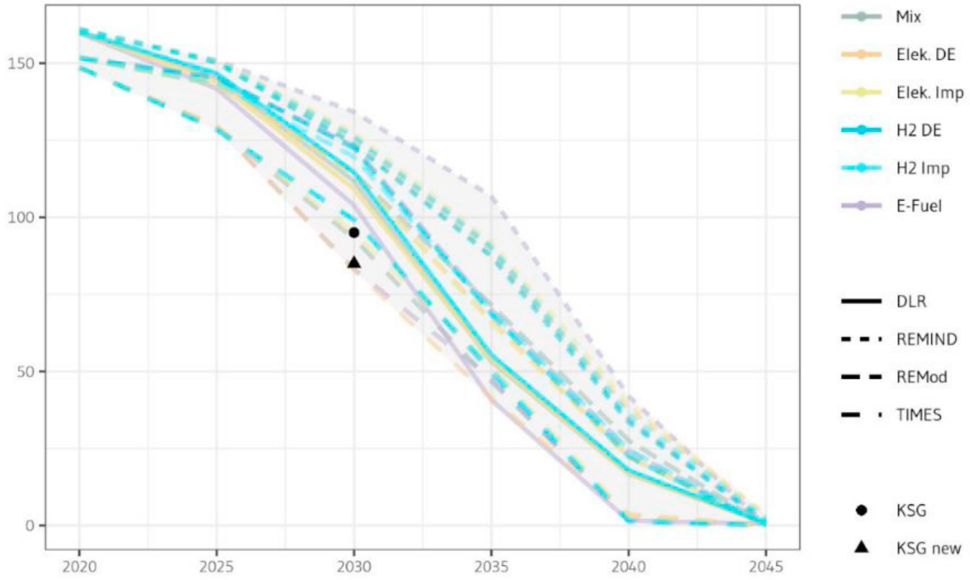

Figure 7: Transport CO_2 emissions of all considered models [Mt CO_2 p.a.]. (Luderer et al., 2021).

4. Discussion and Conclusion

Through an integrated model chain, we provide CO_2 emission trends of the German transport sector. Long-term decarbonization of the sector until in 2045 is reached through the electrification of powertrains combined with the supply of CO_2 neutral liquids for the remaining ICEVs in vehicle stocks. BEVs are the dominant technology in passenger car traffic and feature the highest potential to bring down emissions quickly.

However, the 2030 KSG sector target is missed by all technology pathways. With an average of 27 percent, the overshooting of the target is considerable. The short-term reduction potentials through an exchange of powertrains are limited by the longevity of existing and new bought ICEVs in the near future. Emission reductions in passenger car traffic need to compensate for only limited emission reductions from trucks. A sole focus on technologies will not ensure the emission reductions necessary. Consequently, ambitious measures that promote a chance of mobility behavior by avoiding or switching trips to other modes of transport must be implemented.

Modeling results show that the use of green hydrogen and e-fuels is necessary to decarbonize the sector in the long-run. However, their emission reduction potential until 2030 is limited due to availability constraints. Final energy demand of the sector increases when green hydrogen and e-fuels are used instead of the direct use of electricity. This higher energy demand does not include the energy that is needed to produce these energy sources.

The technology pathways considered provide decision makers with comprehensive insights on future final energy demand and CO_2 emissions of the transport sector and, in this way, give orientation with regard to possible short-run emission reductions and the need for ambitious immediate climate action programs.

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Appendix A. Modeling assumptions (excerpt)

	mix	**direct electrification**	**H_2**	**e-fuel**
CO_2 price	2025: 100€, 2030: 200€, 2045: 500€			
CO_2 fleet targets for cars, by 2030	-50%	-50%	-50%	-50% (credits for e-fuels)
Purchase premiums for cars	9000€ for small and medium BEVs and FCEVs until 2025			
Promotion for trucks	Vehicle tax exemption, purchase premium and toll exemption for BEV and FCEV until 2025, reduced toll rate until 2035			
CO_2 fleet targets for trucks	-31% for light and -30% for heavy duty trucks by 2030	-31% for light and -30% for heavy duty trucks by 2030	-31% for light and -30% for heavy duty trucks by 2030	-31% for light and -30% for heavy duty trucks by 2030 (credits for e-fuels)
Energy costs for cars	15 ct/km	14 ct/km	14 ct/km	15 ct/km
E-fuel blending	from 2023 1%, until 2045 >90% (added to biofuel blend)	from 2023 1%, until 2045 >90% (added to biofuel blend)	from 2023 1%, until 2045 >90% (added to biofuel blend)	from 2023 1%, until 2040 >90% (added to biofuel blend)