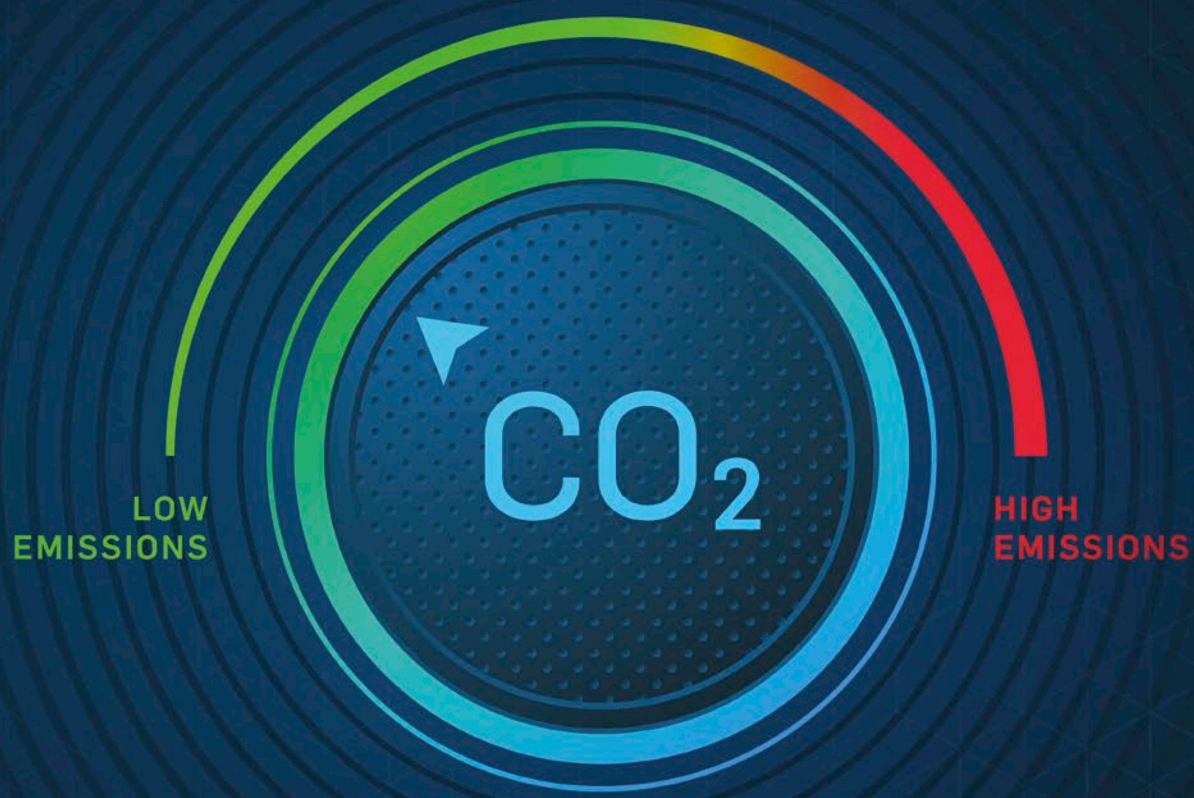
FVV PRIME MOVERS. TECHNOLOGIES.

Six theories on climate neutrality in the European transport sector

Observations from the FVV Fuel Study
›Transformation of mobility to the GHG-neutral post-fossil age‹



FVV

Sustainability is more than just climate protection

Boundary conditions for sustainable mobility

This theoretical paper comprises the key findings from a study commissioned by FVV and conducted by Frontier Economics and ifeu and specifies the resultant needs for action. As in every study that uses models to predict future developments, the results are dependent on the boundary conditions that were set at the beginning. The assumptions upon which this study is based do not follow a single political ideal, but are based on scientific facts and the non-partisan Sustainable Development Goals set out by the United Nations.

The most important boundary conditions for sustainable mobility

The 17 Sustainable Development Goals set out by the United Nations* must be achievable around the globe and for all people. As combustion engines to date have primarily been powered with fossil fuels, particular importance is placed on the 13th goal: taking urgent action to combat climate change and its impacts. However, other Sustainable Development Goals (SDGs) must also be taken into account, particularly affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, sustainable consumption and production and global partnerships.

There are no ›good‹ or ›bad‹ technologies. The benchmark set out by FVV for technologies to defossilise the transport sector is solely the degree to which they can contribute to reaching the goals of the Paris Agreement without coming into conflict with other SDGs. In this regard, technology neutrality does not mean keeping all options open and not making any decisions, but assessing various existing options based on their climate effectiveness and the associated economic costs.

The goals of the Paris Agreement must be achieved. Simply eyeing a period x after which no more greenhouse gases are released into the atmosphere is not conducive to reaching the goals. As CO_2 remains in the atmosphere for a long period of time, the decisive factor in achieving the climate targets (›well below 2°C‹) is the degree to which the various transformation paths on the journey to this goal impact the remaining global CO_2 budget – regardless of which sector the emissions are generated in.

Germany will only meet its goals as part of Europe. Solely observing the balance in Germany is not a sensible approach given the close political and economic links within Europe, as well as the increasing amount of cross-border transport. The FVV study therefore calculates the development of greenhouse gas emissions from the entire European transport sector (EU27 and the UK) in various scenarios.

* More about the UN Sustainable Development Goals on pages 4 – 5

There is still strong demand for individual mobility. Individual mobility is a fundamental right of all citizens in a democratic and free society. Changes to mobility behaviour or the selection of certain technologies will only be successfully established if they benefit the people. We assume that individual mobility must be designed to be both sustainable and affordable.

42 possible transformation paths

The FVV study combined the following paths – solely based on sustainable solar and wind energy – and assumed 100 per cent fleet penetration* by 2050:

7 combinations of powertrains and CO_2-neutral energy carriers
→ Battery electric powertrain | electricity
→ Fuel cell | hydrogen
→ Combustion engine | hydrogen
→ Combustion engine | dimethyl ether (DME)
→ Combustion engine | methane
→ Combustion engine | Fischer-Tropsch fuel
→ Combustion engine | methanol

2 ways to generate electricity or fuels
→ Within the European Union (EU27 and the UK)
→ Internationally at sunny/windy locations

3 efficiency classes in vehicle technology
→ Status quo: current level of series production or estimate of scale effects
→ Balanced: use of additional technologies with a positive cost-benefit ratio, e.g. hybridisation of combustion engines
→ All-in: use of all known technologies to increase efficiency, e.g. lightweight chassis construction

* The study consciously works with theoretical 100 per cent scenarios, albeit hardly realistic or desirable, as these enable an excellent comparison of the technical and economic impact of individual technology paths.

The 17 Sustainable Development Goals of the United Nations

»Decisions almost always come down to sustainability.« In 2015, the United Nations published its Agenda 2030, setting out 17 global Sustainable Development Goals. These goals are intended not just for governments around the world, but also for civilians, the private sector and science. With this in mind, FVV bases its orientation studies around six UN Sustainable Development Goals, each of which is given equal weighting.

FVV pursues the following Sustainable Development Goals on the path to climate neutrality:

7 Ensure access to affordable, reliable, sustainable and modern energy for all.

8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

9 Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

12 Ensure sustainable consumption and production patterns.

13 Take urgent action to combat climate change and its impacts.

17 Strengthen the means of implementation and revitalise the global partnership for sustainable development.

SUSTAINABLE DEVELOPMENT GOALS

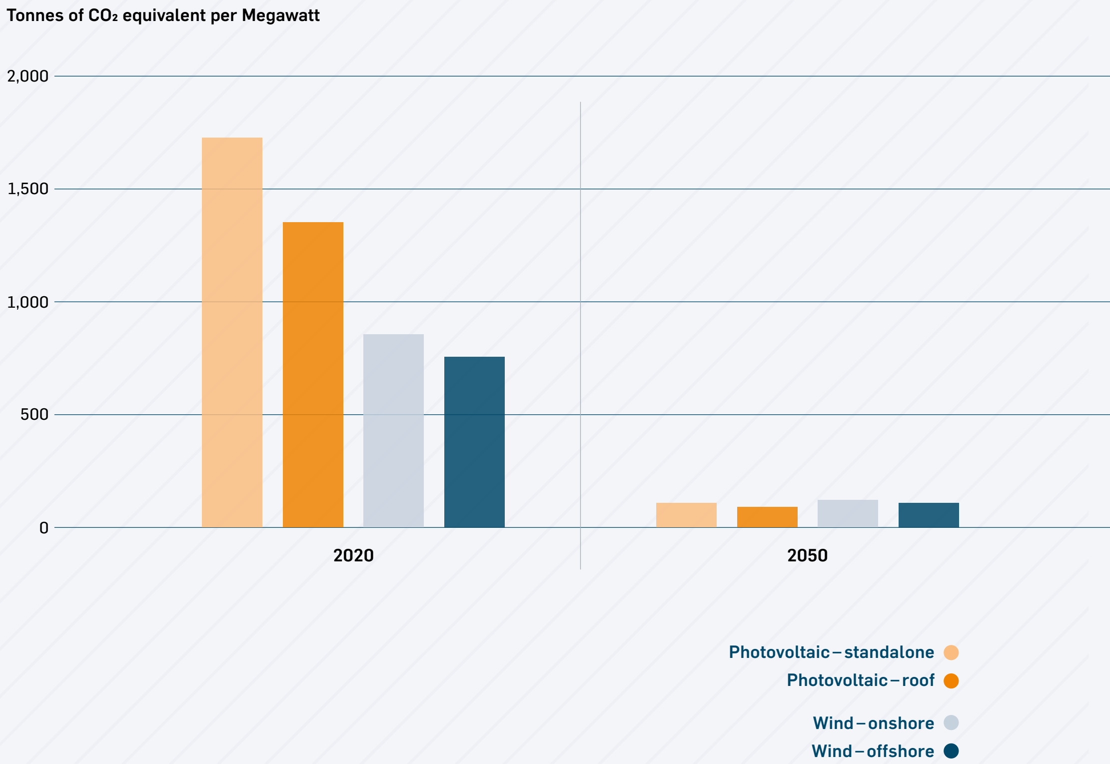
→ https://sdgs.un.org/goals

1. Climate neutrality assessments in the transport sector must include the entire vehicle life cycle and the provision of energy.

To date, the impact of vehicles on the climate was solely determined on the basis of CO_2 emissions output by the vehicle's exhaust system while in operation. However, this approach, dubbed ›tank-to-wheel‹ by experts, does not go far enough. Not only does it fail to consider the CO_2 emissions generated during vehicle production, it ignores all other greenhouse gases resulting from the generation and provision of the energy carriers and their storage, as well as the associated infrastructure. Effective climate protection requires all these emission sources to be taken into account in a holistic environment footprint, known as a ›cradle-to-grave‹ approach. Limiting emissions solely to a tank-to-wheel analysis – as is currently specified – can result in increased cumulative greenhouse gas emissions overall.

In the majority of existing studies, the greenhouse gas emissions resulting from the generation and provision of the energy carriers were amortised over the duration of their use. This conventional approach to balancing not only precludes an objective comparison, but also prevents the optimisation of the energy chain in its entirety. In reality, the remaining CO_2 budget is impacted immediately at the time when the plants are constructed – and not 20 years later. It is of paramount importance that climate-relevant emissions generated due to mobility demands are balanced completely.

The degree to which the construction of wind and solar power plants affects the climate depends on the year in which they are built.



Detailed results can be found in the FVV Fuel Study IV
›Transformation of mobility to the GHG-neutral post-fossil age‹
(H 1269 | 2021 | EN):

→ p. 35 – 66 | Modelling of energy supply chains

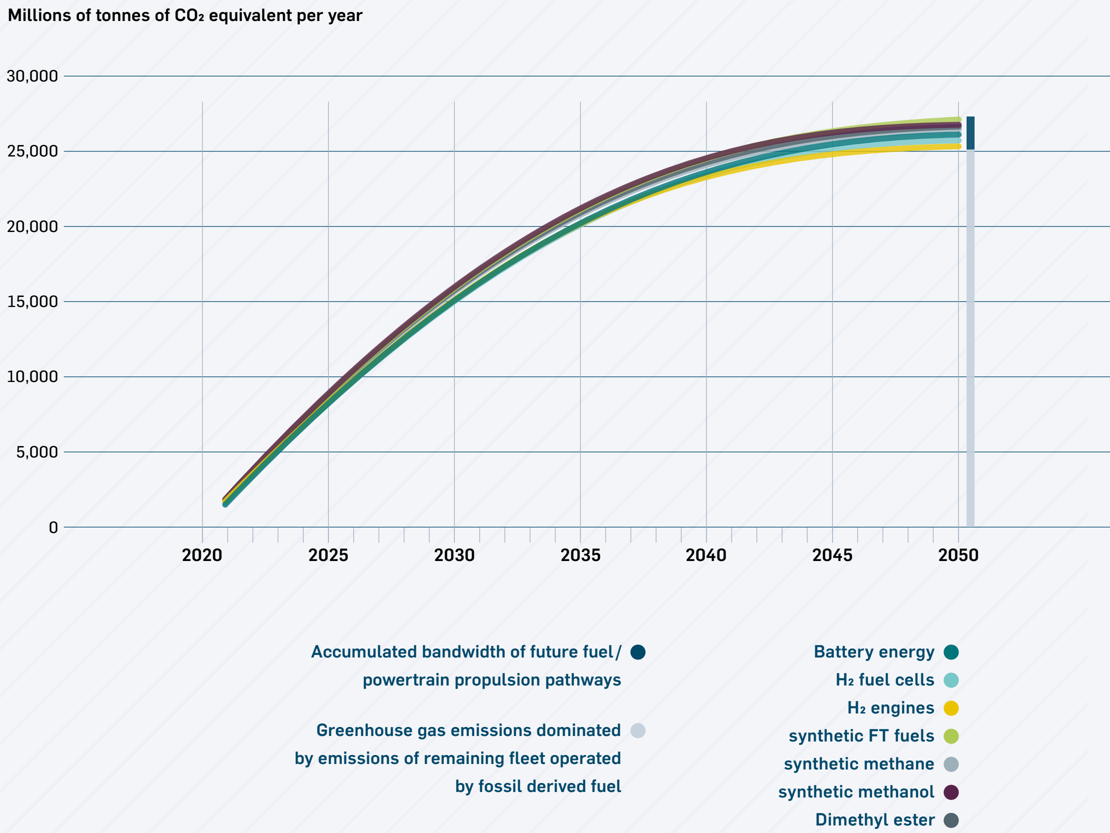
→ p. 76 – 83 | Environmental impact analysis | Build-up of fuel supply chain infrastructure

2. Powertrain technologies are not the decisive factor in achieving the climate goals, but rather the fastest possible departure from fossil energy carriers.

The FVV study analyses a total of 21 combinations of powertrains, energy carriers and efficiency technologies in vehicles. For each combination, a scenario was created in which wind and solar energy was generated entirely within Europe, and a scenario where the energy was generated outside Europe, resulting in a total of 42 scenarios. If we include all emissions from the development of the energy infrastructure and the entire life cycle of the vehicle, the cumulative CO_2 emissions of the calculated transformation paths only differ slightly up to 2050, provided that only emission-free vehicles can be registered as of 2033. The difference between the observed paths is around 14 per cent and, in light of the remaining uncertainties in the forecast, does not represent a decisive criterion for a certain technology.

In other words: it is not the powertrain technology, but the availability of climate-neutral energy carriers that will decide just how quickly and comprehensively the fleet of existing and new vehicles is actually climate-neutral. In addition to sufficient capacities for generating solar and wind energy, the quick establishment of a green hydrogen economy is of crucial importance in all scenarios. This also explicitly applies to the hypothetical scenario of a complete transition to battery electric vehicles powered by electricity generated in Europe. In order to always meet the electricity demands in such a scenario without falling back on fossil energy carriers, hydrogen buffer storage providing energy during cold, dark periods with low wind – based on an electrolysis capacity of around 1,000 gigawatts in total – will be required.

The cumulative emissions of various energy carrier / powertrain combinations hardly differ when the ramp-up times are identical.



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›Transformation of mobility to the GHG-neutral post-fossil age‹
(H 1269 | 2021 | EN):

→ p. 35 – 39 | General assumptions for all fuel supply chains | Hydrogen production and storage
→ p. 96 – 103 | Environmental impact analysis | GHG emissions in the 100 % scenarios

3. The carbon footprint of the existing fleet is decisive when it comes to adhering to the climate budget.

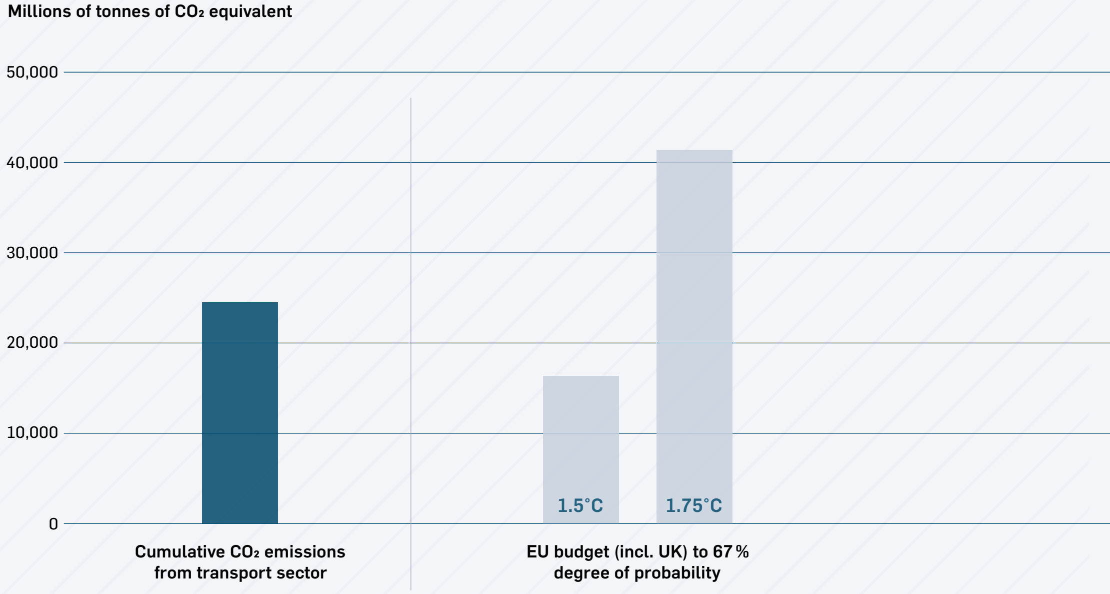
If it is necessary to introduce new vehicle technologies in order to enable climate-neutral mobility, the conversion to sustainable energy carriers is inevitably linked to the fleet turnover rate. As cars are kept for an average duration of 17 years, from 2033 only emission-free cars and small commercial vehicles can be registered if the goal is for road traffic to be completely based on sustainable energy sources in 2050. If the share of newly registered cars reaches 100 per cent by 2033 and every single new vehicle is powered solely using renewable energy during the ramp-up phase – which is far from the case today – a 28 per cent share of fossil energy in the transport sector can be replaced by the year 2030 without negatively affecting other sectors.

However, even if the ambitious goals outlined in the FVV study are met, the existing fleet powered by fossil fuels still makes up a dominant share of cumulative CO_2 emissions. Regardless of the powertrain technologies used in the new, climate-neutral vehicles, these emissions make up around 70 per cent of the total mobility-related emissions based on the assumed ramp-up duration. This would result in Europe's entire greenhouse gas budget, which would enable adherence to the 1.5°C target*, being exceeded as early as 2031 or 2032 – regardless of the scenario model. Our mobility needs alone will account for two thirds of the greenhouse gas budget available to all sectors in Europe in order to limit the temperature increase to 1.75°C – and this is before heating a single house, or manufacturing any other industrial product outside the mobility sector. To prevent this from happening, the mobility sector must stop using fossil energy sources sooner than the vehicle fleet can be replaced with vehicles using new powertrain technologies.

It is therefore an absolute necessity to find solutions that reduce harmful emissions from existing vehicles. According to the current state of the art, and to avoid any appreciable impact on mobility, this will largely only be possible through the use of compatible synthetic fuels (known as drop-in fuels).

* Due to the imprecision of the climate models upon which they are based, the emissions budgets are probable estimates for which a certain average global temperature increase will occur. A probability of 67 per cent is given for the specifications above.

The cumulative emissions from the transport sector exceed the EU's remaining budget that is available for all sectors in order to reach the 1.5°C target.



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›Transformation of mobility to the GHG-neutral post-fossil age‹
(H 1269 | 2021 | EN):

→ **p. 103 – 105** | Environmental impact analysis | Comparison of cumulative GHG emissions with the remaining CO_2 budget

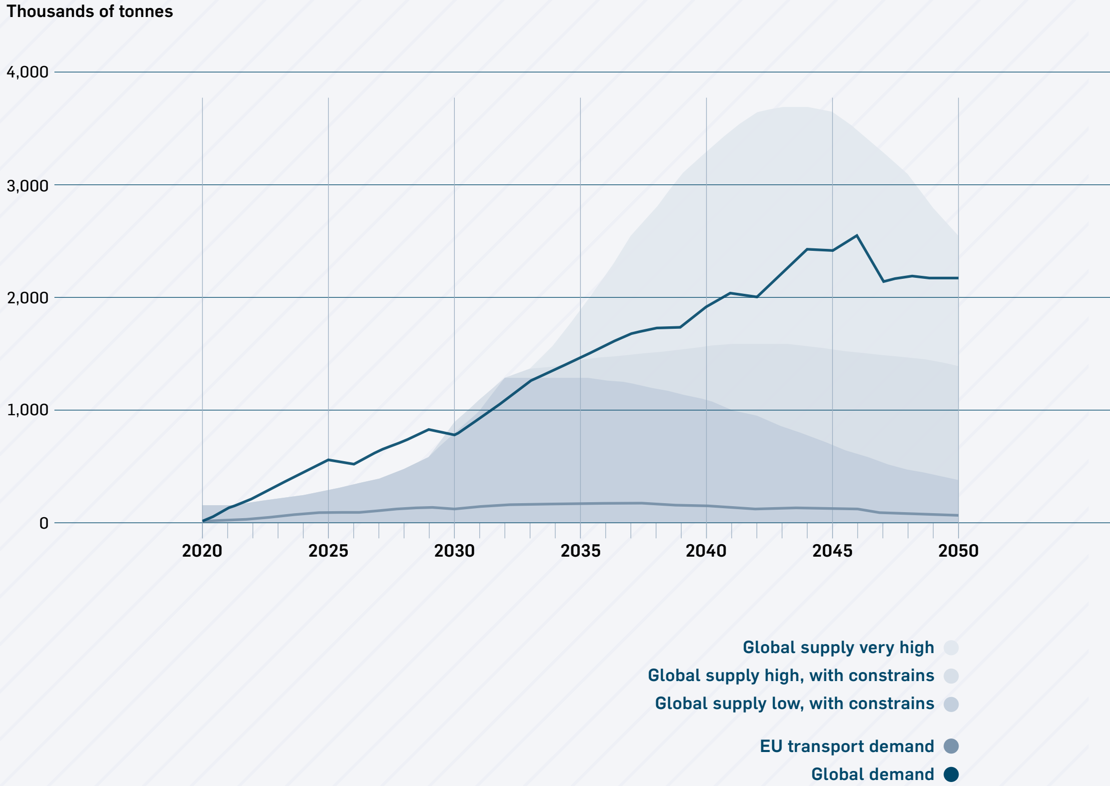
→ **p. 157 – 158** | Key findings and conclusions | GHG emissions

4. Concentrating on a single technology will result in a lack of resources, even in a circular economy.

The FVV study consciously works with what are known as ›100 per cent scenarios‹, as these enable an excellent comparison of the environmental impact of individual technologies throughout the entire energy chain and the vehicle life cycle, while also allowing bottlenecks to be determined. Comparing the demand for critical raw materials with the available reserves and resources shows that – even assuming a high recycling rate – certain raw materials will become very scarce if the rest of the world follows the European model and uses the same technologies. The raw materials in question depend on the selected combination of energy carrier and powertrain.

For example, if the selected technology is battery electric vehicles using the currently dominant battery technology (lithium-ion batteries with nickel-manganese-cobalt cathodes), cobalt and lithium availability will be the limiting factor for the ramp-up speed, and this will have a significant impact on the cost of the batteries. Moving to solid-state batteries with a pure lithium anode will significantly exacerbate the scarcity of resources in the lithium supply chain. For fuel cell powertrains, the availability of platinum is a highly limiting factor. In a scenario in which the entire world transitions to 100 per cent fuel cell use, all known resources will not be sufficient, let alone those that can be tapped in an economically viable manner. No such bottlenecks are currently known when it comes to the use of hydrogen or synthetic fuels in combustion engines.

Lithium demand will outstrip availability if all vehicles around the globe switch to battery electric powertrains.



Detailed results can be found in the FVV Fuel Study IV
›Transformation of mobility to the GHG-neutral post-fossil age‹
(H 1269 | 2021 | EN):

→ p. 113 – 140 | Analysis of critical raw materials
→ p. 159 | Key findings and conclusions | Rare materials

5. Enough energy can be produced to defossilise the entire mobility sector.

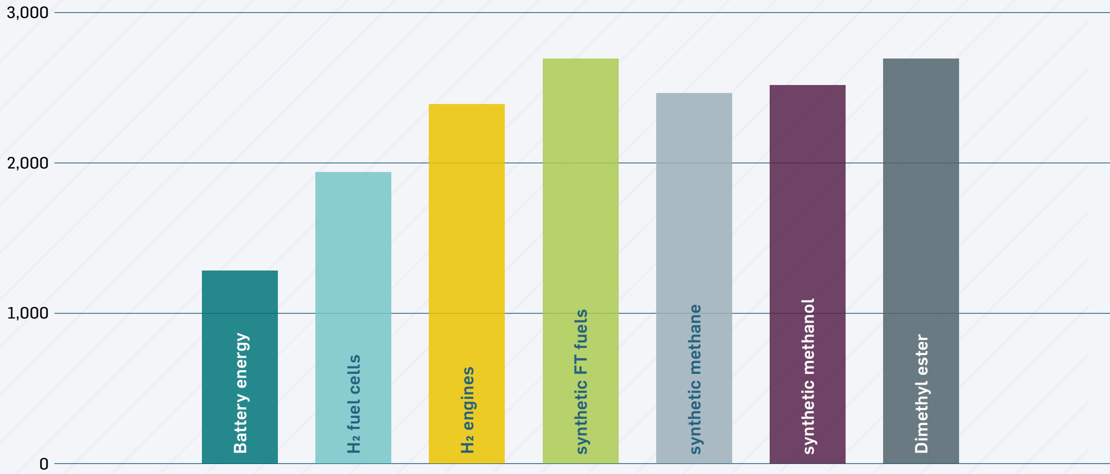
The global potential of sustainable solar and wind energy exceeds the entire primary energy demands of humanity in its entirety several times over. This energy must only be harvested, prepared and distributed using methods that enable technical usage, particularly in the transport sector. This also applies to all mobility transition paths observed in the study – however, the total energy demands for individual energy chains differ significantly. A 100 per cent transition to synthetic fuels used in combustion engines would triple or quadruple energy demands compared to pure battery electric mobility. However, this does not mean that up to four times as many wind energy power plants need to be built. If these fuels were to be produced in regions with plenty of wind and solar energy, the capacity required to generate green electricity would only differ by a factor of two to three.

The additional economic costs to produce energy for climate-neutral mobility are not determined by the amount of energy, but by the capacities required. The increased costs are, however, overcompensated for by the higher vehicle costs associated with battery electric mobility. All things considered, the total costs for an internal combustion engine vehicle powered by synthetic fuels are significantly lower than those for a battery electric vehicle.

All scenarios require a significant expansion of green electricity production. Even the most energy-efficient scenario – the transition to 100 per cent battery electric mobility – will require Europe to generate 1,100 gigawatts of energy in 2050 to cover all of its mobility demands. To compare: according to the International Renewable Energy Agency, the capacity for solar and wind generation in Europe for all sectors will increase to just 690 gigawatts by 2030.

Synthetic fuels from regions with plenty of solar or wind energy require two to three times the electricity generation capacity of electromobility.

Generation capacity in GW in 2050



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›Transformation of mobility to the GHG-neutral post-fossil age‹
(H 1269 | 2021 | EN):

→ p. 71 – 72 | Comparison of energy supply chains for road segment | Capacity requirements in 2050

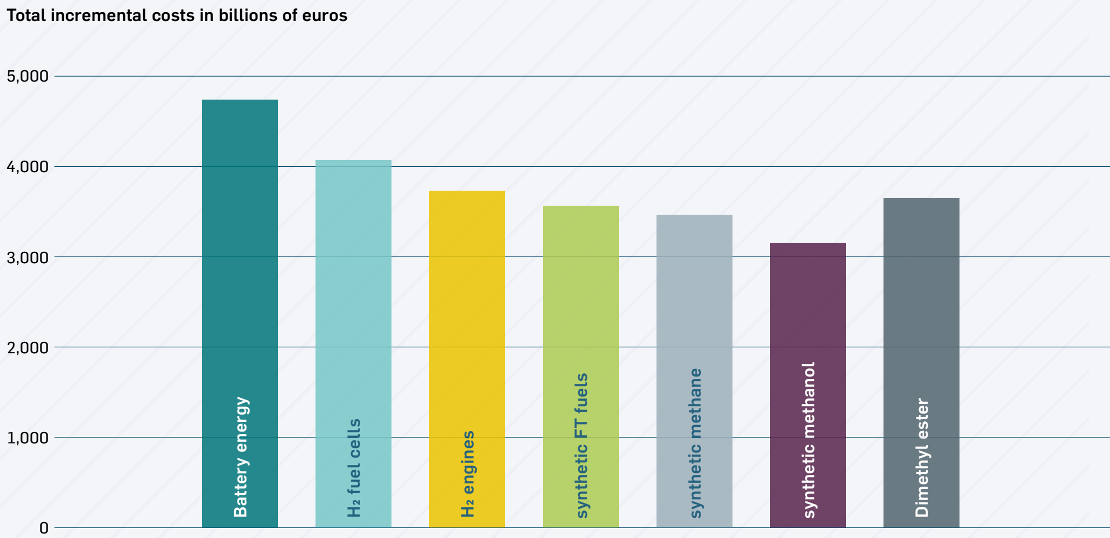
→ p. 160 | Key findings and conclusions | Installed power generation capacity

6. In order to meet the goals of the Paris Agreement, multiple technology paths must be pursued immediately.

If European politics continues to ignore the existing vehicle fleet and only measures the climate compatibility of new vehicles based on tank-to-wheel emissions, the transformation in the transport sector will be doomed to fail. New goals must be defined if we hope to quickly reduce the CO_2 emissions generated by mobility needs. Within the scope of a cradle-to-grave observation, these goals should consider the emissions generated when expanding the energy infrastructure and thus also extend beyond a well-to-wheel approach. European politics must create a market economy framework for the transport sector which then enables multiple technology paths to be established simultaneously. If multiple paths are pursued with the objective of withdrawing from the use of fossil energy carriers, the ramp-up speed will probably also be quicker.

This approach not only benefits climate protection, but also minimises the total economic costs which are dominated by vehicle costs. Cost comparisons that do not include the vehicle costs must therefore be viewed critically. A technology-neutral approach will also ensure that individual mobility remains affordable for a wide section of the population.

Additional costs for the transition to climate-neutral energy carriers and associated powertrains for road transport.



Detailed results can be found in the FVV Fuel Study IV
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(H 1269 | 2021 | EN):

→ **p. 141 – 155** | Cost estimations
→ **p. 160** | Key findings and conclusions | Costs

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FUEL STUDY IV

The briefing paper ›Six theories on climate neutrality in the European transport sector‹ was created to provide a general orientation. The content of this paper cannot and is not intended to replace specific expert advice. FVV does not guarantee the correctness, accuracy and completeness of the information and shall not be liable for any damage resulting from the use of information contained in this study.

The briefing paper is based on the FVV Fuel Study IV (H 1269 | 2021 | EN):
›**Transformation of mobility to the GHG-neutral post-fossil age**‹.

Both publications are available online:

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The new, fourth fuel study published by FVV ›**Transformation of mobility to the GHG-neutral post-fossil age**‹ expands the framework of the previous studies in a number of ways: alongside societal costs and various environmental factors, it also compares the cumulative CO_2 emissions for various energy sources and powertrains and demonstrates how these emissions stack up against the CO_2 budget set for Europe. This analysis shows that it will not be possible to meet the 1.5-degree target without taking existing vehicles into account.

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