FVV PRIMEMOVERS. TECHNOLOGIES.

Climate-neutral mobility that is resource-friendly: How we are speeding up the green transformation

INFORMATION PAPER

Science for a moving society

Introduction


Up to now, fossil energy carriers have been characteristic of the EU's prosperity. With the Green Deal, the EU is now aiming to complete its transition to a world-leading industrial location in which prosperity is shaped by the use of renewable resources. From 2050 onwards, the net greenhouse gases emitted in the EU are to be reduced to zero. This green transformation poses great challenges for industrial companies competing in global markets, as many of their previously successful business models need to be adapted for the future. However, the Green Deal also offers a vast range of opportunities. Only innovations enable emission reduction solutions that support or even increase living standards instead of diminishing them. While this is especially valid in the transport sector, it also applies in other segments.

However, climate protection is just one aspect of sustainability. Only a detailed life-cycle analysis (LCA) provides information on a product's environmental impact and energy balance throughout its entire service life (cradle-to-grave): The life-cycle analysis includes all environmental impacts during production, the use phase and the disposal of a product, as well as the associated upstream and downstream processes such as the manufacturing of raw, auxiliary and operating materials.

Because carbon dioxide (CO_2) is by far the most significant greenhouse gas, we will dispense with technical and scientific language at this point in our information paper and, as is common practice, speak of carbon dioxide or CO_2 emissions when discussing transformation paths.

In a comprehensive series of studies, FVV has compared energy carriers and converters that offer the potential for climate neutrality in the European transport sector, taking into account their entire infrastructure requirement and all CO_2 emissions spanning from generation, through usage, all the way up to recycling. The result was surprising: all of the solutions investigated offer a comparably high level of sustainability when observed over this comprehensive time frame. Rather than the choice of climate-neutral technology itself, it is the speed of its introduction that is decisive for achieving a defossilised, climate-friendly and resource-friendly transport sector in the EU.

Defossilisation can be achieved fastest through a mix of different energy carriers and converters who base themselves on electrochemical or molecular energy storage. This makes it possible to realise even Germany's ambitious goal of achieving climate neutrality as early as by 2045. Under ideal regulatory conditions (accelerated approval processes, attractive business models that are feasible for the long term), this may even be achievable before 2040. On the other hand, using only one technology to achieve carbon neutrality would dramatically delay the achievement of net-zero emissions.

With its new »MAKE IT NEW« mission statement, FVV has taken pre-competitive research on sustainable energy and powertrain systems to a new level: it specifies social demands and the resulting technological requirements from the system level to deep in the component level and implements these in research projects. Life-cycle analyses are the guiding compass for the research activities. Their results point to the fastest possible path to climate neutrality and zero-impact emissions – that is, the time from which vehicle emissions are no longer relevant for the climate, the environment and human health.

FVV's diversification strategy was derived from these studies and encompasses all concepts that offer potential for reducing CO_2, whether these be battery electric solutions, the use of hydrogen in fuel cells or thermal energy converters or other alternative energy carriers. FVV carries out work on electrical machines in collaboration with the VDMA industry association for machinery and equipment manufacturing and FVA (Research Association for Drive Technology). In doing so, FVV is providing the foundation needed to create powertrains for the mobility of tomorrow – with future technologies and through close collaboration within a global research network.

We hope this paper makes for exciting reading and look forward to discussing ideas with you.

Prof. Dr.-Ing. Peter Gutzmer
PRESIDENT

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MANAGING DIRECTOR

SETTING GOALS

Focus on climate neutrality and net-zero emissions

Climate change is a global challenge – it affects each and every one of us. FVV supports the ambitious climate goals set by Germany and the EU.

Within the scope of the 2015 Paris Agreement, 197 countries worldwide (including all EU member states) committed to limiting the rise in temperatures due to the greenhouse effect compared to pre-industrial times to significantly below 2 degrees Celsius (target: 1.5 degrees), counteracting climate change in doing so. This entails a fixed greenhouse gas budget, i.e. an upper limit for all future greenhouse gas emissions. In its special report[1] published in 2018, the Intergovernmental Panel on Climate Change (IPCC) specified a remaining global carbon budget of 420 to 580 gigatonnes if the target of 1.5 degrees is to be achieved. Because CO_2 emissions make up the vast majority of greenhouse gas emissions in the transport sector, in the following we will speak of CO_2 only when greenhouse gases are meant. Other greenhouse gases will be referred to as CO_2 equivalents.

The EU has decided to gradually reduce annual CO_2 emissions in all sectors that consume energy, in doing so distributing the remaining carbon budget over the coming years. Climate neutrality and net-zero emissions are to be achieved in 2050 – i.e. no more CO_2 is to be emitted than can be absorbed by forests or through other means. Germany has also set an interim target for 2030, by which the annual carbon budget is to be 55 % lower than in 1990. In addition, it has committed to achieving climate neutrality as early as 2045. By conducting a comprehensive range of research and development activities for sustainable energy carriers and converters, FVV's member companies make a decisive contribution to achieving the climate protection goals and zero-impact emissions in the transport sector.

[1] With the creation of the report **"Global Warming of 1.5 °C – An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty"** (SR1.5) in 2018, the Intergovernmental Panel on Climate Change (IPCC) complied with a request by the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP 21, Paris 2015). The special report presents the latest scientific knowledge on the impacts of warming of 1.5 degrees Celsius above pre-industrial levels and on greenhouse gas emission pathways that are consistent with such warming. The report also investigates specific measures for strengthening and accelerating the fight against climate change. Furthermore, there is also a dedicated chapter describing how this interacts with the 17 UN Sustainable Development Goals (SDGs).

HOW WE CALCULATE

Our members develop future technologies for climate-friendly mobility that conserves resources. It is therefore especially important for FVV that the environmental impact of all available technological solutions is evaluated throughout the entire life cycle.

When assessing technologies for lowering CO_2, the decisive criterion must be the most efficient use of the remaining global carbon budget. This necessitates a detailed life-cycle analysis (LCA) based on a global and cross-industry / cross-sector approach. During such an analysis, it is essential to consider all direct and indirect impacts at all upstream and downstream stages of the value chain when calculating the carbon footprint. This is known as the cradle-to-grave approach and takes all CO_2 emissions into account without any exclusions. In the case of a vehicle, it not only includes the use of the vehicle (tank-to-wheel), but also its manufacture, provision of the propulsion energy (well-to-tank), building and operating the necessary infrastructure and recycling the vehicle after the end of its life cycle (end-of-life).

Chalk and cheese

Less comprehensive approaches that limit the consideration of CO_2 to a certain stage of the life cycle (e.g. the use phase of a vehicle) run the risk of producing favourable results for technologies that do not reduce CO_2 emissions or even lead to more CO_2 being released overall. However, most current studies and investigations set exactly these limits: They focus only on a certain stage of the life cycle and therefore paint an inadequate picture of the reality of the CO_2 chain. There is also a lack of ramp-up scenarios with realistic introduction speeds for the individual CO_2-reducing technologies. Investigations on this basis are reminiscent of the oft-cited comparison between chalk and cheese: their findings are not suitable for deriving strategies for future transformation technologies to achieve a climate-friendly mobility sector that conserves resources.

Life-cycle analyses (LCAs)

TAKING STOCK

Our LCAs show that the various technology pathways have a very similar ecological footprint and can complement one another: under ideal regulatory conditions, diversification can even help achieve the 1.5-degree target faster.

To provide a sound scientific footing for comparing the different technologies for reducing CO_2 emissions in the European transport sector, FVV has commissioned a comprehensive series of LCAs. All industries involved in the overall energy chain were involved, plus research institutes focussing on technology and economics. In total, more than 60 experts from all over the world collaborated in the analyses. The resulting studies provide the most comprehensive data pool created to date for evaluating the CO_2 relevance of future energy and powertrain technologies for the mobility sector. They are based on the potential of different energy carriers and converters for reducing CO_2 emissions, taking into account all the infrastructure required and all CO_2 emissions from cradle to grave.

Efficient use of the remaining global carbon budget

In an initial meta-study, FVV analysed more than 80 existing studies with almost 500 scenarios in which powertrain technologies are evaluated across all or selected life cycle phases [1, 2].
The analysis of existing studies revealed that these usually exclude emissions arising from the expansion of infrastructure and recycling at the end of the vehicle life cycle. In addition, some energy converters or carriers such as natural gas or renewably generated fuels (e.g. hydrogen or liquid eFuels). and the associated powertrains are not considered, even though these offer considerable technological potential for lowering CO_2 emissions. In spite of these limitations, all the analysed studies reveal that the CO_2 emissions for all combinations of energy carriers and converters lie within a narrow range over their whole life cycle. The average value for the entire vehicle life specified in the studies ranges from 25–35 tonnes of CO_2 per vehicle leveraging the partial use of fossil energies to 9–16 tonnes of CO_2 when using solely renewable energies. In terms of the potential for CO_2 reduction, no technology stands out from the others clearly enough to justify preferential treatment.

Diversification accelerates climate neutrality

In two subsequent LCAs [3, 4, 5], FVV collaborated with a broad, interdisciplinary working group to investigate the findings of the meta-study in greater detail with a focus on the European transport sector. Here, the partners considered the entire “cradle-to-grave” CO_2 chains and all energy carriers and converters that are currently deemed to offer potential for reducing CO_2 and are currently the focus of the research and development activities of research institutes, engineering service providers or industrial companies. Corresponding to the methodology used for national carbon footprints, all CO_2 emissions were offset in the actual year in which they were produced. Furthermore, ideal financial (i.e. the necessary investments are made when they are needed) and political framework conditions (e.g. the immediate issuing of permits and official approvals) were assumed.

As such, the potential for reducing CO_2 offered by the energy carriers and converters for the period up to 2050 was evaluated solely in terms of technological aspects. The studies do not provide any forecasts as to which energy carriers and converters will be used in the future.

The objective of the investigations was to compare the different technologies to illustrate the extent to which they could contribute to the reduction of CO_2 by 2050. The investigations are therefore intended as a tool for politicians, society and industry – but also research and academia – for enabling the correct assessment of technological maturity and in turn deriving appropriate strategies for introduction.

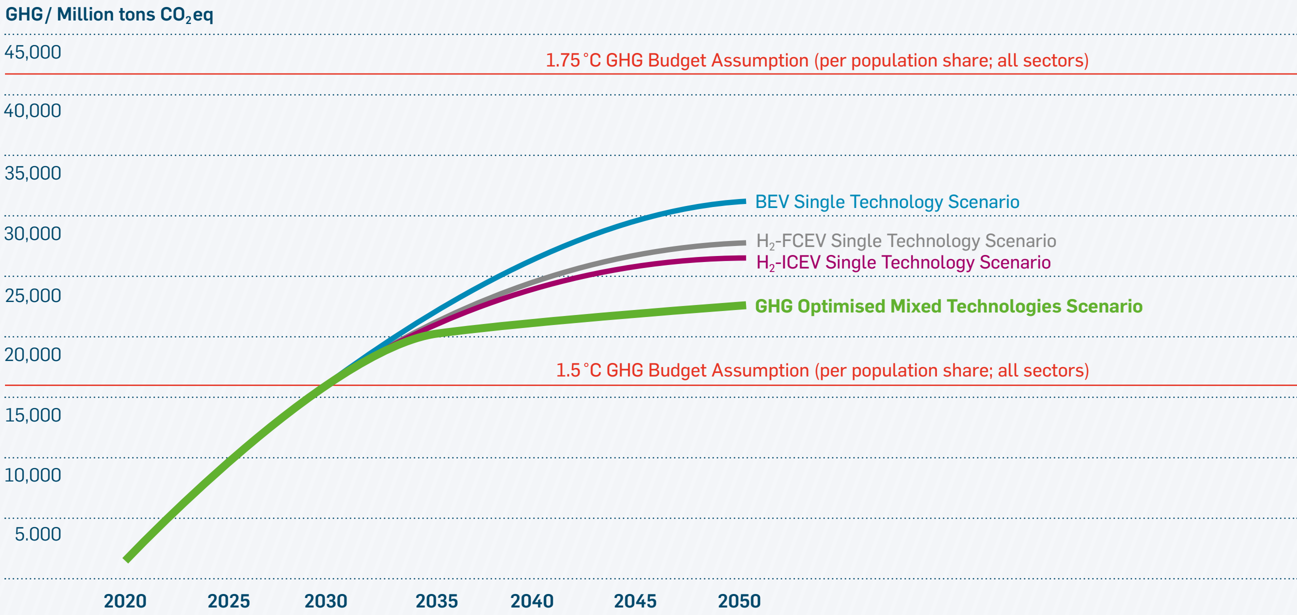
SPEED IS OF THE ESSENCE

If we want to protect the climate, we need to switch the transport sector over to sustainable energy carriers and converters as quickly as possible. Under ideal regulatory framework conditions, climate neutrality could be achieved some 10 years earlier. However, this is possible only with a mix of technologies.

Like the meta-study before them, the two in-depth studies showed that the overall cumulative CO_2 emissions barely differed between the various energy carriers and converters when carbon-neutral energies were used. Moreover, no technology offers a significant advantage in terms of efficiency when considering the complete chain from energy generation, storage and transport to conversion into mechanical energy. One important new finding of these studies was that the speed at which the sustainable solutions are introduced has a significant impact on the overall carbon footprint: the faster the vehicle fleet is defossilised – irrespective of the technology path used – the lower the cumulative CO_2 emissions and, as a consequence, the smaller the negative effects on the climate. As such, the maximum (and fastest) achievable ramp-up of a vehicle technology, including the energy generation capacities, the value chain infrastructure to supply it to the end user and the availability of the raw materials, is especially important.

Technology mix

Defossilisation of the road transport sector in the EU can be achieved fastest using a mix of different energy carriers and converters. This makes it possible to realise even Germany's ambitious goal of achieving climate neutrality as early as by 2045. Under ideal regulatory framework conditions (accelerated approval processes and attractive business models that are feasible for the long term), it may even be achievable before 2040. On the other hand, using only one technology to achieve carbon neutrality would dramatically delay the achievement of net-zero emissions.



Maximum possible share of climate-neutral energy carriers in the EU road transport sector by 2050 under ideal regulatory framework conditions; paths considered among others: Battery Electric Vehicles (BEV), Fuel Cell Vehicles (FCEV), Internal Combustion Engine Vehicles (ICEV) and technology mix (GHG optimised). © Frontier Economics

A mix of technologies counteracts bottlenecks

The evaluation in the second study comprised a total of eleven carbon-neutral pathways: ten single-technology scenarios in which only one carbon-neutral energy carrier/converter is available for all vehicles in each case, and a theoretical »mixed« scenario of diverse technologies in which all carbon-neutral energy carriers and converters are taken into account and which is optimised to minimise cumulative CO_2 emissions [5]. Their distribution can vary freely over the period up to 2050 and in the various vehicle segments.

As the study shows, all carbon-neutral technology pathways have bottlenecks that impede their ramp-up speed. For instance, this can be the availability of the raw materials needed, the expansion of infrastructure or the series development and introduction of the corresponding powertrains.

A mix of technologies therefore allows carbon-neutral mobility concepts to be ramped up significantly faster. Accordingly, a combination of powertrain technologies could bring about a significant reduction in CO_2 emissions. Under ideal ramp-up scenarios and regulatory conditions (accelerated approval processes, attractive business models that are feasible for the long term), the CO_2-optimised technology mix scenario even allows climate neutrality (defossilisation rate of 100 %) as early as 2039. This would achieve Germany's ambitious goal of being climate-neutral by 2045 in the transport sector.

In contrast, a scenario based solely on battery electric vehicles (BEVs) as a carbon-neutral powertrain technology would produce 39 % higher CO_2 emissions by 2050 than a mix of carbon-neutral powertrain technologies over the same period. Moreover, a pure BEV approach would achieve a defossilisation rate of only 76 % of the existing vehicle fleet by 2050. As such, the goals of the Paris Agreement would be clearly fallen short of due to the existing fleet alone.

ACHIEVING THE GOALS

Life-cycle analyses and system efficiency

Thanks to the Green Deal, Europe is to become the first climate-neutral continent that eliminates as many CO_2 emissions as it produces by 2050. To allow the green transformation to pick up momentum, the principle of achieving carbon neutrality as quickly as possible must be the basis for political decisions.

Based on the studies' findings, FVV has drawn up a research roadmap[2] of activities centring around the potential of all energy converters and carriers that are based on renewable resources. This diversification gives politicians, scientists, society and industry the tools they need to evaluate new developments for dispensing with fossil fuels as quickly as possible and adopting carbon-neutral technologies for the various sectors, and to launch them on the market. Diversification also creates redundancies among the energy carriers and converters, which has the effect of safeguarding the goal of climate neutrality by 2050 against factors that are difficult or impossible to estimate or assess. If, for example, a geopolitical problem or an issue with the supply of raw materials delays the ramp-up of one technology, this can be largely compensated by using a different technology.

A strategy of diversifying energy carriers and converters ...
> accelerates the ramp-up of carbon-neutral technologies
> will make the transport sector climate-neutral sooner
> safeguards the climate goals against impenetrable factors
> is the only way to achieve the climate goals set by the EU and Germany in the transport sector

[2] MAKE IT NEW: Mission and scientific research of the FVV (October 2022), in particular the research fields (Terms of References, ToR) of the expert groups: https://www.fvv-net.de/fileadmin/Transfer/Downloads/FVV_MakeItNew_Science_for_a_moving_society_2022_11_EN.pdf

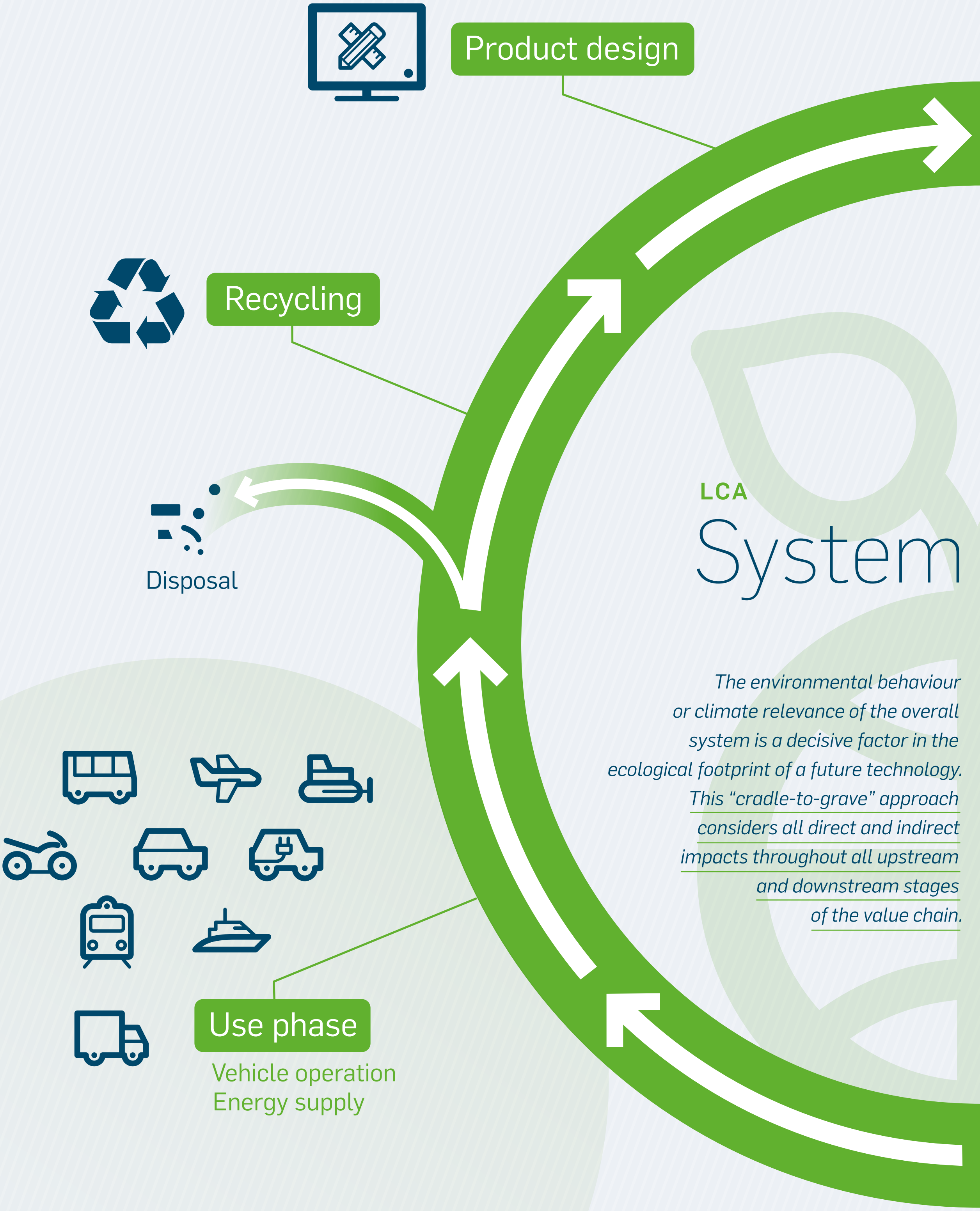
Politicians and society must act fast

FVV therefore calls for society and the political arena to actively promote the diversification of energy carriers and converters in the European transport sector. If additional renewable energy carriers are not considered, we are in danger of leaving potential for reducing CO_2 emissions unused, failing to defossilise energy carriers as quickly as possible and therefore unnecessarily increasing cumulative CO_2 emissions. Political decisions and specifications should be based on a comprehensive LCA, while existing laws and guidelines must be examined on the basis of this and amended where needed.

In view of the incalculable challenges we are facing today (energy costs, raw material bottlenecks, supply chains and the geopolitical situation), FVV recommends that, in addition to the electrification of transport and the infrastructure associated with this, politicians and society should provide broad access to alternative energy carriers such as renewable hydrogen and liquid e-fuels. This is all the more important when one considers that the studies illustrate the outstanding leverage of these technologies for reducing CO_2 emissions, as well as the still large percentage of overall CO_2 emissions that will be generated by the existing vehicle fleet in the future. Moreover, it is crucially important to define intermediate steps on the road to carbon neutrality in the EU by 2050 and to establish suitable mechanisms to assess their achievement.

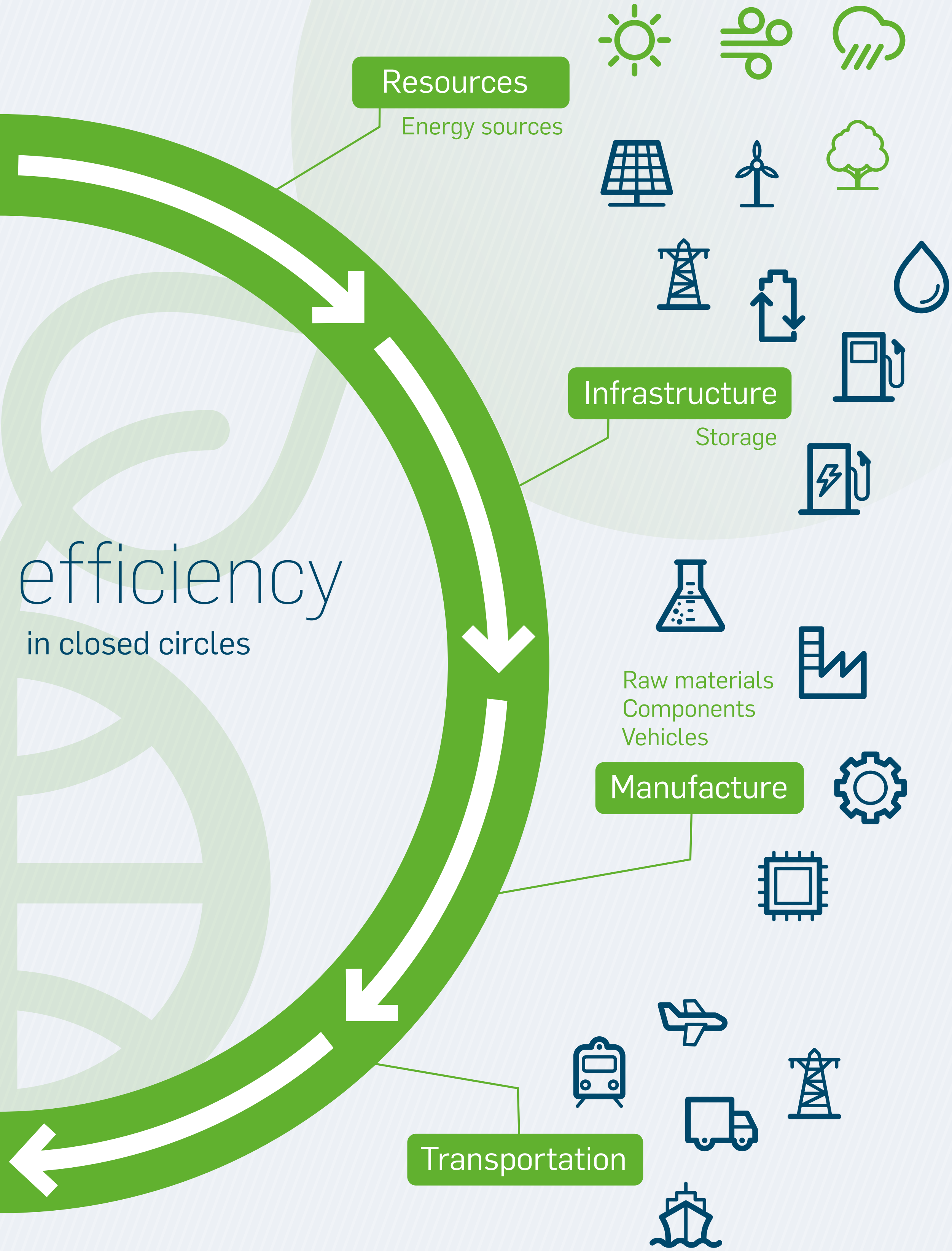
LCA
System

The environmental behaviour or climate relevance of the overall system is a decisive factor in the ecological footprint of a future technology. This “cradle-to-grave” approach considers all direct and indirect impacts throughout all upstream and downstream stages of the value chain.



efficiency

in closed circles



Glossary

Carbon budget

The residual carbon budget is the maximum quantity of CO_2 that can be released if the increase in global temperature is to be limited to 2.0 or 1.5 degrees Celsius. The starting point for this temperature increase is the beginning of the industrial age. The figure is linked to assumptions and probabilities; as such, the IPCC states a remaining global carbon budget of 580 gigatonnes in [1] if global warming is to be limited to 1.5 degrees Celsius with a probability of 50 %, or 420 gigatonnes to increase this probability to 66 % (figures valid in 2018). The remaining carbon budget does not have a time component, as only the cumulative total concentration of CO_2 in the atmosphere affects global warming and not when or where the CO_2 is released..

E-fuels

E-fuels are synthetic fuels that are generated through chemical processes by using electrical energy (»power-to-fuel«). Their carbon footprint corresponds to that of the primary energy used; for example, if the electrical energy for generating the e-fuels is from renewable sources, e-fuels are carbon-neutral. E-fuels are liquids, or gases that can be liquefied at reasonable effort and expense, and are therefore relatively easy to transport. This makes them ideal for importing from especially windy or sunny regions of the world, where renewable energies can be generated with a high degree of efficiency. The fuels can be used in conventional combustion engines, either as a stand-alone fuel or as an additive (»drop-in fuel«), thus allowing them to reduce CO_2 emissions from the existing vehicle fleet.

Energy carrier

Energy carriers store energy in chemical, mechanical, thermal or another physical form. Energy can be derived from energy carriers, either directly or through conversion.

Energy converter

The energy converter transforms the energy stored in the energy carrier into a mechanical movement, for example to power a vehicle.

Bottlenecks

Cobalt availability for electric vehicles

The main bottleneck for electromobility is the availability of primary cobalt for manufacturing vehicle batteries; FVV's studies already make very demanding recycling assumptions in this respect. The strains on supplying cobalt for the NMC (nickel manganese cobalt) batteries that currently dominate the market could be mitigated significantly by using LFP (lithium iron phosphate) batteries. Although LFP batteries offer a considerably lower energy density, they also require far less cobalt. Furthermore, LFP batteries are already suitable for use in series production in the demanding automotive market.

Infrastructure – electricity grid for battery electric vehicles

One bottleneck impeding the spread of sustainable electromobility is the expansion of the European electricity grid. The effort and expense required, in particular for expanding the transmission grid (i.e. transmission lines), is often underestimated or even ignored entirely. This simplification leads to completely unrealistic study results and conclusions. Although a transmission grid already exists, the increase in demand for electricity due to the electrification of the transport sector alone is so great that its capacity will be exceeded by a significant degree. Because the sustainable energy predominantly generated in windy and sunny regions must be transported to the places throughout Europe where it is in high demand, a large-scale expansion of the transmission grid is a matter of great urgency. In Germany, cautious estimates suggest that the transformation to carbon neutrality will result in today's electricity consumption of 600 TWh/year increasing by around 800 TW/h for heat pumps and electric vehicles, which will also have to be transported through the grid. Accordingly, FVV believes that 20 % of demand in the transmission grid can be covered by unused capacity in the existing grid, while 80 % of the required capacities will have to be newly constructed. However, the electricity grid is developing very slowly in the EU – 42,000 km was to be added to the grid between 2010 and 2020, yet less than 10,000 km of this was actually completed.

Energy availability and energy demand

Germany currently requires approx. 3,600 TWh of primary energy per year (EU: 19,000 TWh). The final energy demand in Germany is approx. 2,600 TWh/year. The difference between these figures is the result of unavoidable energy losses that occur during transport and, in particular, when converting one form of energy into another. These can be reduced only by avoiding conversion processes and inefficient forms of transport.

The energy demand can be lowered by increasing the degree of efficiency, e.g. through more efficient vehicles (hybridisation, electric vehicles) and heating systems (heat pump), and through better insulation of residential spaces (lower heat losses) or a reduction in the amount of energy used by voluntarily foregoing consumption or through shrinking economic output.

Various studies are currently forecasting Germany's future energy demand. The published values for the final energy demand in 2050 lie in the region of 1,500 to 1,800 TWh per year, and it is assumed that the primary energy demand will be approximately 1,800 to 2,000 TWh annually (EU: 13,000 to 17,000 TWh per year). However, these studies often make very optimistic assumptions regarding the potential of future energy-saving measures, which could hinder robust planning of the transition to greener energies. For instance, in most cases insufficient attention is paid to the chemical energy storage systems that will be required to cover dark periods; moreover, and in contrast to trends in the transport sector to date, a significant reduction in individual transport is often assumed. Accordingly, it is estimated that the energy demand for transport in Germany (currently approx. 600 TWh annually) will lie in the region of 100 to 140 TWh per year once the switchover to battery electric vehicles is complete. These figures are far too low – according to FVV's calculations, a complete switch to battery electric vehicles would entail an annual primary energy demand of approx. 300 TWh if the current volume of transport is maintained; if the level of traffic increases in line with the EU Reference Scenario 2016, the primary energy demand would total just under 400 TWh annually.

Using excessively optimistic assumptions as the basis for estimating the demands on a future energy system is highly questionable, as energy systems with an insufficient capacity could endanger energy security. A robust estimate of Germany's minimum final energy demand is likely to be a magnitude of at least 2,300 TWh per year. In terms of unavoidable conversion losses, a figure of at least 400 TWh per year should be assumed. These figures result in a more realistic primary energy demand of 2,700 TWh per year to serve as the basis for a robust design for Germany's future energy system.

Solar and wind energy can deliver about 1,000 to 1,200 TWh annually in Germany. Discounting the use of biomass, this would mean that Germany will have to cover at least 55% (1,500 TWh/year) of its energy demand through imports. If the sustainable potential of biomass is leveraged in full, this figure drops to at least 45% (1,250 TWh/year) (sustainable biomass has the potential to provide approx. 250 TWh/year).

Because it is significantly more expensive to generate electricity through solar and wind power in Germany than in the optimum world regions (by a factor of up to 10), it is realistic to expect a much higher share of imports. The only practical way to import the missing energy is in molecular form (as green hydrogen or as a derivative of green hydrogen, i.e. as liquid e-fuel). It is vital to prevent conversion losses when using these energies. To optimise the energy system, it is therefore crucial to consider the efficiency of the entire energy system (system efficiency) and not just that of individual technologies. After all, combining the technologies with the best possible individual efficiency levels does not necessarily result in the highest system efficiency.

Cross-border greenhouse gas emissions versus local air pollutants

Nitrogen oxides and particles have a localised impact, i.e. their emission and concentration at a certain measuring location at a certain time (health impacts) are directly linked. Greenhouse gases such as CO_2 have a global effect, i.e. they affect the climate worldwide, irrespective of where and when they are released. While regionally limited measures can be productive in the event of an excessive concentration of local pollutants, greenhouse gases have to be observed as a whole and reduced on a global basis, in all continents and across national borders. .

Net-zero emissions

To achieve net-zero emissions, all direct and indirect greenhouse gas emissions produced during the life cycle of a product have to be reduced to a level in keeping with the 1.5 degree target of the Paris Agreement. Compensation, for example by purchasing CO_2 certificates, is not permissible.

Greenhouse gas neutrality (climate neutrality

Greenhouse gas neutrality (climate neutrality) is achieved when the volume of anthropogenic greenhouse gases emitted does not exceed that absorbed by forests, sinks or other means. To ensure comparability, the climate impact of greenhouse gases is usually converted into CO_2 equivalents.

Zero-impact emissions

Zero-impact emissions are air pollutants whose concentration is so small that they do not have a measurable impact on the environment or health. The term »zero-impact emissions« generally refers to nitrogen oxides.

FVV LCA / Fuels Studies – Fundamental technical and economic framework conditions | Supplementary notes

https://www.fvv-net.de/fileadmin/Transfer/Downloads/Publikationen/FVV_LCA_Fuel_Study_FAQ_2023_EN.pdf

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How quickly can we be sustainable?
Online: https://www.fvv-net.de/en/science/how-quickly-can-we-be-sustainable
last accessed on 27 February 2023

Study reports

Reports of the Intergovernmental Panel on Climate Change IPCC

SYNTHESIS REPORT | 2023

AR6 Synthesis Report: Climate Change 2023

The Synthesis Report is based on the content of three Assessment Reports: WG I - The Physical Science Basis, WG II – Impacts, Adaptation and Vulnerability, WG III – Mitigation of Climate Change, and three Special Reports: Global Warming of 1.5 °C, Climate Change and Land, The Ocean and Cryosphere in a Changing Climate. All global modelled mitigation pathways that limit warming to 1.5 °C (> 50 %) with no or limited overshoot, and those that limit warming to 2 °C (> 67 %), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade.

https://www.ipcc.ch/report/sixth-assessment-report-cycle/

SONDERBERICHT | 2018

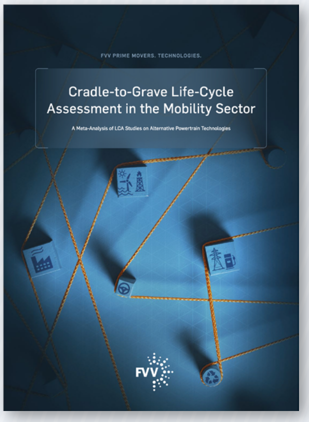
Global Warming of 1.5°C

With the creation of the report *"Global Warming of 1.5 °C – An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty"* (SR1.5) in 2018, the Intergovernmental Panel on Climate Change (IPCC) complied with a request by the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP 21, Paris 2015). The special report presents the latest scientific knowledge on the impacts of warming of 1.5 degrees Celsius above pre-industrial levels and on greenhouse gas emission pathways that are consistent with such warming. The report also investigates specific measures for strengthening and accelerating the fight against climate change. Furthermore, there is also a dedicated chapter describing how this interacts with the 17 UN Sustainable Development Goals (SDGs).

https://www.ipcc.ch/sr15/

Reports of the FVV

Life-cycle assessment in the mobility sector



LCA META ANALYSIS | 2020

Cradle-to-grave life-cycle assessment in the mobility sector

Life cycle analyses (LCA) provide information on how climate-friendly new powertrain systems really are. A meta-analysis, contracted by the FVV and conducted by Frontier Economics, analyses existing life cycle studies from the last 15 years.

https://www.fvv-net.de/fileadmin/Storys/020.30_Bilanz_gezogen/FVV_LCA_Life-cycle_analysis_Frontier_Economics_R595_final_2020-06_EN.pdf

SUMMARY REPORT | 2020

Efficient use of the global CO_2 budget in the mobility sector

A briefing paper summarises key recommendations for drafting future climate protection regulations and guidelines. The study shows that in a global energy and carbon system, various technology options are available from a climate perspective. There is not one single solution for CO_2 neutrality in the mobility sector. The key to sustainable mobility is a fair technology competition and the defossilisation of the energy system.

https://www.fvv-net.de/fileadmin/Storys/020.30_Bilanz_gezogen/FVV_LCA_Life-cycle_analysis_Briefing_paper_2020-06_EN.pdf

Green transformation

FUTURE FUELS – PART IVb | 2022

Transformation of mobility in the GHG-neutral and post-fossil age

Supplementary Study

The supplementary study to Part IV of the FVV advanced future fuels studies addresses the question of how to achieve climate neutrality in the European transport sector as early as possible, taking into account ramp-up potentials of different technology pathways.

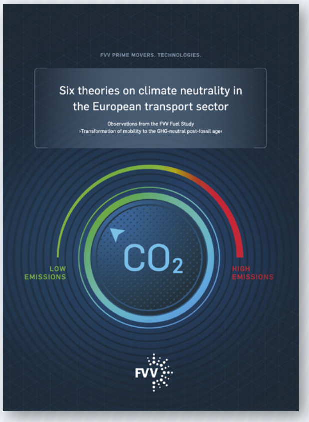
https://www.fvv-net.de/fileadmin/Storys/Wie_schnell_geht_nachhaltig/FVV_H1313_1452_Future_Fuels_FVV_Fuel_Study_IVb_2022-12.pdf

FUTURE FUELS – PART IV | 2021

Transformation of mobility in *the GHG-neutral and post-fossil age*

Part IV of the FVV advanced future fuels studies, commissioned to Frontier Economics and ifeu, looks into the “cradle-to-grave” CO_2 life-cycle emissions of all energy carriers and converters of the European transport sector that are currently deemed to offer potential for mitigating global warming, in order to develop technology pathways that will enable the European transport sector to meet the targets of the Paris Agreement. Corresponding to the methodology used for national carbon footprints, all CO_2 emissions were offset in the actual year in which they were produced.

https://www.fvv-net.de/fileadmin/Transfer/Downloads/Publikationen/FVV__Future_Fuels__StudyIV_The_Transformation_of_Mobility__H1269_2021-10__EN.pdf



SUMMARY REPORT | 2021

Six theories on climate neutrality in the European transport sector

A briefing paper on Part IV of the FVV advanced future fuels studies summarises the boundary conditions for the sustainable design of mobility in Europe. In addition to societal costs and various environmental factors, it compares the cumulative CO_2 emissions for 42 possible transformation pathways and shows how these emissions relate to the CO_2 budget set for Europe. The analysis concludes that it will not be possible to reach the 1.5 °C target without taking existing vehicles into account.

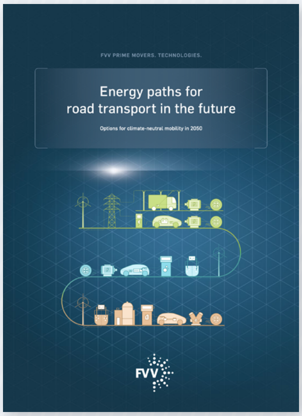
https://www.fvv-net.de/fileadmin/Storys/020.50_Sechs_Thesen_zur_Klimaneutralitaet_des_europaeischen_Verkehrssektors/FVV__1378_Future_Fuels__Study_IV_Briefing_Paper__R600_2021-10__EN_v2.pdf

FUTURE FUELS – PART III | 2018

Defossilising the transportation sector – options and requirements for Germany

Road transport is to be climate-neutral by 2050. However, this objective can only be achieved if energy generated from renewable sources is used in the mobility sector. FVV has therefore analysed various mobility scenarios for Germany with a view to carbon-neutral mobility in 2050: electric mobility, hydrogen and synthetic e-fuels. The results of the study aim to enable a fact-based dialogue on the energy sources and powertrains of the future.

https://www.fvv-net.de/fileadmin/Transfer/Downloads/FVV_Future_Fuels_Study_report_Defossilizing_the_transportation_sector_R586_final_v.3_2019-06-14__EN.pdf



SUMMARY REPORT | 2018

Energy pathways for road transport in the future – options for climate neutral mobility in 2050

100% renewable – but how? One goal, several pathways. The paper summarises the results of the three transformation pathways considered in Part III of the FVV's studies on future fuels – electromobility, hydrogen, synthetic fuels –, analyses the resulting investment needs and identifies research tasks for the future. In addition, further implementation criteria are considered, such as questions of safety or expected market acceptance.

https://www.fvv-net.de/fileadmin/Transfer/Downloads/FVV__Future_Fuels__Study_report__Energy__paths_for_road_transport__final_2018-10-01__EN.pdf

Climate indicator Greenhouse gases (GHG)

Greenhouse gases are mainly released through the use of fossil fuels such as coal or oil. However, they are also produced at all upstream and downstream stages of the industrial value chain. If the content of greenhouse gases in the atmosphere increases, this leads to the warming of the earth's atmosphere and thus to climate change. For this reason, the international community of states agreed at the climate summit in Paris in 2015 that the global temperature increase should not exceed the threshold of 1.5 degrees, if possible. The maximum increase should be 2 degrees. This can only be achieved if global greenhouse gas emissions are reduced quickly and drastically. The emissions of all greenhouse gases (e.g. carbon dioxide, methane) are summarised in a standardised way. Since the different gases affect the climate differently, their effect is normalised to that of carbon dioxide: A carbon dioxide equivalent describes how much a precisely defined mass of a greenhouse gas contributes to the greenhouse effect over a fixed period of time compared to carbon dioxide (CO_2). **All FVV studies calculate with GHG emissions or carbon dioxide equivalents.**

The information paper »Climate-neutral mobility that is resource-friendly: How we are speeding up the green transformation« was created to provide a general orientation. The content of this paper cannot and is not intented 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 science story **»How we are speeding up the green transformation«** is available online:

→ **www.fvv-net.de/en/science/how-we-are-speeding-up-the-green-transformation**

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Transfer // Industrial Collective Research (IGF) empowers companies to solve joint research and technology problems on a science-based approach. It provides access to a continuous stream of new knowledge they can use to create their own products, processes and services. Industrial research and development benefits from the fact-/field-based collaboration with the science community, universities and non-profit research institutions, on the future of technology. This creates innovative power in industry and excellence in research, teaching and learning.

Orientation // Industrial Collective Research (IGF) creates science-based knowledge that is available to each of our network partners and the interested public. In addition to fundamental research topics, FVV initiates orientation studies which support an economy that is climate-neutral, resource-efficient and competitive.

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