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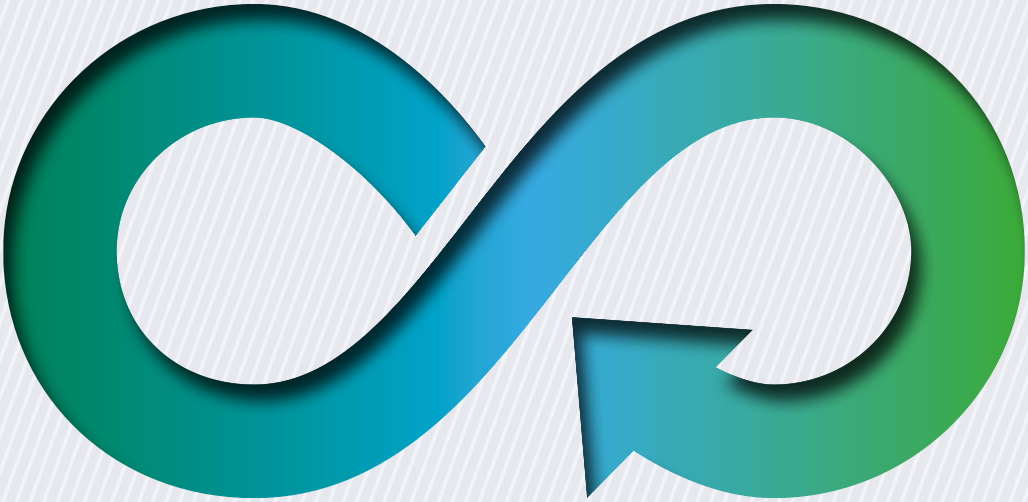
Fundamental technical and economic framework conditions

EXPLANATORY NOTES



Science for a moving society

Introduction

Fundamental facts get visibly ignored in the public debate on the transformation of the energy system in Germany and the EU. Not only in the social media, but increasingly also in quality journalism or in politics. That is why we have bundled supplementary explanations on the basic technical and economic framework conditions of the FVV life-cycle assessment and future fuels studies and their differentiation from other studies in this compilation of facts.

From a methodological point of view, the FVV studies work with theoretical 100 % scenarios, for each of which a market share of 100 % is assumed in the year in which climate neutrality is achieved. The insights gained on this basis are thus also available for the calculation of mixed scenarios, in which different market shares of the transformation paths (combinations of powertrain technologies and CO_2-neutral energy sources based on sustainable solar and wind energy) are taken into account.

The following collection of basic technical facts and economic framework condition, together with the new information paper on **»Climate-neutral mobility that is resource-friendly: How we are speeding up the green transformation«**, is intended to facilitate a fact-based dialogue on energy sources and powertrain systems of the future.

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.

Frequently asked questions

What is the future energy demand in Germany?

The primary energy demand in Germany lies currently in the region of 3,600 TWh per year (EU: approx. 19,000 TWh per year). The final energy demand is approx. 2,600 TWh per year. The difference results from unavoidable energy losses that occur during transport and especially during conversion from one form of energy to another. A robust design of a future energy system must not be based on minimum estimates of future energy demand, as this would endanger energy security. According to FVV estimates, Germany's future 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.

Why do various studies arrive at a lower future energy demand?

The published data for Germany's final energy demand in 2050 lies in magnitude region of about 1,500 to 1,800 TWh per year; assumptions for the primary energy demand lie in the region of 1,800 to 2,000 TWh per year (EU: 13,000 to 17,000 TWh per year). However, these data often make very optimistic assumptions regarding the potential of future energy-saving measures. For instance, in most cases insufficient attention is paid to the chemical energy storage systems that will be required to cover so-called dark periods, i.e. phases in which neither sufficient solar nor wind power is available. Moreover, and in contrast to trends in the transport sector to date, a significant reduction in individual transport is often assumed. Furthermore, many studies do not consider the real consumption of vehicles.
The energy demand of transport in Germany (currently just under 600 TWh per year) is therefore estimated in many studies at only 100 to 140 TWh per year once the switch to battery electric vehicles is complete. These figures are far too low.

According to calculations by the FVV, 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 as much as 400 TWh. Using excessively optimistic assumptions as the basis for estimating the demands on a future energy system is highly questionable, as undersized energy systems with an insufficient capacity could endanger energy security.

Final and primary energy demand – where are the differences?

Final energy demand is the amount of energy that must be made available at the points of consumption (private households and industry) to meet demand. However, this provision is subject to losses. These result, for example, from conversion processes from one form of energy to another and the transport of the energy, such as losses due to the electrical resistance of the power grid. These losses must be compensated for by the generation of additional energy. The primary energy demand is the total energy input that must be covered in order to ensure the supply of consumers. It is therefore the sum of the consumer-dependent final energy demand and the energy demand due to supply losses.

What is the production potential of solar and wind power in Germany and Europe?

The production potential of solar and wind power in Germany is approx. 1,000 to 1,200 TWh per year. Germany will have to cover at least 55 % of its energy demand (1,500 TWh per year) through imports if biomass is left unconsidered. If the country's potential to produce sustainable biomass is leveraged in full, it would still have to import at least 45 % of its energy (1,250 TWh per year). (The production potential of sustainable biomass in Germany lies at approx. 250 TWh per year). Because it is significantly more expensive to produce sustainable solar and wind power in Germany than in the optimum world regions with plenty of sun and wind (by a factor of approx. 10), it is realistic to expect a much higher share of imports.

For Europe (EU and UK), the potential of renewable energies from solar and wind power is in the order of 14,000 to 23,000 TWh per year, depending on the study and scenario. However, these high values include a significant share of cost-intensive floating offshore wind plants. Europe can therefore theoretically supply itself self-sufficiently with solar and wind energy, but only at very high energy costs. In addition, it will hardly be possible to distribute electricity within the EU area via an appropriate grid for decades, as the achievable expansion speed of the electricity grid is significantly too low.

Can the primary energy demand be reduced?

The conversion losses during the transformation from one form of energy to another have a major influence on the primary energy demand. These conversion losses can be significantly reduced by consistently avoiding unnecessary conversion processes. This requires a consideration of the entire energy system. A combination of the most efficient individual technologies can very quickly lead to increased conversion processes and thus to a significant deterioration of the system efficiency, which results in an increased primary energy demand. If, for example, the current annual demand for electricity in Germany (approx. 600 TWh per year) is supplemented by the additional electricity demand for a complete conversion of heating systems to heat pumps (additional approx. 470 TWh per year), the annual demand for electrical energy amounts to 1,070 TWh per year, which is already very close to the limit of Germany's solar and wind energy potential. If the missing energy is imported by ship in the form of renewable hydrogen (e-hydrogen), which is then used to generate electricity, there are inevitably considerable conversion losses: after generation by electrolysis (efficiency about 75 %), the e-hydrogen must first be converted into e-ammonia (efficiency about 55 to 60 %) in the country of production (e.g. Chile, Australia) in order to be able to transport it. In the country of use, it is then converted back into e-hydrogen (efficiency approx. 90 %). This means that only 40 % of the original electrical energy can be found in this e-hydrogen in Germany. If this e-hydrogen is used to generate electricity (electrical efficiency of turbine approx. 40 %), only 16 % of the original energy remains. If you use this electricity in an electric vehicle, the overall efficiency (at 70 to 90 % vehicle efficiency depending on charging speed and energy generation location) is only 11 to 14 %. If one were to use the same e-hydrogen directly in a fuel cell vehicle or a vehicle powered by a hydrogen combustion engine, the overall efficiency would be approx. 20 % (fuel cell) or 15 % (hybridised vehicle with hydrogen combustion engine), although both technologies have a significantly lower propulsion efficiency (fuel cell about 51 %, hybridised hydrogen combustion engine about 38 %). If the e-hydrogen were not converted to e-ammonia in the country of production for transport purposes, but instead to e-methane with the help of CO_2 extracted directly from the air, which would then be transported to Germany by LNG tanker and fed into the natural gas grid, a well-to-tank efficiency of approx. 57 % would be achievable. This e-methane could then be used directly in a hybridised vehicle with a methane combustion engine (»natural gas hybrid«, efficiency about 39 %), with an overall well-to-wheel efficiency of 22 %. In this scenario, the entire natural gas infrastructure (LNG ships, LNG terminals, gas pipelines) could be used without modifications, so that high cost efficiency would also be achieved. This example shows that it is essential to optimise efficiency at the system level.

Can the final energy demand be reduced?

Possibilities for reducing the final energy demand arise from efficiency increases among end consumers, e.g. through the introduction of more efficient vehicles (hybridisation, electric vehicles) and heating systems (heat pumps), as well as better insulation of residential spaces (less heat loss) or lower consumption through consumption cuts or shrinking economic output – which, however, no one seriously wants. Efficiency increases at the end consumers should be used when it makes sense, whereby interactions with the overall system (prevention of conversion losses) must always be taken into account. Simply stringing together the best individual efficiency levels of system components without taking the overall system into account (system efficiency, costs, achievable ramp-up speeds) is not sensible and can lead to incorrect optimisation results that may be very cost-intensive and may even have a detrimental effect on climate protection.

How can we transport or import the missing energy?

The only practical way to transport the missing energy over long distances is in form of energy carrier molecules (as renewable hydrogen or as a derivative of renewable hydrogen, i.e. as liquid e-fuel). When using these carriers, conversion losses must be avoided at all costs. To optimise the energy system, it is therefore extremely important to consider the efficiency of the entire energy system and not the efficiency of individual technologies. The combination of best achievable individual efficiency levels does not automatically lead to the best system efficiency.

To what extent is the power grid a limiting factor for the ramp-up of sustainable mobility?

The effort and time required for the expansion of the electricity infrastructure, especially for the construction of the transmission grid, i.e. long-distance lines, is significantly underestimated. In some cases, grid expansion is even completely ignored and it is simplistically assumed that energy in the form of electricity can be transported everywhere without any problems (assumption: Germany or Europe as a »copper plate«). This simplification often leads to completely unrealistic considerations and conclusions. Since sustainable energy predominantly generated in sunny and windy 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. FVV believes that 20 % of the demand in the transmission grid can be covered by unused capacities in the existing grid, while 80 % of the required transport capacities will have to be newly built.

How come the existing power grid is not sufficient for future requirements?

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. For example, the maximum electrical power generated in Germany at peak times (midday, weekdays) is already around 80 GW, while the grid is only capable of transmitting around 30 GW. The reason this works today is that the sites of large energy consumers have generally been built close to where the energy is generated. In an energy system based purely on solar and wind power, the majority of energy generation will take place in a spatially decoupled manner in preferential windy and sunny regions. This local decoupling of generation and consumption results in a significantly increased demand for electricity transport. In addition to today's electricity consumption (example Germany: approx. 600 TWh per year), further power consumers such as electric vehicles or heat pumps for domestic heating come into play during the transition to carbon neutrality. For the operation of heat pumps, there is an additional demand for electrical energy of about 470 TWh per year. Alongside today's annual electricity consumption of 600 TWh, another 800 TWh per year must be added for heat pumps and electric vehicles, which must be transported through the electricity grid. In contrast, the expansion of the electricity grid is progressing only slowly. Of the 42,000 km of line expansion in Europe outlined in the ENTSO-E grid expansion plan for 2010 to 2020, less than 10,000 km were actually completed in the same period (2010 to 2020), i.e. less than one in four kilometres.

Can all greenhouse gas emissions be avoided in the future?

Fully GHG-free mobility (simplified as climate or carbon neutrality) cannot be achieved even with the exclusive use of energy from sustainable sources. There will always be process-related, unavoidable GHG emissions that do not originate from energy production. For example, the production of concrete for wind turbine foundations entails GHG emissions as a result of calcium carbonate decomposition. For manufacturing a C-segment vehicle, the unavoidable GHG emissions in 2050 (assumption: exclusive use of fully sustainable energy in vehicle production) will be around 1.3 t CO_2 equivalent for a vehicle with an internal combustion engine and around 2 t CO_2 equivalent for a battery electric vehicle.

What is the role of efficiency?

Efficiency is a technical parameter for process optimisation and has only limited significance when considered on its own. Above all, the boundary conditions of the system under consideration must be precisely defined for its evaluation. In addition, optimum system efficiency is not automatically the result of a combination of the optimum individual efficiency levels of each component. A technology assessment based on only one or a few individual efficiency levels in an entire impact chain usually leads to incorrect results. To minimise European GHG emissions, for example, it is essential to optimise the entire European energy system. For passenger cars, the so-called tank-to-wheel powertrain efficiency (mechanical work per chemically bound energy input) under cycle conditions (WLTP, winter operation) is about 88 % for electric vehicles and about 38 % for vehicles with combustion engines (as hybrids). For cyclists, the comparable efficiency is about 20 %. If we now also include the energy supply, the well-to-wheel powertrain efficiency (mechanical work per overall energy input) under identical conditions for electric vehicles with 100 % renewably generated electricity including an energy buffer for dark periods is 55 % and for vehicles with combustion engines (hybrids) operated with e-fuel approx. 22 %. For cyclists, this well-to-wheel efficiency is less than 0.5 % under unfavourable circumstances. Of course, no one would nevertheless seriously advise against cycling for climate protection reasons.

What is the market potential of e-fuels?

Under ideal regulatory and investment conditions, it would be possible to operate more than 75 % of European transport with e-fuels by 2035. The prerequisites for this are short authorisation procedures and good investment conditions in the long term through market-based incentives, such as sufficiently high taxation of CO_2 in the exploration of fossil fuels while abandoning all sector targets.

Is the expansion of wind power and photovoltaic capacities a limiting factor?

The technically feasible rate of expansion of solar and wind energy does not constitute a bottleneck to serve several sectors simultaneously with sustainable energy, including e-fuel production for passenger cars. Instead, the bottlenecks are caused by other technology building blocks, such as grid expansion. The realistically achievable growth rates of wind power and photovoltaic capacities installed annually are approx. 30 % per year.

»E-mobility« and »e-fuels« – are they competitors in the race for the »best« transformation technology?

As the FVV studies show, an approach that includes battery electric vehicles only would achieve a defossilisation rate of only 76 % of the vehicle fleet in the EU by 2050. In other words, 24 % of vehicles would still emit CO_2. This scenario would clearly miss the climate targets of the Paris Agreement. Renewable energy, which is produced in sunny and windy regions of the world, converted into molecules and thus imported into the EU, could fill this gap. These molecular energy carriers can be hydrogen or derivatives such as liquid e-fuels. In contrast, transporting the energy as electricity over a distance of several thousand kilometres would not be technically feasible in the time remaining. E-fuels are additional energy sources that can be made available in preferred locations of renewable energy production that would otherwise not be available. In addition, e-fuels offer the advantage that they are easy to handle, can be distributed via the existing refuelling infrastructure and can also be used in the existing vehicle fleet. E-fuels are thus the perfect complement to green electromobility, also in the passenger car sector. Both transformation technologies are not in competition with each other, they complement each other sensibly in order to achieve the climate goals.

What are the benefits of a diversification of energy sources and conversion systems for the transport sector?

As the FVV studies show, one single technology path alone is not sufficient to implement the ambitious EU targets of climate neutrality by 2050, and 2045 by Germany respectively. These goals can only be achieved through a clever mix of different energy sources and conversion systems. In addition, diversification creates redundancies so that the climate targets are safeguarded against raw material-related or geopolitical imponderables. In summary, a strategy of diversification in energy sources and converters accelerates the ramp-up of carbon-neutral technologies, leads more quickly to climate neutrality in the transport sector, safeguards climate targets against uncertainties and is thus the only way to achieve the climate targets set by the EU and Germany in the transport sector.

The supplementary notes support the information paper on **»Climate-neutral mobility that is resource-friendly: How we are speeding up the green transformation«**. Both documents are available online:

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

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