2 Climate Neutral Mobility: Natural Gas and Methane as Part of the Solution

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2.1 Introduction

Mobility is an important prerequisite for economic exchange and individual prosperity and good transportation systems fulfil the mobility needs of the population. Not only has the passenger car assumed a dominant role within the domain of private transport, road transport is the mainstay of freight traffic. Motorized traffic, as it exists today, has many negative effects on the environment and also on people: greenhouse gas emissions, air pollution, noise, land consumption and the use of resources for the creation of infrastructure, the vehicles themselves and the fuels (see also [1]). The focus of this contribution lies on the greenhouse gases caused by motorized traffic.

This book considers natural gas as a current and future source of energy for the transportation sector. This prompts us to describe additional options and scenarios in an introductory section that are necessary if one is to reform transportation—and in particular motorized traffic—to be more climate neutral. After the introductory section and the problem statement from the point of view of climate protection in Sect. 2.2, Sect. 2.3 provides a short overview of possible non-technical measures, followed by the technical measures for energy supply in the transportation sector in Sect. 2.4. An investigation into the existing infrastructure in Sect. 2.5 will reveal that natural gas can be one step on the road towards greenhouse gas neutral transportation and that it may be worthwhile to reflect on technologies particularly in conjunction with renewable methane generated from electricity.

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What Is Driving Growth in the Transportation Sector and the Problem of Greenhouse Gas Emission?

Over the last century, transport performance (measured in person-km or ton-km) has risen drastically, whereby the increase over the last 20 years has been over-proportional to economic growth. The most important reasons for this were and still are on the one hand the relatively favorable price development of fuel in all transport domains and the associated widespread increasing amount of traffic per manufactured unit of the gross domestic product (GDP), and on the other the integration of Germany into the growing European Union (EU). Diagram 2.1 shows a comparison of the development of GDP and traffic volume over time in Germany. All highly developed countries experienced identical development trends.

There has been a consensus in the scientific world for the past 20 years that current climatic changes are mainly linked to human activities and the associated emission of greenhouse gases (GHG) [5]. This awareness has also reached international politics and is concentrated in, for example, the Kyoto process and other measures in order to limit the growth of or to obtain a reduction of climate gas emissions. There are fundamental initiatives that primarily affect areas other than transportation, for example emissions trading systems in the stationary industrial sector. In parallel, there is an almost shocking development in the transportation sector on a global scale. Diagram 2.2 shows scenarios of the development of the transport sector in Germany and the associated climate gas emissions. The amount of traffic is increasing: there is a simultaneous albeit dampened growth in climate gas emissions that decreases in the long-term. Compared to other sources of GHG emissions however, traffic itself has shown substantial growth since 1990, although there has been an increase in technical efficiency and the energy required

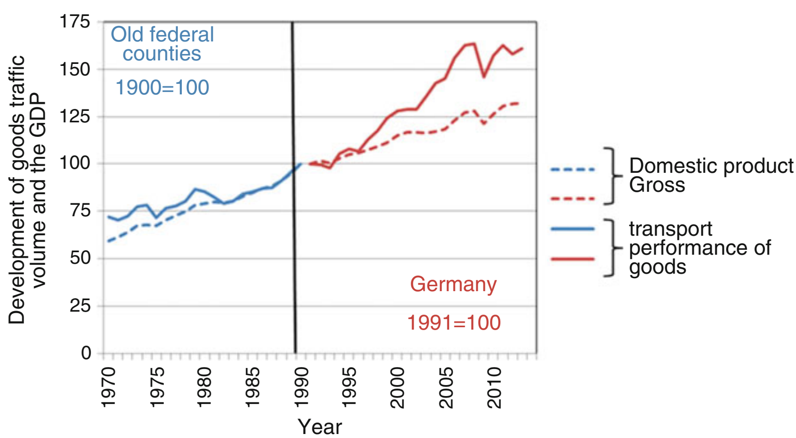

Diagram 2.1 Development of the transport performance of goods and the gross domestic product (adjusted for seasonal and calendar effects) in Germany. Data from economic statistics [2] and traffic in numbers [3, 4]

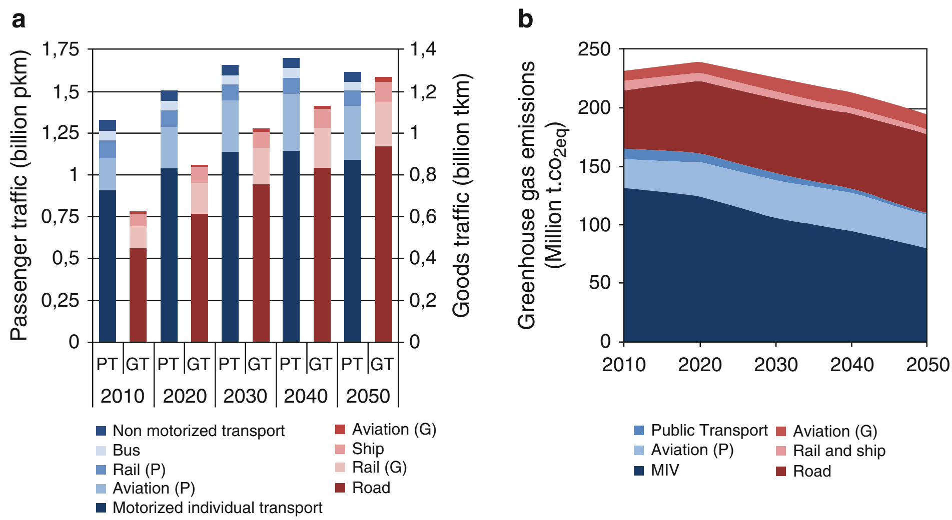

Diagram 2.2 (**a**) Development of person and goods transport performance in Germany and (**b**) the corresponding transport-related GHG emissions according to [6]

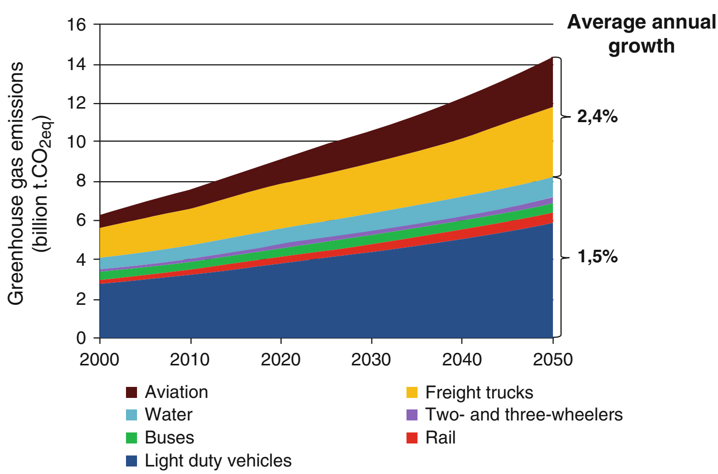

Diagram 2.3 Development of greenhouse gases (incl. upstream emissions) caused by global transport, split according to different means of transport with growth rates [7]

to fulfil one unit of the transport performance has fallen. Diagram 2.3 and the underlying study forecasts a further increase of the transport performance on a global scale.

There are two main drivers that can be differenciated: On the one hand, there is a global increase in long-haul goods transportation and air traffic; on the other hand, the Asian states are in the throes of rapid economic growth (see Diagram 2.4).

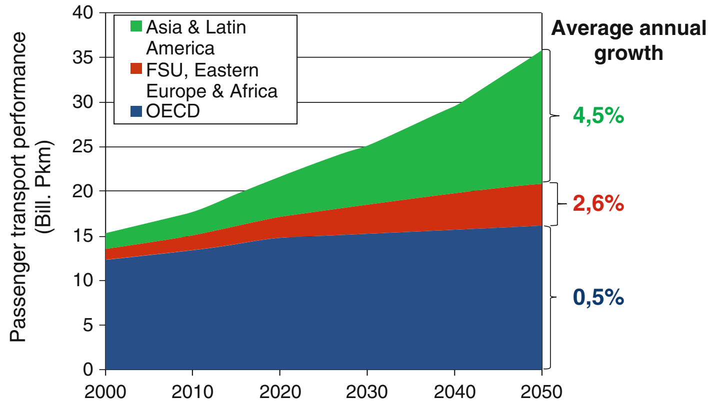

Diagram 2.4 Development of passenger transport performance by light duty vehicles are passenger cars and light duty commercial vehicles light-duty vehicles in various regions with average growth rate. Data from [7]

Even if the focus is on climate gas emissions, it is important to point out the other consequences of this development. A major deterioration of air quality is associated with the development of the Asian region, which generally speaking is mainly due to the burning of fossil primary fuels, a large part of which originates from traffic.

The diagrams show that considerable effort is required in the transport sector such that transportation can contribute anything at all to climate protection. All signs indicate that there will be no major decoupling of GDP and the growth in transport, not even a dampening effect in the current development. A first success would be if energy consumption in transportation did not increase faster than economic growth. It is also clear that the climate protection contribution required from traffic is not possible by concentrating on a single task. It is inevitable that the focus must actively shift to the avoidance of traffic, to modal shifts on more environmental compatible means of transport and to the environmental compatible handling of the remaining transport. Both of the first two points are necessary on a global scale, but are probably very difficult to implement, even in highly developed industrial nations. Even the technical issue of increasing efficiency alone will not be sufficient to make the necessary contribution.

Additional fundamental and globally compatible solutions must be found. The use renewable energy in transportation seems obvious, although closer inspection of various options quickly reveals that the possibilities are limited. The use of cultivated biomass for example has been closely examined by the German Environment Agency [8]. The conclusion was that it does not represent a long-term solution. The reasons lie in the domain of associated social issues, for example “tank versus plate”, environmental damage such as a drastic increase in water consumption, intensive fertilization and the negative consequences for the soil, and the insufficiently positive climatic impact. For these reasons, current discussions are focussed on the direct or indirect use of regenerative and practically unlimited electrical energy [6, 9]. A global approach is required since the subject of energy supply for transportation should not be evaluated on a limited regional basis.

2.2 Contribution of Transport to Climate Change or Alternatively, the Non-contribution of Transport to Climate Protection

Currently, transport contributes significantly to global greenhouse gas emissions and hence climate change due to the burning of fossil fuels by the various modes of transportation. Since 1990, first attempts have been made to limit climatic change to a value of 2° or below. Over the same period of time, the contribution of emissions by traffic has increased disproportionately from 12.9 to 14.5 % [10].

Climate change is an environmental problem with non-local effects, i.e. emissions from the whole world contribute to a global effect, without a correlation between local effects and local greenhouse gas emission. For this reason, climate protection must be driven on an international level, whereby nation states and groups of nations have not been able to agree to date on how to distribute the burdens of climate protection. The UN's Intergovernmental Panel of Climate Change (IPCC) recommended a greenhouse gas reduction target corridor for the year 2050 for differently developed states [11] in its fourth status report (2007). The fifth status report (2014) no longer contains this suggestion—it now derives only globally acting reduction targets for the 2-degree target [10]. IPCC scenarios in which the 2-degree target is complied with in the twenty-first century are characterized by a reduction in emissions of 40–70 % by 2050 compared to 2010 and emissions being practically zero in 2100. If transport were to contribute to this reduction in accordance with the size of its emissions share, then greenhouse emissions in 2050 would only lie between 2 and 4 billion $tCO_{2,eq}$. This range is contrasted in Diagram 2.4 with the predicted emissions according to WBCSD (World Business Council for Sustainable Development). The WBCSD scenarios only contain, however, moderate improvements in efficiency, low avoidance of transport and transport modal shift measures.

The discrepancy between the forecast emissions—as shown here with the WBCSD example—and the "permissible" emissions from the point of view of climate protection show how important it is to make substantial reductions in greenhouse gas emissions. This can be achieved through increased avoidance of traffic and modal shifts, increases in efficiency of transportation means and the use of fuels with low specific CO_2 emissions per useful energy. The short-term replacement of gasoline by natural gas is conceivable for the second aspect, whereas in the medium and long term, it appears expedient to employ electro-mobility and fuels generated using electricity from an environmental point of view. Low volume potential could also be covered with alternative fuels based on wood and straw residues (Diagram 2.5).

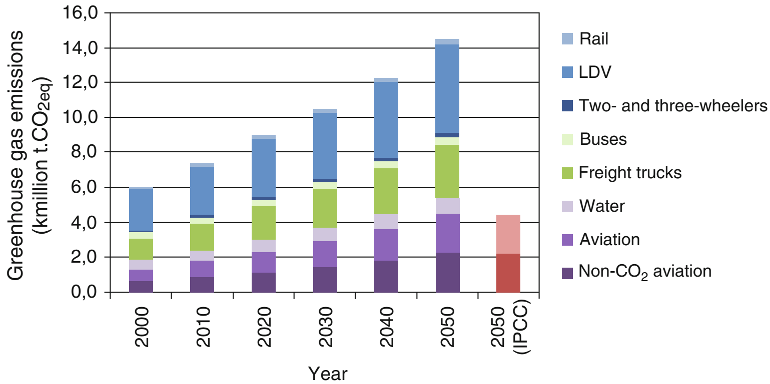

Diagram 2.5 Comparison of direct greenhouse gas emissions for a reduction target of between 40 and 70 % for the year 2050 (based on [10]). The modes of transport are clustered and colored according to their potential for electrification. The non-CO_2 effects of aviation have been taken into account. Data from [7]

It is conceivable that a part of the transportat could be largely or completely electrified by the year 2050 (for example passenger cars and two-wheelers) and hence no longer directly emit greenhouse gases and, if supplied with electricity from renewable sources, only have very low upstream emissions. For others, for example long-distance buses or long-haul trucks, this is principally technically possible, however it is not clear to what degree electrification is really possible. It does not appear possible that international shipping and aviation will have a significant proportion of electrification by 2050. Further discussion on the options for energy supply for transportation will be covered in Sect. 2.4.

Aviation is proving to be the problem child due to the direct CO_2 climatic effects, the additional non-CO_2 effects that cannot be avoided even with greenhouse gas-neutral fuels, the strongly limites potential of electrification and forecasts of huge growth rates of 5 % per year. In 2050, the non-CO_2 effects of aviation emissions will already correspond to the "permissible" greenhouse gas emissions based on a reduction of 70 % compared to 2010 in order to keep global warming below 2°C.

Another mode of transport with strongly increasing greenhouse emissions is road-based long-haul goods transport, which could however be electrified in various ways, e.g. overhead lines, power rails or inductive systems.

Currently, it is not clear whether sufficiently high traffic densities can be achieved on a global level that would make widespread electrification economical (for example in central Europe or North America, densities are possibly higher). Such an undertaking would also require a huge effort in standardization in order to develop international systems. Alternative, low-greenhouse gas fuels such as methane or hydrogen produced from renewable electricity together with liquid fuels produced from renewable electricity can contribute to a low-GHG supply of such modes of transportation. The emission of nitrogen oxides and particulates/soot by long haul transport can be reduced via the currently adopted technical solutions of exhaust aftertreatment and filter systems, even though these systems are sometimes very complex. The target for the future must be to guarantee the endurance and performance of these systems their service in the field to a high degree.

It may seem appropriate at this point to enter into deeper discussions concerning the technical issues concerning fuels. However, since there are numerous non-technical measures that can be employed to significantly reduce greenhouse gas emissions (and also to reduce many other negative impacts of transport), these will be discussed first.

2.3 Non-technical Measures for Climate-Friendly Transport

A catalogue of measures is needed to achieve the ambitious greenhouse gas reduction targets, since single measures do not have the required effect and only an integrated approach can be effective, particularly in the transport sector. This section will deal with so-called non-technical measures as examples of what can contribute to climate-friendly transport. In this section the examples describe the situation in Germany, if not stated differently.

Economic Measures

Economic incentives can be created with appropriately structured energy taxes, amongst other things. Currently, different energy taxes lead to a distortion of competition. For example, there is no taxation of kerosene in aviation, whereas railway companies are burdened with taxes on their electricity by the German Renewable Energy Act (EEG). A further hidden subsidy is the tax on diesel fuel. The energy tax advantage of approximately 18 cents per litre of diesel over gasoline is not justified from a climate-political point of view. The German Environment Agency therefore recommends a gradual alignment and the levying of energy taxes on the basis of fuel carbon content [12]. A further economic measure would be the elimination of the company car privilege and a differentiation of tax according to CO_2 emissions. Company cars represent a large part of the fleet in Germany.

“Company cars are vehicles that can be used by the employee for private use. This private use is subject to a monthly income tax of 1 % of the vehicle list price upon first registration as monetary value. [. . .] Company cars are normally larger vehicles with above-average fuel consumption. The company car privilege also pushes the passenger car as a mode of transport and contributes to the environmental pollution caused by road traffic. [. . .]”[13].

Allocating the true costs of traffic is a further point for discussion. For example, since 2012, external costs for air pollution and noise can be added to road tolls, according to the EU guideline 1999/62/EG, however only up to a relatively low-capped value. As stated by the current road cost report from the Federal Ministry of Transport and Digital Infrastructure, the true external costs are much higher [14]. Further external costs caused by traffic, for example land fragmentation or traffic accidents, are not allowed to be considered so far.

The increase and extension of the truck toll scheme could be an appropriate step to burden goods transportation with a part of the external costs caused by this sector and to participate them in infrastructure maintenance. According to the study “Renewability II”, truck tolls should be extended to all truck categories upwards from a total permitted weight of 3.5 tons for all road categories and gradually increased [15].

The instrument of car tolls could also be implemented to transfer costs to the passenger car sector and simultaneously make citycenters more accessible and liveable. London and Stockholm have good experience with this model and passenger car traffic has been reduced by approximately a fifth. In general, from an environmental point of view, only kilometre-related passenger car tolls are recommendable, as they can have a steering effect [16].

Estate Structure

The structure of an estate creates transport performance: planning mistakes create traffic. Estate, production and infrastructure in the past few years have developed in such a manner that distances between the start and end of journeys have increased. At the same time, there was a focus on mono-functional estates, for example shopping centers on greenfields or suburbs on the edge of large cities, while inner city sites and brownfields remain unused.

“The elimination of the commuting allowance would be an important step against the trend to suburbanization and to promote more traffic-free estate structures. Employees can write off the commuting allowance for journey to the workplace against income tax, currently 30 cents per kilometre distance between place of abode and the workplace. This reduces the tax burden as soon as the annual professional expenses allowance is exceeded (currently 1000 €; 2010: 920 €). Such a comparable tax relief does not exist in the majority of EU countries. The commuting allowance supports the growth in transport performance, the trend towards long journeys to work and the urban sprawl in the countryside. Above all, it favors passenger car traffic, since the availability of public transport particularly in places with low population density is very limited and is therefore not an alternative for many employees. The commuting allowance works against climate protection and contributes to air pollution and noise. The use of land as a result of urban sprawl is an important reason for the loss of bio-diversity and has further negative environmental effects. [. . .]” [13] The elimination of the commuting allowance could reduce CO_2 emissions by 1.8 million tons by 2015 [17]. The recommendation is thus to eliminate the commuting allowance and to permit the journey costs to be recognized as tax-relief in the form of exceptional burden to support those in dire need. According to the latest calculations by the Ministry of Finance, the state could increase tax income by approximately five billion euros.

The implementation of the planning concept “City of Short Distances” is a further measure that can help reduce greenhouse gas emissions originating from traffic. Federal states, counties and municipalities should follow a twofold strategy: (1) Prioritized use of existing space in estate inventory instead of previously undeveloped areas in exterior areas or city borders (inner development), (2) Simultaneous urban developmental by the upgrading of residential areas concerning the quality of the environment, so that residing and living in a city is attractive. This includes new forms of residential layout (for example modern townhouses, car-free estates, communal housing) that can compete with detached single-family houses in suburban countryside. The main areas for action concerning the control of residential areas are city planning, building and planning regulations, and instruments of estate-related financial politics. Regional planning must contain and limit the growth of estates on the outskirts of cities. In regions where further estate development is necessary due to continuing population expansion, development must be concentrated in focal points of estate development [12]. Such a trial in space trading is currently taking place for German communities (www.flaechenhandel.de).

Regulatory and Planning Measures

Lower speed equals less energy consumption—this is a well-known physical law. Reducing the speed therefore means directly saving energy. According to the German Environment Agency, a speed limit of 120 km/h on German motorways would save 2.9 $MtCO_2$ in 2020 and 3.2 $MtCO_2$ in 2030 [12]. Even though these calculations are based on numbers from the 1990s and require updating, it can be said that a speed limit would be a step towards effective energy saving. Lower permissible top speeds would also mean that vehicles could be constructed lighter, since the safety requirements and design of the corresponding vehicle components also depend on the expected collision speeds. The project Renewability II calculated that a speed limit of 120 km/h on German motorways would reduce the average fuel consumption by 6.5 % [15]. Apart from better quality of life and a reduced number of accidents in cities, a blanket speed limit of 30 km/h in inner cities would also offer the potential to reduce CO_2 [18].

The challenge to reduce greenhouse gases in transport requires support from all political levels and also cities and communities. The setting of concrete targets (such as Stockholm's goal of being greenhouse gas neutral by 2030) by those responsible gives them a development path and hence steps to take. A suitable instrument is a traffic development plan [19], or also "Sustainable Urban Mobility Plans" [20], as they are called in a European context. The participative creation of such traffic development plans with the goal of reducing greenhouse gases can unfold a long-term saving effect, since it is a consensual and integrated plan with a high probability of implementation in the communities.

Measures Targeted on Behavioral Change

Behavioral change begins in the mind and is therefore only achievable through a paradigm shift. Nevertheless, steps for behavioral change offer the possibility of being sustainably and permanently effective with relatively low input of financial means. Behavioral changes are desirable so that people avoid unnecessary car journeys for example, by walking short distances or using a bicycle if possible, or public transport.

The promotion of active mobility (walking, bicycling, public transport) is therefore recommendable, since multi-modality is the key to sustainable mobility: The best combination of transport media is used to satisfy the mobility needs. On one day, a person could cycle to work, on another day travel by train and walk to the station, for example if it is raining. Car sharing and bicycle sharing systems offer good opportunities to do justice to the slogan "Use instead of Own" [21].

Good communication work and campaigns such as "Mind On, Engine Off", new resident marketing, residential location advice or campaigns such as "On Your Bike" or "City Biking" can help to promote behavioral change.

Ecodriving, i.e. driving in manner that saves fuel, can reduce fuel consumption in passenger cars by 7 % and in trucks by up to 8 % [15].

Finally, there is huge potential offered by mobility management to change traffic behavior. Although the effects of CO_2 saving are difficult to verify since it is a bundle of initiatives, it can be assumed that the effect of job tickets, mobility advice and communication campaigns is positive—as demonstrated by projects such as the German promotion *effizient mobil* (efficiently mobile) or the Austrian *klima.aktiv* (active climate).

Infrastructure Measures

It is urgently recommended to prioritise the preservation of existing infrastructure over new road construction—on the one hand because the existing budgets do not permit new construction, and on the other because it is well-known that new roads inexorably lead to more traffic and thus directly to an increase in CO_2 emissions [12]. The support of combined traffic and optimization of logistics promises positive effects [15]. The desired shift towards the environmentally friendlier rail transport can only be achieved with a focussed expansion and upgrading of the German rail network [22].

A further appropriate step is the expansion of public transport and making it more attractive.

The economical viability of so-called non-technical measures in the transport sector has been proved for individual bundles of activities [23].

The complexity of the total system must always be considered. A key aspect is integrated traffic planning. One study [20] showed, as an example, how the promotion of bicycle routes as a system could save 40 $MtCO_2$ per year.

2.4 Transport's Energy Supply: Sustainable, Climate-Friendly Fuels for Transport

Up to now, traffic is practically completely based upon mineral oil products: In 2010 the share of fossil oil in the energy required for traffic in the EU was 94 %. It is important to promote low CO_2 alternatives to de-carbonise transport. In this context, the EU underlined gaseous fossil fuels as a part of the proposal package "Clean Energy in Transport" in 2013. The use of Liquefied Petroleum Gas, or LPG is already relatively widespread in the EU. It has a share of 3 % of fuels and is used by nine million vehicles. Liquefied Natural Gas, LNG and Compressed Natural Gas, CNG play an increasingly important role in the gas market for vehicles.

The advantages over oil are the lower greenhouse gas emissions per heat unit. The German energy agency (dena) states that the life-cycle GHG emissions for natural gas are 124 $gCO_{2,eq}$/km, whereas it is 164 $gCO_{2,eq}$/km for gasoline and 156 $gCO_{2,eq}$/km for diesel fuel [24]. Compared to gasoline, the emissions are almost a quarter less. The mobility and fuel strategy devised by the Federal Government also reflects the high importance of gas use and suggests steps for the intensification of its use, for example via the expansion of highly frequented filling stations to include natural gas pumps, or an increase in the number of natural gas filling stations.

A much larger greenhouse gas reduction can be achieved on the basis of electricity; either directly (as for example already practiced by the railways) or via gaseous or liquid fuels produced by electricity on the basis of regenerative energies. However, compared to natural gas, the production processes for the latter fuels are still in the early stages of development and test. Electricity is used to split water into hydrogen (PtG-hydrogen) and oxygen using electrolysis. Further chemical reactions convert this into methane (PtG-methane). Fischer-Tropsch synthesis is able to combine carbon-based gases with hydrogen and form hydrocarbon-based liquid fuels (PtL). To ensure that the result is climate-friendly fuels, the power to gas (PtG) and power to liquid (PtL) process steps need to use energy from renewable sources. An extension of current natural gas infrastructure can be used for electricity-generated methane, since this can be transported in pipelines and, in contrast to hydrogen, can be mixed in large volumes, stored and implemented in current natural gas tanks. The existing distribution network can also be used for liquid fuels. Which fuel and powertrain options are best suited for which mode of transport and which changes to infrastructure will be necessary, will be discussed in the following chapters.

The different modes of transport pose very different technological requirements on the energy supply independently of their effect on the environment and eliminate certain fuels or fuel storage systems because of them. The volumetric and gravimetric energy density of the fuels in particular, together with the energy storage itself, and the mass and volume of the fuel store are decisive.

This is particularly prominent in aviation, where alternatives to kerosene are conceivable at best in the long-term and then only for short-haul flights. These could be future hybrid planes with batteries and hydrogen fuel cells, or even jet engines powered by hydrogen.

The gravimetric energy density is mainly influenced by the choice of fuel, whereby the volumetric energy density can be increased to a certain degree, for example by the compression or liquefaction of fuels that are gaseous under normal conditions. The compression of natural gas, methane or hydrogen should suffice in the medium term to satisfy the range requirements of passenger cars, whereby the liquefaction of gaseous fuels for commercial long-haul trucks cannot avoid large amounts of cooling in order to guarantee the required range. Similar requirements also eliminate other energy supply options for transport such as battery-driven long-haul trucking at least until the middle of the twenty-first century, unless an unexpected technological breakthrough occurs.[1]

If the additional requirements are considered, i.e. that the fuels and energy stores must be manufactured in a sustainable and environmentally friendly manner and enable at least a practically greenhouse gas neutral transport system, then the number of energy distribution options is limited further.

The strict requirements for a particularly large reduction in greenhouse gas emissions from fuels up to greenhouse gas neutrality result from the wide-ranging necessities for climate protection that are required to limit global warming to a value below 2°C. This also requires huge reductions compared to the forecast in greenhouse gases in the transport sector—both in developed countries and in developing countries. Both criteria named result in fossil energy carriers not being an option for supply in 2050. Only the following post-fossil energy supply options remain for transport:

– direct use of electricity: battery-driven and cable-dependent forms of electro-mobility
– indirect use of electricity: gaseous and liquefied fuels on the basis of renewable energies [for example Power-to-Gas (PtG: hydrogen or methane) and power-to-liquid (PtL)]
– biogenically based fuels from residual waste.

Biofuels of the first generation produced from cultivated biomass cannot fulfil the requirements for fuel sustainability, since they are associated with social and ecological problems such as land use and competitive use of land, polluted water and over-fertilized land [8]. Only first generation biofuels based on biological waste and second generation biofuels from that use wood or straw have a high probability of fulfilling the necessary large reductions in GHGs and have total ecological advantages [25]. The potential amount for these fuels is, however, very limited and can only cover a share (approx. 10 %) of the global energy supply for transportation in 2050. In the long-term, biofuels of the third generation on the basis of algae are conceivable, but will not be discussed further here, since sound predictions concerning costs and efficiency are not possible. Thus large disruptions in energy distribution are necessary for sustainable and climate-friendly supply of the transport sector, since practically all fuels must be replaced. This is the reason the talk is of energy transition in transport. A transition towards a shift and an avoidance of traffic is unavoidable in order to reduce the energy requirements of the transport sector on a global basis and thus to enable a first successful energy transition in the transport sector.

[1] A significant increase in the volumetric and gravimetric energy density has been considered in this timescale within the scope of assessable technological development.

Contribution to the Discussion for Efficiency

A fundamental element of future action is to increase the technical efficiency of each and every mode of transport. This means that the energy consumption per relative value must be reduced. To achieve this, a variety of steps are necessary in the area of the total vehicle. The current discussion around improving efficiency continually calls for further tightening of the CO_2 fleet emissions for passenger cars, or that they should be introduced for commercial vehicles. It is also important that such targets and limits be introduced for shipping and aviation. This is to be welcomed in principle.

In the future though, this CO_2 limitation is no longer systematically useful, since this approach originates from a time when mainly gasoline, diesel, heavy oil and kerosene were used in solely combustion engine driven vehicles. This will change in the future. Other energy carriers (for example hydrogen, compressed natural gas, liquefied natural gas, synthetic fuels, direct use of electricity) and hybrid systems will prevail. Because of this development, CO_2 will not be the unique indicator of energy consumption (for example, see [26]). From the point of view of the environment, it will also be necessary in the future to have not only climate-friendly energy distribution, but also resource-friendly energy distribution. In face of this, it is wise to use energetic consumption as an indicator of the efficiency of a vehicle [26]. This can provide orientation concerning the depletion of resources. It can also be the basis to provide information on CO_2 emissions under constantly changing boundary conditions (for example the degree of expansion of renewable energies).

Diagram 2.6 shows which energy distribution options will be principally suited for which mode of transport in 2050. This evaluation is based in results from a study by the Federal Environment Agency "Post-fossil energy supply options for a greenhouse-neutral transport sector in the year 2050: A cross-transport mode evaluation" [27].

However, in order to gain a holistic view of energy supply, not only are sustainability requirements placed on fuel production and greenhouse gas reductions decisive, but ecological, economical, technical, infrastructural and systemic aspects must also be

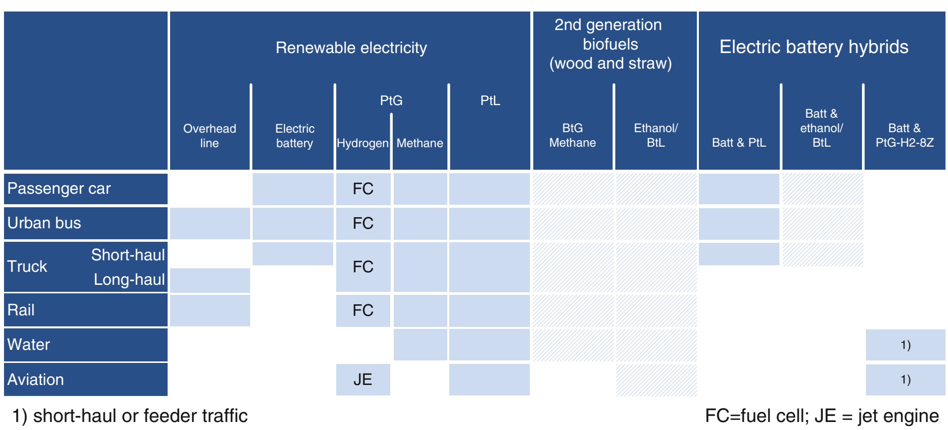

Diagram 2.6 Post fossil energy supply options for transport in 2050 for different modes of transport. Options with limited volume potential are shaded, see [27]

evaluated. The direct use of renewable electricity normally represents the most climate-friendly and the most economic variant. For this reason, wherever technically possible, battery-driven or plug-in hybrid vehicles should be an important pillar of transportation. This is true for passenger cars, light-duty trucks and short-haul trucks, buses and to a certain degree long-haul trucks. Fuels produced on the basis of renewable energy are of interest to these means of transport, with the exception of niche applications, that cannot directly use electricity such as shipping and aviation, since they offer large volume potential. Considerable amounts of regenerative electricity are required for their production that generally require additional renewable energy plants such that it needs the erection of PtL and PtG plants on internationally suitable renewable energy sites.

2.5 Infrastructure for Transportation Energy Supply

The supply of transportation with energy, currently in the form of fossil fuels mainly requires, apart from a few exceptions, an infrastructure exclusively used by vehicles. This infrastructure of transport is mainly connected to the overall energy supply infrastructure, as are other consumers. The construction and maintenance of the transportation supply infrastructure is associated with huge economical effort and negative ecological consequences. For these reasons, when regarding various energy supply options for transportation, it is worth checking how worthwhile and sustainable it is to have different supply infrastructure (at least for a time of transition or even long-term) for the same means of transport, or at least the same transportation platform (for example road transport). First, road transport will be considered, where natural gas is already offered as a fuel, followed by a short overview of other means of transport.

When considering road transport, it is conceivable that a large proportion of the vehicle fleet could be battery-driven for climate-protection reasons and that this would make a corresponding charging infrastructure for passenger cars and light duty trucks unavoidable. Hybrid vehicles would require at least one other supply infrastructure. It needs to be critically examined whether other fuels with different physical states or different types of fossil or renewable source should be made available.

Regarding only the effort required for a supply infrastructure for the entire transport volume, it appears prudent to limit the supply to the fewest possible and most similar fuels. Other scenarios could result from a systemic holistic view in which different means of transport and under certain circumstances even parts of the transport means are optimally provided for. In this case, the additional effort required concerning the infrastructure must be weighed against the advantages for the means of transport. It is however questionable, how far the state is able to or even has an interest to control the market to a large degree to avoid too many parallel transportation energy supply infrastructures. A diversification of transportation energy supply and the different transportation platforms may even be advantageous in reducing the dependency on certain countries and regions.

Generally speaking, different fuels require separate supply lines; particularly if they have different physical properties under standard ambient temperature and pressure. The effort required by the road traffic supply infrastructure for various fuels is different. For example, it is somewhat higher for natural gas than for liquid fuels, since compression to pipeline pressure is required when first connecting to a pipeline infrastructure and at the filling station to filling pressure. Whereas liquid fuels can normally be delivered by truck to the filling station, which requires little effort, is relatively simple and permits the delivery of different fuels in liquid form, natural gas typically requires a pipeline. The filling station is connected to the general natural gas network with its additional function as a storage. There are non-negligible losses in the transportation of natural gas through the pipeline to the vehicle's tank, but they are significantly lower for example than for hydrogen [28]. Nowadays there is already a sufficiently widespread supply infrastructure for natural gas and liquid fuels for road transport.[2] There is also a very well developed general infrastructure for both fuel types to supply transport as consumer of these fuels.

The statements concerning the availability of infrastructure are also valid for alternative fuels based on renewable energy. Methane and liquid fuels produced from electricity already have a well-developed general infrastructure and also a well-developed traffic supply infrastructure: for fossil natural gas and fossil liquid fuels. It is probable that PtG-methane can be mixed with fossil natural gas, since there is only one natural gas network, so that the user only fills up with a share of the fuel.[3] In the case of PtL-fuels, depending on how the system establishes itself, both balanced or physical delivery are thinkable. There is currently no sufficiently developed supply infrastructure for PtG-hydrogen, neither for transport purposes or otherwise. However, there are initiatives in Germany and Europe to develop a hydrogen supply network.[4] What this application of PtG-hydrogen will look like regarding road transport depends on the general development trend.

Similar basic demands on the infrastructure also exist for alternative fuels based on biomass. In the case of biogenic synthetic natural gas, it is possible to physically deliver it or mix it with fossil natural gas. Biogenic liquid fuels can also be mixed with gasoline or diesel and can than be used by vehicles, with possible slight modification, can be refueled with the fuels in a pure state. In both cases, slight modifications to the supply infrastructure may be needed.

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[2] In Germany there were about 900 natural gas filling stations and a total of approximately 14,000 filling stations for liquid fuels, mainly based oil-based.

[3] Similar to renewable electricity that is not physically consumed, but whereby the renewable electricity is fed into a general production pool and the customer consumes power from an unknown source: the renewable power is then charged by share. This system is also used for example by Audi for Audi-e-gas, whereby customer consumption of e-Gas is registered via a filling card and the corresponding amount of PtG-methane is fed in to the natural gas network.

[4] In Germany there are approximately 40 hydrogen filling stations, seven of them of operated publicly.

Other means of transport, for example inland water and maritime traffic, are also currently intensively being checked to see whether liquid natural gas (LNG) could be used on a large scale instead of heavy oil, due to increasingly strict pollution emission requirements. From a supply infrastructure point of view, these fuels will require their own supply network. However, the possibility of deploying LNG in ports is easily conceivable in the medium and long term, since natural gas is already transported in liquid form by seafaring vessels to selected ports and it is probable that in the future appropriate infrastructure for landing and storing such fuels will be build up in more and more ports.

2.6 Summary

An element in the action plan to comply with the global 2-degree limit is that transportation at least massively limits the growth in its greenhouse gas emissions or rather contributes significantly to a reduction in emissions. This is necessary on both a national and a global level. The whole world is experiencing a massive surge in the growth of the transport performance: all forecasts point to further growth. It is therefore a problem of global proportions for which an exclusively national view is insufficient. Apart from the different boundary conditions in the various regions, it must be noted that the different transportation platforms have different growth and have different potential and options for the reduction of greenhouse gases. Forecasts assume that the GHG emissions due to transportation will more than double by 2050, from 6 $GtCO_{2,eq}$ to 14 $GtCO_{2,eq}$.

Since economic growth and traffic growth are coupled in many countries, steps to drastically reduce the volume of traffic or to reduce its growth are politically difficult to impose. The conclusion is that it is highly probable that only minor successes can be achieved in this area. It appears that the key to the transport-based climate issue lies in the domain of transport's energy supply.

Global transport must reduce its forecasted greenhouse gas emissions in 2050 by about 80 %, if it is to comply with the 2-degree goal set out in climate protection. To do this, there is a range of indicators that even deem it necessary to reduce the levels by 100 % after 2050.

A drastic reduction of greenhouse gas emissions in global transportation cannot be achieved alone through steps to avoid transport shifting transport to more environmental modes of transport and reducing the specific energy consumption by the required amount. The targeted emissions reduction in the transportation sector is only possible on a global scale if energy supply options are available that contribute to substantial reductions.

There are a variety of options available for the different transportation platforms: The direct use of electricity based on renewable energy is practicable. The current level of knowledge states that there are no short or medium term globally available options for the direct use of electricity for heavy-duty traffic, shipping or aviation. However it must be mentioned that the direct use of electricity in commercial vehicles is in its infancy. Since the greenhouse gas emissions from the transport sector from a global perspective are currently still increasing, the pressure to act and solve issues in traffic is growing rapidly.

It is therefore high time to develop strategies to make technologies and energy carriers available for the transportation sector and if possible for other sectors too that have no negative impact on the climate.

An important element in such a strategy is, according the wisdom of today, the production of synthetic methane utilizing electricity. This affects the purely technological availability of production and its future development. It can be the basis for a climate-neutral energy supply for transportation, where for example direct use of electricity (rail, passenger car, light-duty trucks) is not possible. Without a massive increase in the development of renewable electricity supply up to the time corridor 2050–2070, this technology, as a contribution towards climate-protection, is however not very practicable. In parallel to this important initiative, the basis of every action in the transport sector is to significantly reduce the specific energy consumption of each individual traffic platform to dampen the growth of transportation effort.

The use of synthetic methane is practicable in view of the already widely available infrastructure.

Natural gas has the potential of reducing the CO_2 emissions in transport due to its physical properties (C/H ratio): It increases the efficiency of Otto engines since higher compression ratios are possible; methane can also be produced synthetically. Natural gas represents a step towards greenhouse gas neutral transportation. The next step would be the fastest possible formulation of a globally effective strategy for the industrial production and use of electricity-based fuels from renewable energy sources (for example PtG-methane) and the direct use of electrical energy in the transportation sector. At the same time, directed further development of the technical processes needs to be initiated, unless other more realistic methods can be found how to comply with the 2-degree limit without having to use electricity-based fuels.

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