Renewbility: options for a decarbonisation of the transport sector up to 2050

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Keywords

alternative vehicles, alternative fuels, electric vehicles, climate policy, scenarios, transport policies and measures, urban transport, energy efficiency improvements

Abstract

The project "Renewbility" presents several climate protection scenarios for the transport sector in Germany, modelling vehicle stocks, transport demand, energy consumption, CO_2-emissions and economic effects. Funded by the German Ministry for the Environment, this project has involved a broad range of stakeholders of the transport sector and thus included different positions and interest in the design of the scenarios. Common objective of all scenarios is the full decarbonisation of the transport sector by 2050.

The results show the need for clear and future-oriented political action: Electric vehicles need to be an essential pillar of an overall strategy against climate change up to 2050. Power-generated fuels should only be used where no other option exists – probably in air and maritime transport. Effective policy measures include the phase-out of the internal combustion engine, which could be realised by more ambitious CO_2-standards combined with increasing fuel prices.

Moreover, the scenario analysis indicates that increasing sustainable urban mobility would be an effective strategy not only for a higher quality of life for citizens, but also against climate change and other negative environmental effects. In order to offer alternative options for car users, the promotion of sustainable transport modes such as public transport and cycling is necessary. Important policy measures for local authorities include parking space management. Implementing measures for enhancing the quality of public transport, rail freight traffic, and life in cities is even expected to increase GDP and to reduce external costs.

In summary, the decarbonisation of the transport sector offers the opportunity to combine climate protection with a positive economic balance. It is the role of policy makers in partnership with industry and other stakeholders to build up the necessary framework to realise these benefits and successfully combat climate change. In order to fully decarbonize the transport sector by 2050, transformation processes in both society and industry have to begin as soon as possible.

Introduction

Climate change presents a growing challenge. Greenhouse gas (GHG) emissions need to be reduced in a radical way to effectively delay global warming. At the climate summit in Paris in 2015, the global community has committed to an almost neutrality of GHG that are induced by our mode of life and economic activities. Therefore, the GHG emissions have to be reduced in the second part of the century to net zero emissions globally.

The need for action such as the implementation of political measures is already enormous. The reconstruction of energy, production and transport systems is complex – also due to the high variety of stakeholders involved – and needs a lot of time.

Even if the entire economy contributes to climate protection, a full decarbonisation is not feasible in all sectors. For example, in agriculture natural limitations exist for a total reduction of GHG. This implies that energy-related emissions need to be reduced to zero by 2050. This applies also to the transport sector.

Power needs to be generated from renewable sources. A CO_2-free transport sector can only be achieved through a combination of technological innovations, energy-saving measures and a regulatory framework which supports a change in mobility behaviour. To make matters worse, in Germany, for example, the GHG emissions of the transport sector are still at the same level as 1990.

Only some studies explore national scenarios that focus on the transport sector and model a 95 % reduction of GHG emissions by 2050. Often transport is just one subject amongst others and is therefore not examined in detail. For example, the study "Pathways to decarbonisation in the United Kingdom" (IDDRI & SDSN 2015) investigates in addition to the transport sector the GHG emissions induced by energy production and building infrastructure in the UK. The study analyses three scenarios to show how GHG emissions can be reduced by 80 % until 2050 compared to 1990 levels. Regarding the transport sector, this study focuses on the parameters of oil consumption, decarbonisation of passenger car demand and the transition in vehicle type in the transport freight sector. The authors estimate that the overall oil consumption in the transport sector in the UK can be reduced 20 % by 2030 and 70 % by 2050 respectively compared to 2010.

Cuelenaere et al. (2014) take a slightly different approach. Focusing on transport energy carriers in the Netherlands they assume that the target of reducing CO_2-emissions by 60 % by 2050 relative to 1990 is met in every single scenario. Depending on the scenario and the measures involved, they calculate the total final energy mix per scenario, the CO_2-emissions (TTW) per transport mode, the CO_2-emissions (WTW), total cost of ownership of road transport, NO_x and PM10 emissions, tax revenue and social costs.

The research "Nordic Energy Technology Perspectives" by the IEA (2013) develops five possible scenarios for the Scandinavian countries up to 2050. This research looks into GHG emissions generated by the transport sector as well as by the industrial construction sectors. All Scandinavian countries present high reduction targets for GHG emissions. However, a difference at the national target level can be identified. While Iceland and Finland target a reduction of GHG emissions of 50 % to 70 % and 80 % respectively by 2050, the goal of the Swedish government is to have a vehicle stock that is independent of fossil fuels by 2030 and a 100 % net reduction of GHG emissions by 2050. The Norwegian government aims to cut GHG emissions 100 % by 2050, and the objective of the Danish government is to use only renewable energies by 2050. Investigating a variety of parameters, the report assumes for the ambitious 2-degree scenario (2DS) a reduction of the energy consumption in the transport sector of 24 % by 2050 compared to 2010. This reduction is mainly driven by lower energy consumption in passenger (-50 %) and freight (-15 %) transport. Furthermore, the study estimates that the growth in passenger transport for the 2DS and the carbon neutral scenario (CNS) will only be slightly lower than in the more moderate 4-degree scenario (4DS). The difference compared with the 4DS occurs due to a shift in the transport mode with the share of rail and bus increasing from 12 % of total passenger transport in 2010 to 20 % in 2030 in both scenarios. Regarding CO_2 emissions, the report states that the 2DS (37 $MtCO_2$) implies a reduction of 50 %, while the CNS implies a reduction of 80 % (12 $MtCO_2$) by 2050.

In the past ten years the project "Renewbility" has looked into climate protection options for politics, industry and civil society for the transport sector in Germany. The results of the third phase of "Renewbility" show that a full decarbonisation of the transport sector could be possible – and which options are expected to be most effective.

Renewbility III: Research setting

The project "Renewbility" develops and analyses scenarios for the German transport sector based on complex models estimating future vehicle stock, transport demand, material requirements, energy demand, CO_2-emissions and economic effects (Zimmer et al. 2016). These models also capture interactions between the energy and transport sector. The project was conducted by the Öko-Institut, Institute of Transport Research at DLR, INFRAS and ifeu-Institut on behalf of the German Ministry for the Environment.

A TCO-based model was developed to simulate new registrations of cars and trucks (especially powertrain choice and efficiency of new vehicles), taking into account user profiles (km driven), restrictions due to long trips, fuel and vehicle prices and political instruments such as the EU regulation on 443/2009 on CO_2 emission performance standards for new passenger cars.

In order to assess the impact of measures on passenger transport demand, several demand models were deployed, each focussing on specific travel markets: a macroscopic daily travel model, a macroscopic long distance travel model and a microscopic model for selected areas (TAPAS). The daily travel demand model is used to represent short distance trips (travel distance up to 100 km) in Germany. It employs a fine-grained zoning structure and follows the "EVA" approach (see e.g. Vrtic et al. 2007), providing simultaneous calculation of trip distribution and mode choice. Competing modes include car, public transport and also the non-motorized modes (bicycle, walking). The long distance travel model contains a coarser zoning structure and a different mode choice set, excluding the non-motorized modes but including airplane travel, rail, coach etc. It is set up using a classic nested logit approach. The regional model TAPAS determines the daily mobility pattern of individual agents following an activity-based approach.

For forecasting, the travel demand models require input regarding the population, motorization rate, vehicle fleet characteristics, fuel prices, public transport fares etc. This information is obtained either as an input from other models in this research project or derived from available forecasts. The output from the travel demand models includes the total number of trips per year, origin and destination of trips, mode shares, vehicle and person miles travelled by mode etc. Car travel is also differentiated according to the type of vehicle/propulsion system used, therefore enabling accurate subsequent modelling of emissions and energy consumption. Information on travel expenditures is also used in the economic analysis. For further details on the travel demand models see Zimmer et al. (2016), Mocanu & Winkler (2016) and Heinrichs et al. (2016).

In order to analyse measures for their impact on modal split, ton and vehicle kilometres of fright transport, the dedicated transport model FRIDAY was used. Vehicle costs were provided by the fleet TCO-model. Model output was used to derive economic and environmental impacts. The macroscopic model considers all surface freight flows in, through, into and out of Germany. Freight demand was based on the national forecast provided for the German transport infrastructure master plan (German traffic forecast 2030). For the year 2050, this demand was extrapolated from 2030 by means of GNP elasticities of 24 different commodity groups and separately for national, international continental and overseas demand. The freight demand of the base scenario was adjusted to reflect a decarbonised economy according to estimates from Öko-Institut and Fraunhofer ISI (2016). The model consists of a discrete choice model for the modes rail, road and inland waterway transport, and factor approaches to convert flows into vehicle trips with nine different transport means (vehicle size/train class). The model reflects changes to costs and travel times. The effect of measures on detailed cost components and utilisation of trains/vehicles is converted in a transport cost model into relation based costs for the three modes. The analysed measures can address different market segments like combined transport, bulk goods or different types of general cargo.

An important question to fully analyse the different scenarios is whether and how they affect the economy. To answer this question, the project "Renewbility" uses an economic simulation model that builds on differentiated input-output-tables covering the main transport sectors in Germany (VEDIOM). Basis for the VEDIOM-model is the officially published German input-output-table of the year 2008. Within the project, the most important transport sectors were then differentiated so that, for example, passenger road transport, freight road transport and passenger rail transport could be analysed separately. Using already existing data material for 2030 (German traffic forecast 2030, 2014) and projections for 2050 by the multi-regional and multi-sectoral general equilibrium model FARM-EU, projections up to 2030 and 2050 have been made. Based on these pillars, the input-output-model VEDIOM was constructed in order to analyse the economic effects of the different scenarios. For these simulations, we use the before presented data on passenger as well as tonne-kilometres, energy quantities and the number and prices of vehicles as main input data. Thus, transport demand reactions stem from the transport modelling. Within the economic analysis these effects are verified. At last, all these inputs are converted into economical quantities such as expenditures of consumers, investments by companies or required tax amounts of the government.

The project "Renewbility" is the first project combining a stakeholder participation process with the scientific development of scenarios. Due to the participation of stakeholders from transport and energy sectors the design of the scenarios takes into account the points of view and interests of different groups. The researchers held meetings regularly with a so called scenario-group which was composed of representatives of the automotive, train, energy and logistic industry as well as of environmental and consumer protection associations, complemented by bilateral interviews. In the course of the development of an integrated strategy for a sustainable mobility in Germany such a participation of stakeholders was considered essential.

In the first two phases of the project scenarios up to 2030 were developed while in the third phase the examination was extended up to the year 2050. The main precondition for the third phase of "Renewbility" was that only scenarios were examined that result in a full decarbonisation of the transport sector by 2050. That implies that the energy demand at this particular time is met by renewable electricity, power-generated fuels (produced with renewable electricity) or by biofuels. In different scenarios the decarbonisation of the energy demand was then combined with additional options regarding vehicle efficiency and measures resulting in a change in mobility behaviour.

To be able to assess the effects of a decarbonisation, in a first step we developed a baseline scenario (business as usual),

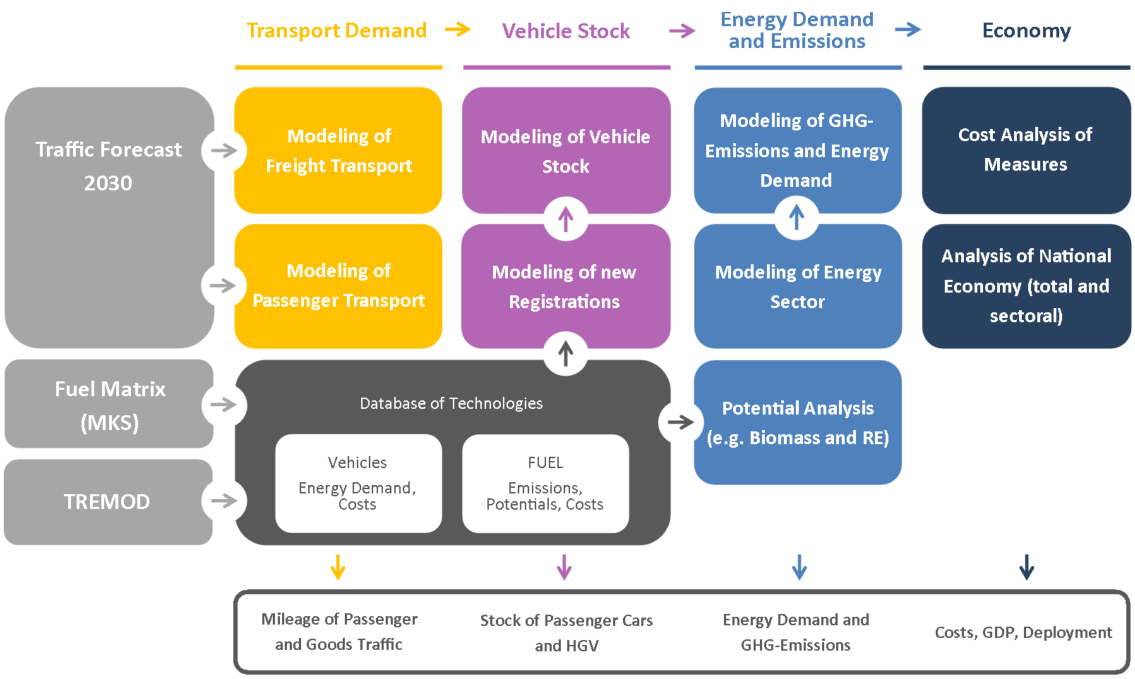

Figure 1. Framework of model modules used in the project Renewbility.

which was mainly based on the German traffic forecast by the ministry for transport (German traffic forecast 2030) and a climate protection study from Öko-Institut and Fraunhofer ISI (2016). Based on this baseline scenario two climate protection scenarios ("Efficiency" and "Efficiency plus") with additional sub-scenarios were developed.

Electromobility and energy demand

Technical efficiency enhancement and the use of renewable energies are of special importance for climate protection in the transport sector. In the "Renewbility" scenarios 95 % of the fuels in 2050 are power-generated and the additional costs of their production are borne by the users; power-generated means liquid fuels like diesel or gasoline produced by renewable electricity via electrolyses and Fischer-Tropsch-Synthesis.

The "Efficiency" scenario assumes an ambitious adjustment of the CO_2-standards for passenger cars as well as the introduction of overhead lines on motorways for lorries. On the contrary, the so called sensitivity-scenario "Focus Fuels" assumes no further adjustment of CO_2-standards and no trolley-trucks, so only the additional costs for power-generated fuels drive the demand for more efficient vehicles. The comparison of these two scenarios shows that without further adjustment of CO_2-standards the demand for electric vehicles will be much lower than in the Efficiency scenario. If the goals for climate protection are mainly achieved by power-generated fuels and less by the deployment of electric vehicles, the demand for electricity in the transport sectors increases dramatically until 2050 (Figure 2). The demand of the German transport sector will then be even higher than today's gross power generation in Germany. The reason is that the production of power-generated fuels for use in conventional internal combustion engines requires a lot more energy than the energy use of electric vehicles. In other words, electric vehicles drive about 6 times further with the same amount of electricity than a car with a combustion engine with power-generated fuels – depending on the technology development (UBA (2016).

It can be concluded that power-generated fuels should be used only if no other option exists – as expected in air and maritime traffic. If society wants to go an energy efficient way for climate protection in the transport sector, Government may have to force the efficiency enhancement of vehicles including electric vehicles by political measures, mainly by an ambitious adjustment of CO_2-standards combined with higher fuel costs to avoid rebound effects.

Urban Mobility

Approximately two thirds of the energy consumption and CO_2-emissions of the transport sector in Germany are induced by passenger transport. The demand for personal mobility, as measured in passenger kilometres travelled, is expected to increase in the baseline scenario between 2010 and 2050, in spite of a population decrease of nearly 10 %. Increased car availability, slightly higher personal incomes and an ageing population all contribute towards this development.

About 20 % of the overall passenger kilometres travelled in Germany stem from short trips (no longer than 100 km) which either begin or end in inner cities (own calculation based on the demand model). At the same time, those cities are increasingly affected by fine-particle and noise pollution and a growing competition for urban space. Hence, cities are not only in need for political action, but cities offer at the same time diverse options for the application of measures that both make every-day mobility more sustainable and contribute to climate protection.

As shown in the previous section, the scenario "Efficiency" addresses two general possibilities for reducing GHG emissions in transport: the deployment of more energy efficient vehicles and the decarbonisation of the energy carriers used. Other approaches include the reduction of transport demand or stimu-

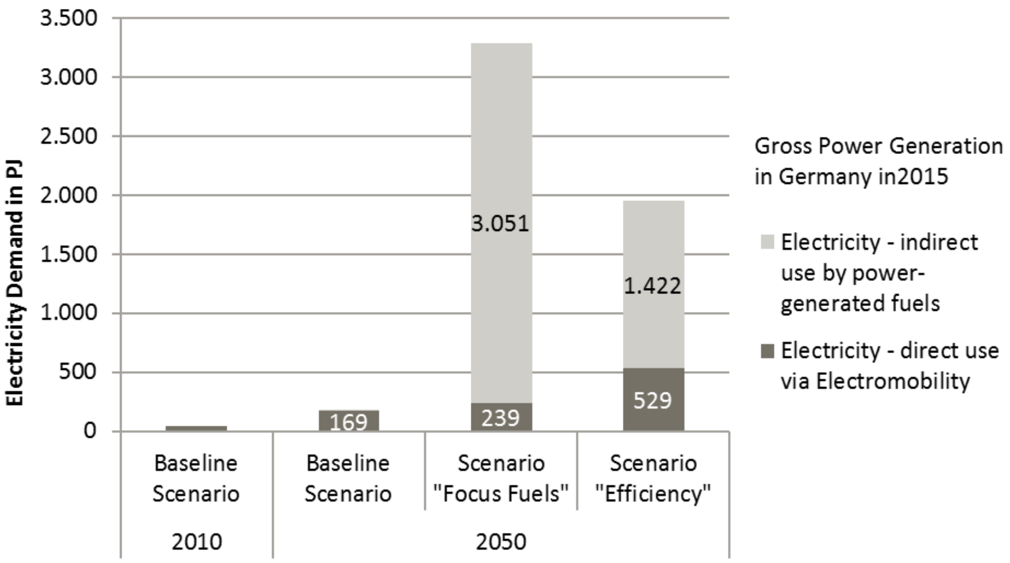

Figure 2. Electricity Demand by Transport Sector 2050.

lating a shift from individual motorized transport towards more energy-efficient and environmentally friendly modes of transport.

The latter was put into focus in a scenario called "Efficiency plus". In addition to the electrification of vehicles, "Efficiency plus" contains a set of measures meant to promote a modal shift and to improve quality of life in (inner) cities. Measures include an improved local area supply and a stronger land-use mix in the spirit of the "city of short distances" planning concept, a country-wide introduction of car sharing in cities over 50,000 inhabitants and inner-city access restrictions for polluting vehicles in cities over 200,000 inhabitants. Furthermore, a large-scale expansion of parking space management with a substantial increase in prices, a 30 km/h speed limit for all urban secondary roads and an increase in the attractiveness of cycling and public transport were assumed.

Model results for the scenario "Efficiency plus" clearly indicate that the measures included in the scenario constitute a relevant lever for climate protection in the transport sector. The motorization rate in cities with more than 100,000 inhabitants is lower by a third compared with the baseline development in 2050. Particularly in urban areas attractive alternatives to the private car are available and will be used, resulting in a reduction of urban passenger kilometres travelled by car by almost a half (see Figure 3). At the same time, distances covered by cycling, car-sharing and public transport increase in absolute and relative terms and account for almost 60 % of passenger miles travelled in the scenario "Efficiency plus" in urban areas. Overall, passenger kilometres travelled in German cities are lower by 20 % compared with the baseline scenario in 2050. As denser, more diverse cities and an altered mode use promote the visit of closer destinations, this is mainly due to decreasing trip lengths and only slightly due to a reduction in the number of trips (7 %).

Also from the Germany-wide perspective, a reduction in the private vehicle stock by 15 % compared to the baseline development and 10 % compared with scenario "Efficiency" can be seen – primarily driven by the development of car-ownership rates in the cities. Passenger miles travelled by car are reduced by 23 % compared to scenario "Efficiency" while those travelled by public transport and non-motorized modes increase by 17 % and 43 % respectively.

The scenario "Efficiency Plus" addresses every-day mobility, especially in urban areas. It illustrates that a comparable degree of mobility could be realized with less negative effects. The promotion of public, pedestrian and bicycle transport modes generates attractive alternatives, resulting in a substantial decline in vehicle miles travelled.

Not only in cities, but also in suburban and surrounding areas, the measures can be shown to impact daily mobility. For instance, in this scenario commuters are opting more often for public transport services as an alternative to the car. Overall, negative environmental impacts such as pollutant emissions and noise can be substantially reduced as well. Municipalities play a crucial role in shaping sustainable mobility. One of the key elements could be a more concisely applied parking space management – with pricing both reflecting the value of the space and providing a steering effect.

Freight Transport

Freight transport is responsible for about a third of the transport sector's CO_2 emissions and about 20 % of final energy consumption in Europe. This share may even rise in the coming decades. In many European countries passenger transport tends to reach a peak, while freight transport is bound to further increase significantly, in Germany by about 50 % before 2050 (measured in ton kilometres). Thus, it is of great importance to improve the energy efficiency and reduce the carbon emissions of freight transport.

As in passenger transport, four types of measures support this end: avoid unnecessary transport, shift traffic to energy ef-

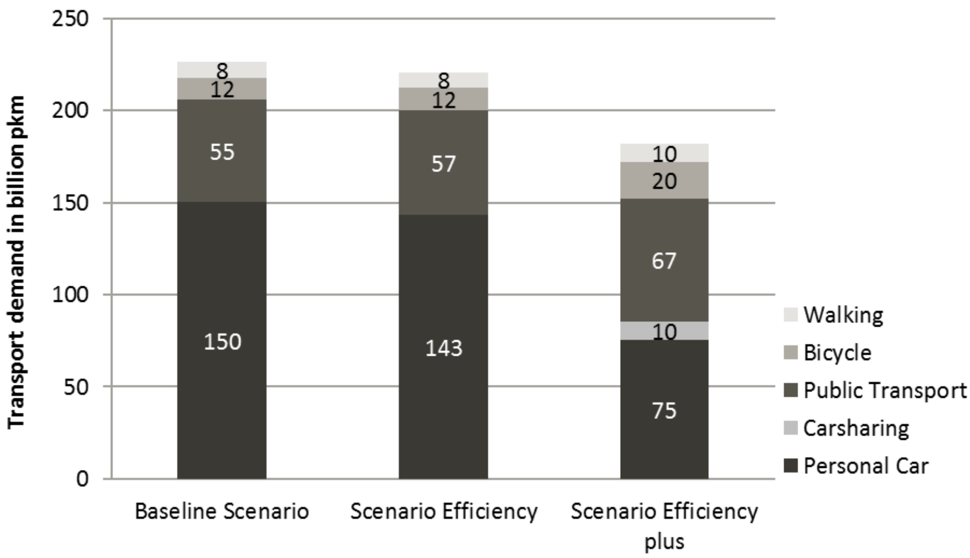

Figure 3. Modelled passenger miles travelled in German cities in 2050.

ficient modes (namely railways), make the remaining traffic as energy efficient as possible (e.g. by energy efficient engines) and reduce the carbon content of the used fuels. So, what are the pros and cons of these areas in general?

Due to the crucial role of freight transport for a thriving economy, measures thwarting freight traffic will always have to be critically assessed against their impact on trade and the economy and often lack public support. Making freight transport more efficient, on the other hand, is often a win-win situation for both the energy consumption and the economy. However, the most economically efficient transport might not be the most energy efficient solution from a systems perspective. Modal shift to energy *in*efficient modes can be the consequence of efficiency improvements (and thus cost reductions) of these modes. Policies supporting efficiency of road freight should be carefully checked for their potential to attract additional traffic (away from more environmental friendly modes) and, if necessary, balanced by measures countering this shift (e.g. likewise improvements of rail transport). Reducing the carbon content of fuels (e.g. by converting renewable electricity to liquid or gaseous power-generated fuels) helps the climate, but lets primary energy demand soar as has been illustrated in Figure 2.

"Renewbility" focused on three sets of measures for freight transport:

- attracting as much traffic to railways as the most energy efficient and least carbon dependent mode of transport by speeding up processes at rail yards and terminals, increasing train size and operation speed, i.e. improving the existing system;
- decarbonising fuels in road and inland waterway transport; and
- reducing primary energy consumption of road traffic by fostering electric vehicles, namely the introduction of overhead lines on motorways for lorries

What can we learn from the models' results? Road traffic will continue to play the prominent role in freight transport (more than 70 % of ton kilometres travelled on German territory in all scenarios). Its efficiency and decarbonisation is, thus, paramount. However, efficiency gains in road transport might frustrate efforts to make rail transport more competitive. Cost reductions in road freight by about five percent overall due to more efficient vehicles lead to a shift of more than 10 billion ton kilometres away from railways and inland waterways.

Electric engines for road freight vehicles are currently too expensive for them to be accepted under market conditions. Increasing fuel prices, emission standards and emission-based tolls/taxes will be required to make them attractive and enable economies of scale in their production. The high prices for power generated fuels (two times as high in 2050 as diesel in the baseline scenario) are a driver to support electric vehicles.

The most energy efficient vehicles are those using electricity directly (c.f. section on electromobility and energy demand). For long distance trips in freight transport, this requires overhead lines (or a comparable technology) as batteries will require too much space and will remain to be too heavy to be viable as far as can be currently foreseen. With the assumed high prices for alternative fuels, infrastructure costs for overhead lines of about 2 m Euro per km[1] paid for by the users and only the most frequented motorways equipped, this system would be slightly cheaper than trucks using power generated fuels. However, the exact costs of the system are still uncertain. The primary energy savings of this system would be offset by about ten billion additional ton kilometres attracted to road transport from rail and inland waterways or one billion additional road vehicle kilometres. The relevance of the European context, funding modalities and the transition period until the infrastructure is operational, however, require additional research. It should be noted that such a system would have to be installed to large extent in parallel to existing railway tracks, further fuelling competition between rail and road.

Measures directed at making the existing rail system more efficient are urgently needed and are suitable to achieve a modal shift. The effect, however, appears to be limited: a change of modal split from 19 % to only 23 % of rail freight, i.e. in consequence a reduction of vehicle kilometres travelled on roads by not even 8 % and 1.5 % less energy consumption. In particular the potential of intermodal transport has to be leveraged in order to shift significant shares of freight over long distances to rail.

The main goal of making freight transport more energy efficient and environmentally friendly is to attract as much of the freight traffic demand to railways, as they are already to a large extent decarbonised and energy efficient. The capacity of the railway network has to be adjusted to this demand by means of technology, operational measures and infrastructure extensions. As road traffic will always be needed to fill the gaps (especially in collection and distribution) left by railway transport, we have to step up existing efforts to make it more efficient – without frustrating efforts for modal shift towards railways, in market segments where they can play a major role. The consequence is to significantly improve intermodal transport by efficient terminal handling and fast and reliable transport by rail, thus combining the advantages of both modes.

Economic results

In general, the scenarios described above influence the economy via three different impact chains, firstly by changes in household expenditures due to a smaller amount of income that is spent for transport services. Secondly, changes in energy and transport demand directly affect the underlying energy and transport suppliers, e.g. power plants or vehicle manufacturer. Lastly, the government expenditure quota may change, and, as we assume that rising government expenditures are directly financed through higher tax revenues, this influences the budget restrictions of the households. When analysing the economic effects, the main focus is on the value added, i.e. GDP, and the overall and sectoral employment. The direct impacts are covered as well as all indirect impacts in Germany (along the supply chains). Additionally, external cost savings in the different scenarios have been estimated to get a more complete analysis of the economic effects of the scenarios. Again, all results in the scenarios are compared to the baseline scenario.

1. Based on scenarios and costs from UBA (2016); different research states even higher costs (Wietschel 2016).

How do the different scenarios affect the economy in Germany in 2050? In the "Efficiency" scenario, decarbonisation is achieved due to a strong focus on vehicle efficiency and the decarbonisation of the fuels with correlated higher fuel prices. This leads to a shift in the transport modal-split, with a higher share of public transport and a lower share of road transport and an overall decreasing transport demand. These changes come with a strong rise in the demand for electricity in the passenger as well as in the freight transport sector because the assumed vehicle emission targets push the share of electrical vehicles. At large, households spend less on transport due to higher transport prices but consume more in all other sectors as we assume constant saving rates. Overall, no significant impacts on GDP can be found in this scenario in the long-run. On top of that, the external costs can be reduced due to smaller external climate costs, less air pollution and decreasing health costs. Taking into account both changes in GDP and in external costs, a small positive effect on general welfare can be found for the "Efficiency" scenario.

The scenario "Efficiency plus" assumes that further measures are taken compared to the "Efficiency" scenario. These measures render inner-cities more liveable and further improve the quality of public transport, strengthening the relative attractiveness of public transport and weakening the one of road transport. These measures come with a heavy decrease in road passenger demand, and therefore with large negative impacts on the attached sectors, an effect that is up to 50 % higher in this scenario compared to the "Efficiency" scenario. Then again, due to smaller transport expenditures the households have more disposable income and can thus spend more in other sectors. To conclude, the additional measures in the "Efficiency plus" scenario lead to small positive effects on GDP.

Given the expected volume of GDP in Germany in 2050, the reported effects of both climate protection scenarios are very low. The analysis thus shows that the decarbonisation of the transport sector alone would not be accompanied by major shocks to the German economy. However, this does not imply that no other sectors are affected when decarbonising the transport sector, as this shift comes with some rather large effects in single sectors. Regarding the employment effects of the scenarios one quickly sees some major differences across various sectors. For example, there won't be any need for services and products of the mineral oil processing industries in the climate protection scenarios. This means that all of the today's employees in this sector will vanish until 2050, reflecting a loss of 100 %. But while sectors such as air transport and assurances will also be faced with reductions of sales and employees, other sectors will benefit from these changes: positive employment effects can be found in the power generation sector, in the public transport sector, in the building and construction sector as well as in several service sectors (see Figure 4).

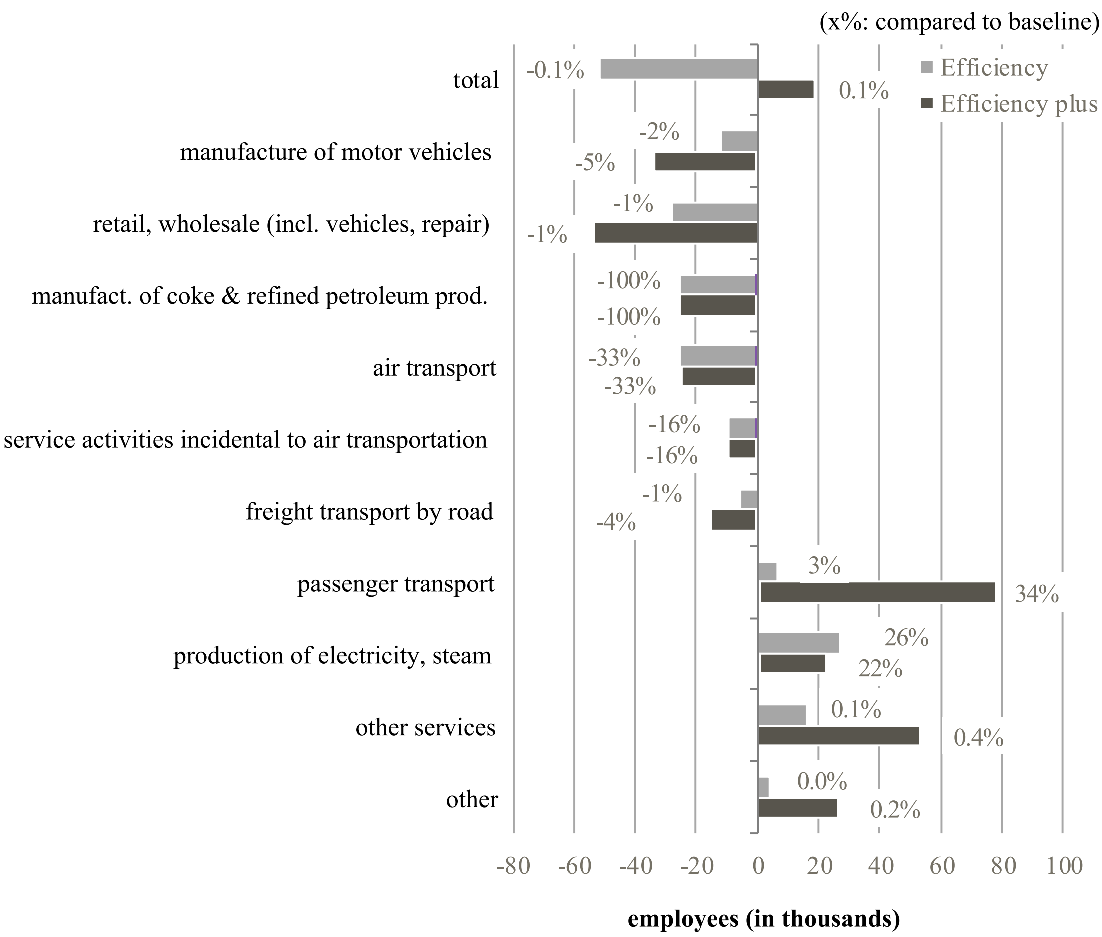

Figure 4. Changes in employment across sectors compared to the baseline scenario in 2050.

Table 1. Welfare effects 2050 of the analysed scenarios.

in bn. Euros compared to the baseline scenario	"Efficiency" scenario	"Efficiency plus" scenario
GDP	0	5
Reduced external costs	17	18
Total	17	23

Concluding, there won't be a major drop in GDP due to the decarbonisation of the transport sector in Germany but there will be structural changes in several sectors. For these changes to be adequate and appropriate and in order to get planning reliability, they must be prepared early and carefully. Furthermore, the decarbonisation process in the transport sector has to be harmonised with similar activities in the rest of the economy. How strongly each sector will be hit by these changes will depend on the general conditions and the economic framework as well as on the reactions of each company to the changing environment and these new challenges.

Thus, the two alternative (non-baseline) scenarios analysed offer good prospects to attain the goals of climate protection without any significant losses in GDP. If we add the impacts on external costs of the scenarios to the GDP impacts, an overall welfare benefit exists. For both scenarios the overall economic effects are slightly positive as shown in Table 1.

However, to attain this slightly positive economic impact a few prerequisites are necessary: Beside a fixed and predictable framework for the decarbonisation process it is important that Germany and its industries can keep up the technological know-how of today's production in the future. The vehicle manufacturing industry, especially, must remain competitive to be able to hold today's market shares. Thus, adapting to new vehicle technologies is essential to avoid economic shocks.

Conclusion

The project "Renewbility" demonstrates that a full decarbonisation of the transport sector in Germany is possible. Several options for decarbonisation exist showing different kinds of opportunities and risks. It is almost certain that a change in travel behaviour – which can particularly well be addressed in cities – and the use of electric vehicles are essential for an energy and economically efficient way to decarbonise the transport sector. In summary, the decarbonisation of the transport sector offers the opportunity to combine climate protection with a positive economic balance. Politics need to set up the framework: The transport system needs to be transformed towards higher efficiency by means of modal shift, vehicle efficiency and transport demand reduction. In freight transport, support of inter-modality is necessary to strengthen railway transport for long distance trips. Vehicle efficiency with carbon free energy requires the promotion of electric vehicles. In order to achieve a full decarbonisation of the transport sector by 2050, transition processes in both society and industry need to be initiated as soon as possible with the energy transition being a prerequisite for the decarbonisation of transport.

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Acknowledgements

We acknowledge the federal ministry for the environment, nature conservation, building and nuclear safety for financing the project, as well as Thomas Bergmann, Moritz Mottschall, Dr. Hannah Förster, Dr. Katja Schumacher (Öko-Institut), Dr. Christian Winkler (DLR), Frank Dünnebeil, Claudia Kämper, Horst Fehrenbach, Kirsten Biemann (ifeu) and Damaris Bertschmann, Remo Zandonella (INFRAS) plus the agency Agentur tippingpoints. More information can be found under www.renewbility.de.