Development of Application-Related Emissions in the Course of the German Energy Transition

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Abstract:

This paper develops a methodology to determine the direct and indirect emissions from different applications in the final energy sectors. This enables the emissions of the energy industry to be allocated to the respective final energy consumers. The methodology is carried out for the years 2006 to 2016 and the result for the most recent year is described in detail. It becomes clear that the provision of mechanical energy and process heat, which contribute to 64 % of total energy-related CO_2 emissions in 2016, are stagnating in their development. While CO_2 emissions for process heat have decreased by about 5 % from 2006 to 2016, the reduction of emissions related to mechanical energy is below 1 %. Thus, great efforts are needed especially in these areas to avoid the risk of failing to meet decarbonisation targets.

Keywords: Emissions balance, CO_2 emissions, decarbonisation, energy transition

1 Introduction

Despite the considerable deployment of human and financial resources, so far Germany has largely not achieved the targets for the implementation of the energy transition [1]. With these harsh words, the Federal Audit Office starts its evaluation report of the implementation of the energy transition in Germany. In fact, achieving the envisioned reduction of about 55 % of greenhouse gas (GHG) emissions by 2030 compared to 1990 seems unlikely, when considering the development of CO_2 emissions in recent years. Energy-related CO_2 emissions, which were responsible for 98 % of all energy-related GHG in 2016, have fallen by 24 % since the base year 1990. However, in recent years they have stagnated and in some years even an increase can be observed. But to achieve the targets for 2030 a reduction of more than 20 mio. t of CO_2 per year is needed with the assumption that other GHG emissions fall accordingly. [2]

To be able to focus specifically on applications that are stagnating in their development, it is necessary to allocate the emissions to the different applications (e.g. mechanical energy, process heat, space heating, lighting) in each sector and track them over time. By doing so, the relevance of the respective application for achieving the climate protection targets based on their contribution to total emissions and recent reduction achievements can be determined. Ultimately, measures must be found to decarbonise these applications in a targeted manner to contribute to a successful energy transition.

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This paper presents a methodology to identify and evaluate direct and indirect energy-related CO_2 emissions of different applications. While ‘direct emissions’ are the emissions emitted in the final energy sectors due to the combustion of fuels, ‘indirect emissions’ describe the emissions occurring in the energy supply sector for the provision of final energy carriers such as electricity, district heat and fuels. The methodology is then applied for the years 2006 to 2016 and as a result, the application-related emissions balance for these years is presented.

2 Methodology and Input Data

In order to identify applications with high CO_2 reduction potential and to derive relevant abatement measures, an application-related emissions balance for 2014 was drawn up in [3]. The approach, which is summarised in Figure 1, enables the allocation of indirect emissions arising in the energy supply sector to the respective final energy sectors and applications.

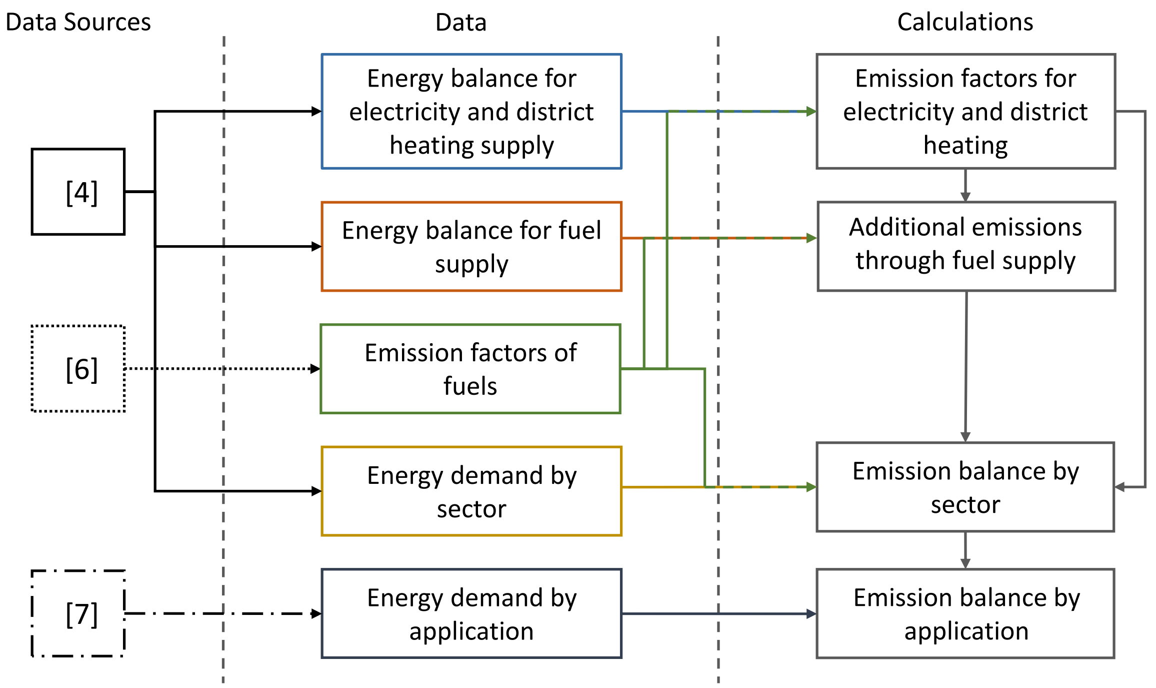

Figure 1: Methodological approach for application-related emission balancing

In the following, the main data sources shown in Figure 1 are subsequently described in order to provide an overview of the input data used for the development of the application-related emission balances. [4] contains a detailed energy balance for Germany, which lists both the energy generation and the energy consumption by energy carrier. On the generation side, primary energy input by energy carrier and resulting electricity and district heating generation are stated. The electricity supply side is split into public and industrial autoproducer electricity supply. Emissions resulting from industrial autoproducer electricity generation are assigned to the different industry branches based on [5]. It is assumed that the total electricity produced by industrial autoproducers is also consumed in the industry sector. In the case of combined heat and power generation, the energy input is allocated using the Finnish Method. In addition, the energy consumption for fuel supply, for example in coking plants or mines, as well as energy imports and exports are provided. The energy demand side is divided into the sectors industry, private households, service and transport. The industry sector is further broken down into individual branches and the transport sector into the modes of transport.

While the second main source of data is [6], providing combustion-related CO_2 emission factors for all relevant fuels in Germany, the third source depicted in Figure 2 is [7], which contains the energy demand by application and energy carrier for each sector. The energy applications are mechanical energy, process heat, space heating, hot water, space cooling, process cold, lighting and information communication technology (ICT). All data is available from 2006 or earlier to 2016, with the exception of the energy balances by application. Therefore, the data from [7], only dating back to 2008, is kept constant for the two previous years.

Based on the described data, in a first step, emission factors of district heating and of electricity from industrial autoproducers and from power plants feeding in the public grid are calculated. As shown in Figure 1, these emission factors are then used to calculate the emissions associated with the supply of fuels. In a next step, these indirect emissions for fuel provision are distributed to the four final energy sectors in proportion to the sector's final energy consumption for gas-, coal- and oil-based fuels. Accordingly, the indirect emissions from the generation of electricity and district heating are allocated to the different sectors proportionally to their demand for these secondary energy carriers. Next, the emissions balance by sector is determined by combining these indirect emissions with the direct emissions occurring in the sectors due to the combustion of fossil-based energy sources. The application- and energy carrier-specific energy balance is then used to distribute the emissions of the sectors among the different applications. Finally a temperature adjustment is carried out on the basis of [8] to account for the temperature dependency of heating applications.

3 Results

In this section, the development of energy-related CO_2 emissions between 2006 and 2016 is analysed. In this context, applications lagging behind the targets are identified and their relevance for the achievement of climate goals is discussed. The year 2016 is then examined in more detail. Wherever possible, a temperature adjustment was carried out.

3.1 The Trend in CO_2 Emissions

Table 1 shows the emission factors of electricity and district heating for each year. For electricity, a distinction is made between public supply and industrial autoproducer electricity.

Table 1: Energy-related CO_2 emission factors of general electricity, industrial electricity and district heating from 2006 to 2016 in g CO_2/kWh

Emission factor in g CO_2/kWh	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*
Electricity (public)	576	592	557	551	535	550	555	553	536	500	491
Electricity (industry)	883	923	885	762	811	768	736	741	741	790	791
District heating	266	287	274	270	273	280	277	277	279	273	267

Using these emission factors, the resulting indirect emissions for fuel supply are calculated as described in Chapter 2. Subsequently, the total emissions are allocated to the final energy consumption sectors. Figure 2 shows that total emissions have decreased between 2006 and 2016. However, from 2015 to 2016 an increase of 5 mio. t CO_2 can be observed, which can be traced back to an increase in emissions in the transport sector. This is due to an increasing demand in diesel and kerosene as a consequence of more freight road transport and air traffic. As a result of the economic crisis, the industry recorded lower emissions in 2009. A similar, yet less drastic effect is recorded for the service sector and for private households.

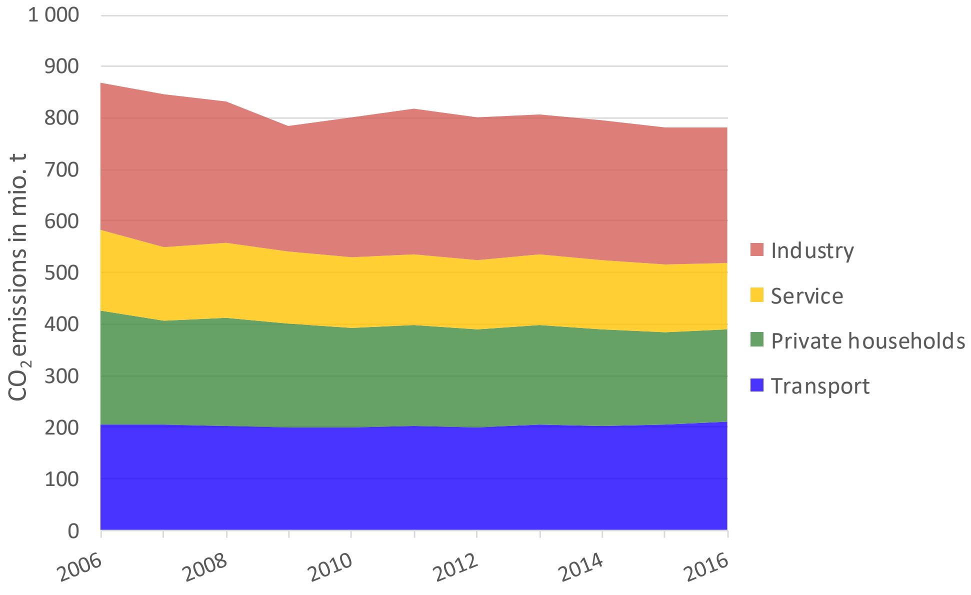

Figure 2: Development of energy-related CO_2 emissions by sector (temperature-adjusted)

When allocating the CO_2 emissions to the different applications (cf. Figure 3), it can be seen that the largest share of emissions is caused by the generation of mechanical energy, which is particularly needed in transport and industry. In 2016, this caused 42 % of the CO_2 emissions in Germany. However, process heat and space heating also account for a large proportion of CO_2 emissions in Germany with 22 % and 20 % in 2016, respectively.

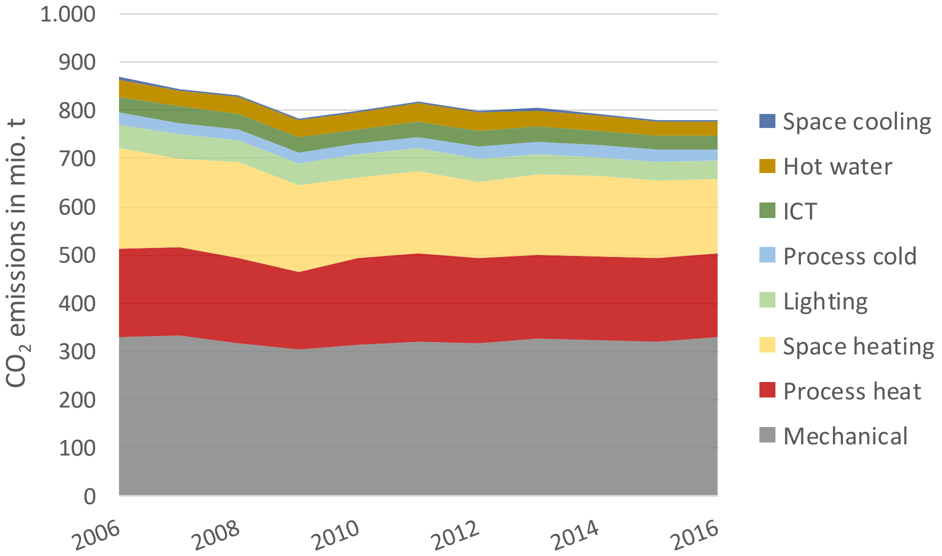

Figure 3: Development of energy-related CO_2 emissions by application (temperature-adjusted)

Figure 3 shows that in total energy-related CO_2 emissions from mechanical energy and process heat remain almost unchanged at approximately 500 mio. t CO_2. This is also underlined by Figure 4, depicting the change in CO_2 emissions of the individual applications compared to the base year 2006. It becomes clear that, in the period under consideration, the progress of these two applications is in the single-digit percentage range. While process heat shows about 5 % less CO_2 emissions in 2016 compared to 2006, the reduction of emissions related to mechanical energy is below 1 %. It also becomes clear that emissions from the provision of space cooling have risen significantly. This can neither be explained by rising emissions from energy supply nor by technology changes, but is due to the fact that the useful energy demand for space cooling and the associated final energy demand has increased. On the other hand, the emissions related to ICT, hot water and lighting decreased significantly. Although the final energy demand in these applications remained almost the same, the decreasing emission factor of electricity reduced the emissions. In the case of space heating, the reduction in emissions is due to a lower energy consumption through insulation and the use of less emission-intensive heating systems such as the change from oil to gas heating systems. However, this development must be further intensified if climate targets are to be achieved.

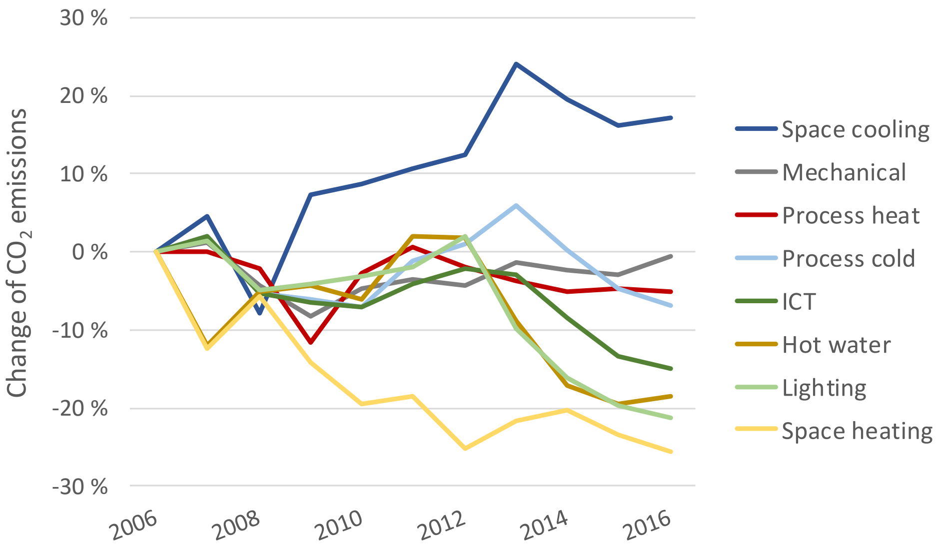

Figure 4: Change in CO_2 emissions in comparison to the base year 2006 (temperature-adjusted)

Especially the stagnation of emissions in the two emission-intensive applications, mechanical energy and process heat, carries the risk of not achieving future climate targets. To prevent this from happening, next to efficiency efforts there will have to be a change in technology in the form of electrification or a switch to lower-emission synthetic fuels in the coming years.

A more detailed analysis of the sectors and their emissions is given in the following, taking the most recent year 2016 as the example.

3.2 The State of CO_2 Emissions in 2016

For the year 2016, the energy-related CO_2 emissions are 795 mio. t, of which the amount of 362 mio. t is due to the provision of electricity, district heating or fuels such as gasoline, diesel or gas. Figure 5 shows the emissions in the energy supply sector by primary energy source and final energy carrier. With 65 %, the generation of electricity from lignite and hard coal is responsible for the largest share.

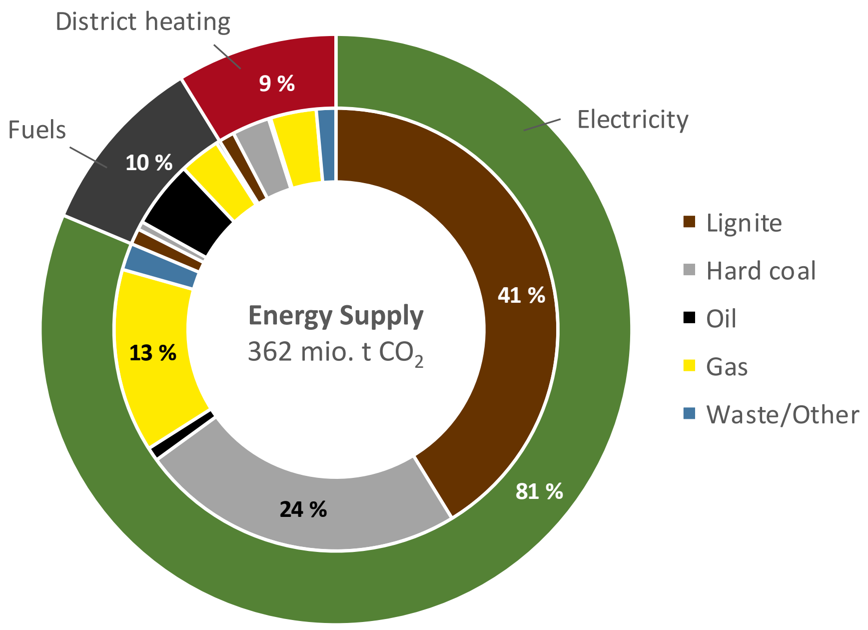

Figure 5: Energy-related CO_2 emissions in the energy supply sector by primary energy source and final energy carrier (not temperature-adjusted)

Next, these 362 mio. t CO_2 are assigned to the different sectors in proportion to their final energy demand. From the results in Figure 6 it can be seen that 25 mio. t CO_2 are allocated to other European countries due to a positive energy export balance. The largest share of indirect emissions, namely 149 mio. t CO_2, is attributable to the industry sector. While only 25 mio. t of the CO_2 emissions arising from energy supply are allocated to the transport sector, 83 mio. t CO_2 and 81 mio. t CO_2, respectively, are assigned to the sectors private households and service.

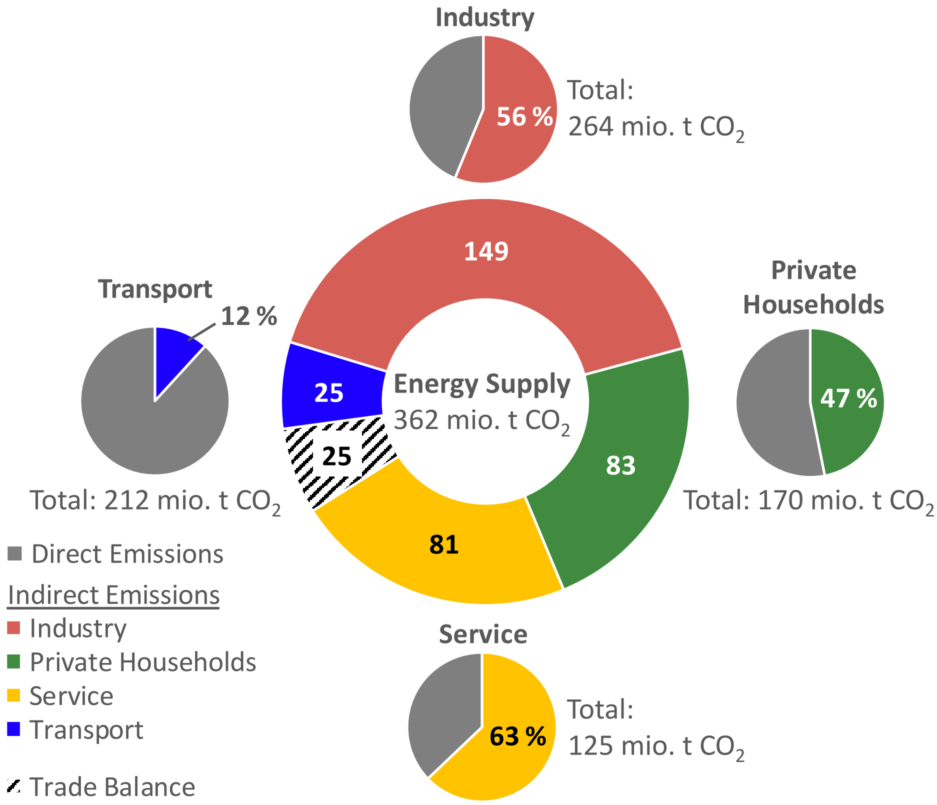

Figure 6: Distribution of CO_2 emissions in the energy supply sector in 2016 (not temperature-adjusted)

The large share of indirect emissions in the service sector of 63 % is due to a high share of electricity in final energy consumption. The opposite is true for the transport sector with a share of indirect emissions of only 12 %. This can be explained by a low share of electricity as well as comparatively low indirect emissions associated with the provision of liquid transport fuels.

Finally, the aggregated result of the application-related emissions balance for 2016 is depicted in Figure 7. Due to the temperature adjustment the emissions of space heating increase by 8 % and thus 12 mio. t CO_2.

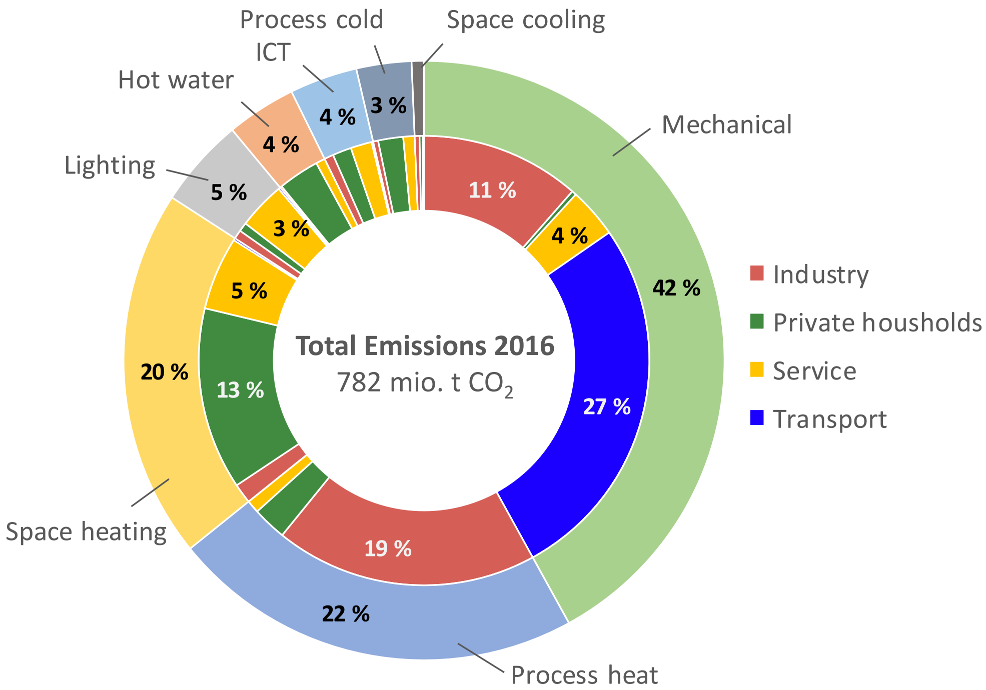

Figure 7: Energy-related CO_2 emissions by sector and application in 2016 (temperature-adjusted)

According to Figure 7, mechanical energy demand in transport and industry is responsible for the biggest share of emissions. Further applications being characterised by large shares are the generation of process heat in industry as well as space heating in private households and the service sector. While in industry and transport most emissions stem from only few applications, the sectors private households and service are struggling with a very diverse structure. However, as depicted in Figure 6, a large proportion of the emissions in these sectors originate from the supply of energy. Thus, the further expansion of renewable energies for the generation of electricity and district heating has a great potential. The mechanical energy required in industry, for example for pumps and compressed air, is also largely provided by electrical energy and could thus be decarbonised. Mechanical energy in the transport sector, on the other hand, is mainly provided by gasoline, diesel and kerosene. To reduce these emissions, structural changes such as the electrification of road vehicles or the integration of synthetic fuels are needed. Similarly, natural gas and oil heating systems are largely used for space heating. In addition to electrification and synthetic fuels, insulation can lead to major improvements in this application.

4 Conclusion & Outlook

The application-oriented emissions balance shows that in 2016 84 % of the energy-related emissions are associated with the generation of mechanical energy, process heat and space heating. These are primarily caused by the combustion of oil-based fuels such as heating oil, petrol, diesel and natural gas. While progress has been made in the area of space heating as a result of steadily increasing insulation and switching from oil to gas heating, emissions from mechanical energy and process heat have stagnated. In the future, emissions from these applications will have to be increasingly reduced in order to achieve emission targets. Due to the progressive reduction of the emission factor of electricity and the increasing expansion of renewable electricity systems, electrification is a viable option to reduce CO_2 emissions in large parts of both applications. Wherever necessary and possible, synthetic fuels can supplement and compensate for the disadvantages of electrified applications. In the project BEniVer (funded by the German Federal Ministry for Economic Affairs and Energy - BMWi, funding number: 03EIV116C) the ecological advantages of synthetic fuels for generation of mechanical energy most notably in the transport sector are investigated. Furthermore, the assessment of the cost efficiency of these different options for CO_2 abatement, while considering their dynamic interaction with the energy supply sector, is subject of the project Dynamis (funded by BMWi, 03ET4037A).

As a further step, it is possible to extend the described methodology to other European countries. Eurostat's database provides data of a similar kind as ‘AG Energiebilanzen’ and could therefore be used to derive application-oriented emission balances for different countries in Europe.

5 References

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