Roads to Carbon Reduction in Germany.

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Abstract:

In the last decade the annual CO_2-emissions in Germany have been reduced considerably (more than 15% since 1990) mainly due to the breakdown of eastern lignite energy supply. The annual rate of CO_2 reduction has, however, continuously decreased and in the last years stabilized close to zero. Whereas it is a good chance for Germany to fulfill the EU-commitment by 2010, further ambitious national political targets for the period up to 2030 (-40% to -50%) can only be met if considerable effort is made. Based on findings achieved with model calculations during the IKARUS-project, we present technological scenarios to realize such future goals.

▪ Introduction

In Germany there has been a continuous discussion in the last 10 – 15 years about ways of reducing greenhouse gases. Already at the beginning of the nineties different commissions of inquiry of the German parliament did pioneering work to get a solid grounding of the complex of greenhouse gas effect and the necessary greenhouse gas reductions. The Federal Government pledge itself already 1990 to reduce the emissions of CO_2 with about 25 % up to 2005. This unilateral obligation is far sharper than the 21 % "Greenhouse gas basket" -reduction until 2010-2012 within the framework of the Kyoto agreement. However, this national obligation also plays an exceptional role within the framework of the reduction target destination of 8 % within the European Union.

For systems analysis and advisory service for politicians one important thing is to find the effect of different technical measures on CO_2 emissions and identify optimal reduction strategies.
With a model of the national energy system, as for example developed within the framework of the IKARUS project, the impacts on such measures on energy demand, emissions and costs can be found and bundled into a cost effective reduction strategy.

The amount of CO_2-emissions in Germany caused by energy conversion was in the last year (2002) about 834 million tons. This is a reduction of about 15% compared to the emission level of 1990. However, because of the mild climate of the last year, the temperature corrected value was by far higher (851 million tons). (Figure 1) The high reduction rates in the first half of the nineties was in particular due to measures of restructuring in the newly-formed German states (East-Germany) that among other things led to a drastic reduction of the use of lignite. The annual decrease of the temperature corrected emissions (corrections for climatic variations) shows, however, a clear attenuation in the last years. An extrapolation of the trend of the CO_2 emissions indicates only a minor reduction for the coming years up to 2005. In order to reach the reduction target of -25 % compared to 1990 as earlier projected by the Federal Government for the year 2005, a reduction of more than 90 million tons would be necessary in the next three years. This would mean an average annual reduction of about 30 million tons, which would be even higher than typical reduction rates of the first half of the nineties. This illustrates impressively the pretentious goal of the Federal Government, but of course is highly unlikely to happen. Compared to the year 1990 the emissions from the different energy sectors were decreasing except for the traffic sector and residence sector. The rise of the CO_2-emissions in the traffic sector was especially significant and amounted to about 12 % in the period 1990 to 1998.
In their current climate protection program the Federal Government states that, with the reduction measures introduced since 1990 until today, the 25%-reduction target is not to be met by 2005. Examples of important measures introduced up to now are regulations for insulation of houses and a law of the use of renewable energy that allows the financial promotion of technologies using renewables and thus causing a forced penetration of such technologies into the market. Another reduction target is the pledge of the German Federal Republic to reduce the emissions of the six greenhouse gases performed in the Kyoto-record of in total 21 %, according to the country-specific EU distribution key, up to the period 2008 - 2012. However, already in 1990 a German parliament commission of inquiry "Provision to

the protection of the atmosphere" stated that for the long term a much higher reduction would be necessary. It recommended a reduction of 50 % up to the year 2020 and even up to 80 % until 2050 when compared to the emissions of 1987.

- **Formulation of a consistent CO_2 reduction strategy**

At the beginning of the nineties the former Federal Ministry for Education, Science, Research and Technology (BMFT) initiated the IKARUS-Project[1] with the objective to establish a sufficiently homogeneous data base as well as models on which basis consistent climate gas reduction strategies could be formulated and calculated. With the aid of the models climate gas reduction strategies can be developed and evaluated within the frame of energy technology and energy policy. One element of the IKARUS-instruments is an optimization model mapping the energy system of the German federal republic in form of cross-linked processes. Such processes are for example the extraction or the import of primary energy, the transformation in secondary energy (for example electric power production) and their distribution as well as the use of final energy carriers in the end use sectors for the demand of energy services (for example mobility, space to be heated, industrial production). In the model a great number of technological options are included with their corresponding specific emissions and the corresponding costs as well as possible networks of the energy fluxes. In addition general political set-ups are considered (for example the agreement of the dynamics of future shutdown of nuclear reactors). The energy system is formed within the model in such a way that the demand for energy services is fulfilled. With the mathematical method of Linear Programming the future demand for energy services is determined in the model in such a way, that targets expressed by energy- and environmental policy are met with economically minimized costs.

- **(Cost) effective CO_2 reduction strategies**

In the following a climate gas reduction scenario is shown in which a CO_2 reduction path is imposed to the model up to the year 2020 taking into account the measures planned and taken until now. A CO_2 reduction of 40 % in the year 2020 was chosen as a very frequently mentioned reduction mark within energy policy. In parallel to that a reference scenario is developed in which no CO_2 restriction is explicitly set. The reference scenario is characterized

[1] **I**nstrumente für **K**li**m**ag**a**s**r**eduktion**s**strategien

as a business – as - usual – scenario. However, it must not be understood as a forecast or prediction in the sense of an expectation of future energy supply and demand. The scenarios are based on a great number of assumptions, that are to be considered when valuating the results. For example we assume only a moderate increase of energy prices. In addition our calculations are based on a annual growth rate of the gross domestic product between 2 and 2,5 % for the period to 2020. The demand for energy services in the final consumption sectors is, with the exception of the traffic sector, only slightly increasing. In the traffic sector we expect a strong increase of 50% of the freight traffic as well as a considerable increase of 15 % of the passenger traffic. In addition the reduction measures already introduced by the Federal Government are taken into account (for example energy-saving-regulation, additional use of combined heat and power). Also the political frame set by the Federal Government is to be included in the considerations. For example the agreement between the federal government and utilities concerning the nuclear phase-out, the minimum electrification of lignite in East-Germany or the minimum use of domestic hard coal.

Figure 2 contains the emission projections of the reference- as well as the reduction scenario. The essential difference between the two scenarios is on one hand made up of the CO_2-reduction targets being put on the reduction scenario. On the other hand further restrictions were set for the traffic sector requiring that traffic-made CO_2-emissions of the year 2010 respectively 2020 must not exceed the emission levels of the years 1995 respectively 1990. The reason for these CO_2-restrictions especially set for the traffic sector is due to the low load factor of transport vehicles making reduction measures here relatively expensive and therefore normally not chosen by the optimization model. In order to include in the calculations the implications of several reduction measures in the traffic sector and since a significant contribution from the traffic sector to the over all CO_2-reduction is also considered as politically desirable, the corresponding restrictions were made.

Figure 2 shows, that in the reference case without CO_2-targets a reduction of 22 % is achieved up to the year 2020 as compared to 1990. The reduction goal of the Federal Government for the year 2005 is (of course) not met. In order to meet the pretentious mark of –40% in 2020 further measures are necessary. In the corresponding reduction scenario the technical feasibility of such a reduction strategy is shown and necessary measures are identified. Figure 3 illustrates the contributions of the individual sectors to CO_2-reduction as compared to the reference scenario. Until 2015 the conversion sector takes a share of about 50% of the CO_2-

reduction, basically due to changes of electric power production. Up to 2020 this share is reduced to 40 %, and more measures are taken in the final consumption sectors. Table 1 makes clear, that about 80 % of total reduction necessary to reach the reduction goal of 40 % in 2020 are in the sectors conversion, residence and traffic. In the following the emphasis of the outline is therefore placed on to these sectors.

- **Electricity production**

Considering the electricity production Figure 4 shows the differences between the reduction scenario and the reference case. Within the given time horizon the electricity production from Gas Combined Cycles and Renewables is rising significantly, substituting electricity production from coal fired power plants and from nuclear. In the year 2020 Gas Combined Cycle plants are achieving a total capacity of approx. 48 GW, whereas the capacities of coal fired and of nuclear power plants are decreased to 8 GW resp. 5 GW.
Due to the increased contribution to electricity production combined heat and power plants, based on natural gas are playing the dominant role, regarding CO_2 reduction targets.
As a consequence of the German Climate Protection Programme an enlarged use of biofuels is being expected. According to this financial support, lower limit bounds for electricity production by biofuels were introduced. However the model is optimizing within various options for electricity generation, such as biomass, biogas and others.

Until 2020 the share of CO_2 emissions from electricity production is reduced significantly by 13 % (reference case) resp. 35 % (reduction scenario). The difference, which relates to an amount of 60 Mill. t. CO_2, can be explained by the substition of coal. The additional investments requested for the application of these measures accumulate to a net yield of 12 billion Euro over the time period considered. Related to specific electricity generation costs, an increase of 0,6 cts/kWh (2020) is expected.

- **Residence sector**

The final energy consumption of the residence sector decreases in the model calculations from 1990 to 2020 continuously. In the reference scenario the decline is 11 % (in the case of the reduction scenario 26 %), where an essential part of the energy saving after 2010 is caused by measures of thermal insulation. Next to the insulation measures coal and oil are replaced by natural gas and biomass.

Due to energy saving and substitution of energy carriers the percentage of CO_2-reduction in 2020 is even in the reference scenario nearly 30 % as compared to 1990. In the reduction scenario this value increases to about 50 %.

In the reduction scenario additional measures are taken by the model compared to the reference scenario, that is exchange of technique, substitution of energy carriers and energy saving. Figure 5 shows the impact of these additional measures on the final energy consumption respective on the CO_2-emissions in the residence sector. The result is an additional drop of the final energy demand up to 2020 of about 400 PJ corresponding to a reduction of 17 % compared to the reference scenario. The extra measures for thermal insulation contribute to this drop with approx. 70 % (280 PJ). The substitution of conventional heating (fuel oil, coal products) by new systems based on biomass, long-distance heating and particularly natural gas give a further saving of 120 PJ. The additional use of natural gas mainly occurs in efficient gas condensing boilers.

Compared to the reference scenario the additional CO_2 reduction in the year 2020 is about 30 million tons. This reduction of 28 % is mainly due to measures of heat insulation in buildings.

The potential for saving of space heating is considerably greater for old buildings than for new buildings. In the field of old buildings the space heat saving is between 5 respective 13 kWh/m^2 (in 2010) and 10 respective 35 kWh/m^2 (in 2020) in the reference- respective reduction scenario. Compared to the 1995-value of approx. 142 kWh/m^2 this means a saving of up to 35 %. In the field of new buildings the energy saving - being at most 7 - 8 kWh/m^2 or approx. 9 % (relative to the 1995-value) – is considerably smaller. Correspondingly the potential of CO_2-reduction in the old buildings is 10 to 30 times greater than in the new buildings. Compared to the reference scenario the total (old and new buildings) CO_2-reduction due to additional measures of insulation of buildings in the reduction scenario is about 20 million tons in the year 2020.

For costs reasons the thermal insulation in the old building will preferably take place within the renovation cycles. At the end of the time period, however, the model also chooses more expensive measures outside of the renovation cycle, in particular in the field of the multiple dwelling.

The corresponding annual investments for the additional thermal insulation in the reduction scenario increase from 2.5 billion Euro in 2010 to about 6.5 billion Euro in 2020. This means that the annual capital costs for the additional thermal insulation measures in old buildings are about 1.5 Euro (in 2020) per square meter of living space, i.e. the additional costs can constitute up to 150 Euro per annum for a 100 m^2 apartment. In the field of new buildings the costs are considerably lower.

- **Traffic sector**

Since 1991 the passenger and freight traffic in Germany has increased with 11 % respective 37 %. As a consequence, the CO_2 emissions in the traffic sector in the decade up to 2000 went up with around 17 million tons or about 10 %. In the model calculations we assume, that the traffic services, in particular the one of the freight traffic, will continue to increase up to 2020. In spite of a noticeable reduction of the specific fuel consumption of vehicles, in the sense of an autonomous technical progress, CO_2 emissions will climb with approx. 47 million tons up to 2020 as compared to 1990. As already mentioned, in the reduction scenario this rise is prevented by limiting the CO_2 emissions in the traffic sector in 2010 respective 2020 to the values of 1995 respectively 1990. The magnitude of these emission restrictions is to a certain extend arbitrary. They serve the purpose to explore the CO_2-reduction potential of the model with regard to technological changes as well as changes of the traffic carriers (Figure. 6). For this the following options are available:

- Vehicles with energy saving (Strong reduction of the specific fuel consumption combined with higher vehicle costs by preservation of vehicle qualities like size of vehicle, engine power etc. and preferences for comfort and other indicators of behavior.)
- Substitution of vehicles or fuels (for example diesel- instead of gasoline engine, or use of alternative fuels such as methanol, bioethanol, etc)
- New technologies (for example fuel cell)
- Change of the modal split (for example railway instead of road traffic, or public passenger transport instead of private vehicle traffic)

Figure 6 shows that in the field of passenger traffic all options except for a further shift of the modal split are realized by the model (the potential of an extension of railroads and buses is already partly exhausted in the reference case). In the area of passenger traffic a noticeable shift to energy saving diesel cars occurs. Also vehicles based on alternative fuels like for example Bioethanol and LPG as well as cars with fuel cell technology are chosen. They are

substituting conventional vehicles with gasoline engine. These structural changes affect about half (600 billion person-kilometers) of the demand of passenger traffic in the year 2020.
In the area of freight traffic trucks with strongly reduced fuel consumption (energy-saving-trucks) will substantially replace the conventional trucks by 2010 in the reduction scenario. At the same time the share of goods transported by railway will increase. After 2010 the street bounded freight traffic clearly decreases and the rail-mounted transportation increases strongly. Latter is in the year 2020 approx. twice as high as in the reference scenario (Figure 6).

- **Renewable Energy**

In the long term energy carriers and -techniques, that in the net balance virtually do not emit any CO_2 or other climate gases are of special importance. The nuclear processes fusion and fission belong to this category as well as the renewable energy carriers like solar-, hydro-, wind power or biomass, rapeseed oil etc. The additional use of renewable energy in the reduction scenario compared to the reference scenario is presented in figure 7, expressed as primary energy equivalent. In the period 2010 to 2020 an extra amount of 250 to 450 PJ replaces a similar quantity of hydrocarbons, corresponding to a share of approx. 7 % to the entire primary energy consumption in the year 2020 (compared to3% in the reference scenario and less than 2% today). The composition of the basket of renewable energy carriers is quite manifold, including hydro power, biogas, biomass, rapeseed oil and bioethanol. The share of the solar energy (photovoltaic, solarthermal processes), however, is only marginal due to the high capital costs.
With this additive use of renewable energy, taking place in all sectors, we calculate a CO_2 reduction of approx. 15 million tons for the year 2010 growing to nearly 30 million tons up to 2020.

- **Costs of the CO_2-reduction**

The future evolution of the CO_2 reduction costs is shown in figure 8. The specific values are referred to one ton of CO_2 reduction and is to be understood as mean costs for the respective year. The specific CO_2 reduction costs are formed as a quotient where the total amount of additional costs of the energy system as compared to the reference scenario, that is the integral measure costs, is divided by the corresponding CO_2-reduction. The costs of CO_2 avoidance in the system increases from 100 Euro/ton to 170 Euro/ton in the period 2010 to 2020. In the year 2010 the entire annual additional costs are approx. 12 billion Euro. Up to the year 2020 these costs climb to 29 billion Euro per year. This corresponds to an additional annual burden per capita in the range of roughly 150 Euro (in 2010) to 350 Euro (in 2020). The magnitude of the additional costs is a measure of the expenditure which must be raised in order to achieve the corresponding CO_2-reduction. The expenditure includes the costs of the technical effort as well as the costs for the national economy by importing energy carriers.

We would like to point out that we left needs for consumption and desire for comfort as well as consumer behavior unchanged compared with the reference scenario. This means for example in the case of the traffic sector that the behavior behind the wheel does not change and the size of the car as well as the auto ride comfort remain as it was. However, a modification of shares of different means of transportation (car, bus, train etc.) is of course possible.

The reason, why changes of behavior are considered only in a very limited way, is the fact that behavioral changes could possibly lead to cost reductions that would then be assigned to the CO_2 reduction in the calculations. This in turn would be methodically questionable, since these changes in the true sense do not represent any (technical) expenditure for an additional CO_2 reduction. Also the purpose of these calculations is to find the impact of technical measures on CO_2 emissions and system costs.

The development of the additional costs in the traffic sector plays for the total reduction costs as represented in figure 8 an important role and reflects among other things the high capital expenditure for vehicle substitutions. The share of costs for measures in the traffic sector to the total additional costs increases from about 60 % in the year 2010 to approx. 70 % in the year 2020. In this case only system costs arising immediately from measures in the traffic sector are assigned to that sector. In order to avoid multiple counts, costs of energy carriers in the model are counted just once in the sector where the energy carrier are produced or imported.

Altogether the costs in figure 8 appear quite high and represent a noticeable financial burden. However, the order of magnitude is comparable to many other expenses or subsidies in the energy economy. For example the annual ecotax in Germany in the year 2000 amounted to 8.7 billion Euro and is estimated to increase to approx. 16 billion Euro for this year. Another example: For the extraction of domestic hard coal in Germany a subsidy of about 30 billion Euro is planned for the period 1997 to 2005.

The specific carbon reduction costs are of course quite high. Referring to one ton of carbon the average "avoidance costs" come to about 600 Euro in 2020. In comparison, the price of imported hard coal, i.e. "provision costs of carbon", is about 50 Euro/ton.

- **Final remarks**

In the scenarios discussed above measures and their impacts on a possible future CO_2 reduction are shown. The results must not be interpreted as an expectation in the sense of a forecast. Within the frame of several assumptions concerning the energy economy (for example economic growth, energy prices, development of passenger and freight traffic etc.) as well as political frames (for example the electrification of German hard coal, the agreement to back out of nuclear energy) scenarios are generated showing possible paths to a substantial CO_2 reduction within the German energy system. The use of a energy system model guarantees the consistency of the analysis (f. ex. the interaction of different measures) and allows the repeatability of scenarios. In addition robust solutions can be identified with the aid of extensive sensitivity runs. Results of such scenario calculations serve as an aid for understanding the effect of certain assumptions in energy economy aid and represent one element among several within a decision-making process. The political instruments necessary to put the scenario results into action can only be found outside of the model frame.

It has to be stressed that the list of measures established by the model as well as the costs resulting out of it strongly depends on the exogenously assumptions that are set. For example the assumed future demand in the model (passenger traffic, living space, industrial production etc.) is of great importance. An important role plays the dynamic shape of the CO_2 restriction over the period up to the year 2020. For example instead of the annually given CO_2 upper limits for the period 2000 to 2020 one can put a bound on the corresponding cumulated amount of CO_2 for the same period. In this case costs can be reduced substantially (up to 40 %) since in such a case the model can unfold the cumulated CO_2 reduction in a cheaper way. This leads normally to a release of the restriction up to the year 2010 and a tightening thereafter. In that way costs are reduced and used more efficiently.

The scenario results show that the costs of the compliance of the reduction scenario are considerable. Therefore a discussion about the most suitable or most cost-efficient measures for emission reduction should also contain an examination of the frame or boundary put up by energy policy. Changes of this frame can sometimes cause considerable cost reductions.

Not only energy but also capital is a limited resource that has to be used efficiently. From this point of view it is important to consider, whether a greater amount of emission reduction can be achieved with the same invested capital in other countries within the framework of joint-implementation initiative or other Kyoto mechanisms.

Sector	Measures	CO_2-Reduction in 2020
Conversion	• Additional wind power plants • Power plants and CHP-Plant fired with biogas, biomass and waste • Power plant and CHP-plants (gas combined cycle) substituting coal fired plants • Other savings (also refinery, coal conversion etc.) **Total Conversion**	5,9 Mill. t 6,6 Mill. t 48,8 Mill. t 6,3 Mill. T **67,6 Mill. t**
Industry	• Substitution of oil and coal by gas and biomass • Energy saving (different processes) **Total Industry**	5,0 Mill. t 5,1 Mill. t **10,1 Mill. t**
Small consumers	• Substitution of oil and gas by gas, district heating and renewables, extended use of heat pumps • Energy saving (heat insulation) **Total Small Consumers**	12,4 Mill. t 2,2 Mill. t **14,6 Mill. t**
Residential	• Substitution of oil and coal and gas by district heating and biomass, use gas condensing boilers • Heat insulation **Total Residential**	12,6 Mill. t 18,7 Mill. t **31,3 Mill. t**
Transport	• Alternative fuels (biofuel, bioethanol) • LPG and methanol, substitution of gasoline and diesel • Goods transport by train • Energy saving due to high efficient cars **Total Transport Sector**	10,0 Mill. t 1,3 Mill. t 10,5 Mill. t 25,3 Mill. t **47,1 Mill. t**
All Sectors	• Increased use of renewables • Substitution processes • Energy saving measures **Total (All Sectors)**	29 Mill. t 78 Mill. t 64 Mill. t **171 Mill. t**

Tabelle 1: The most important measures in the reduction scenario.

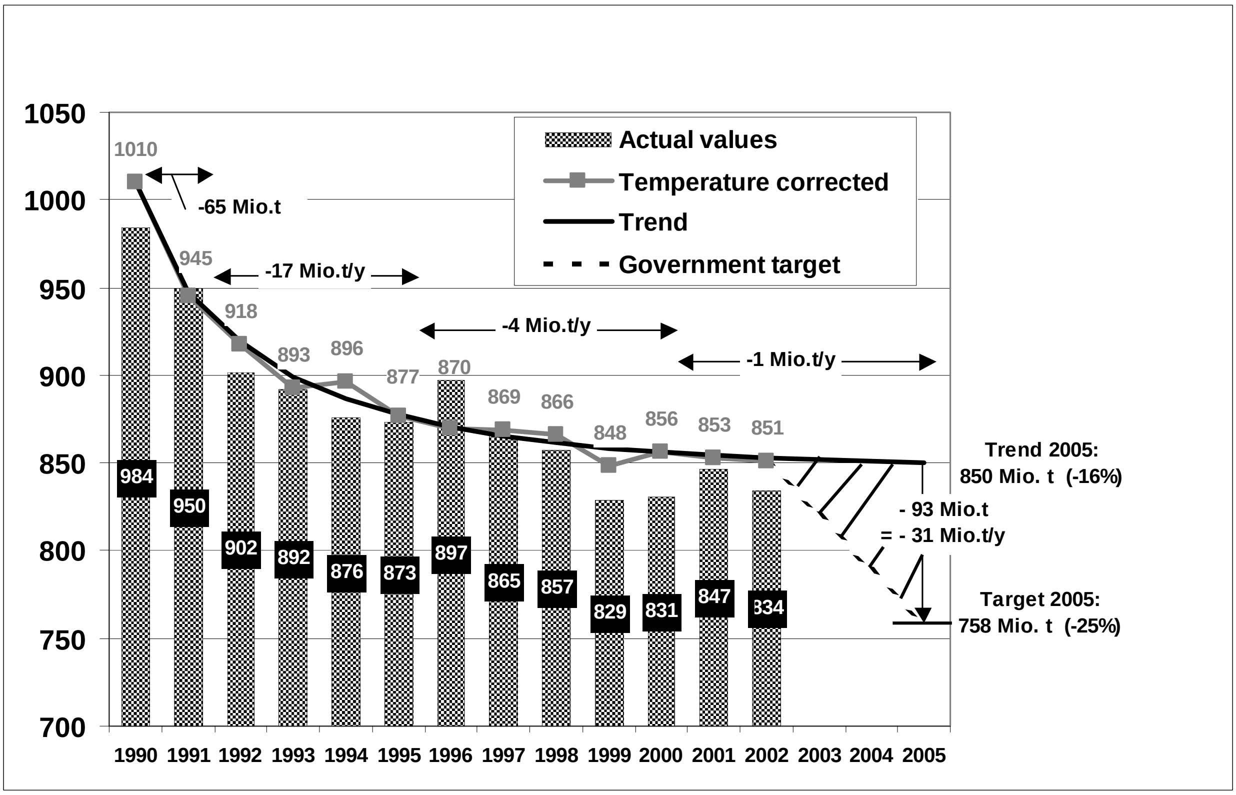

Figure 1: CO_2 emissions in Germany

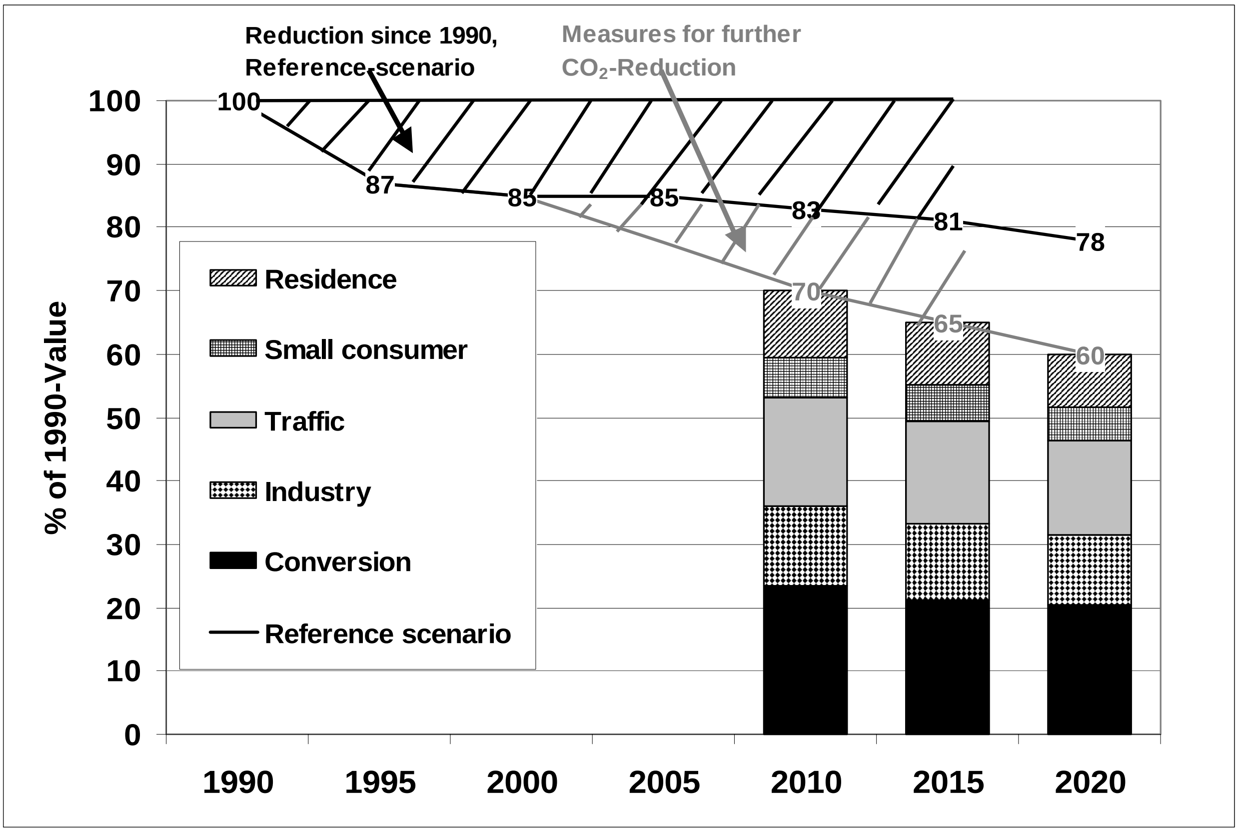

Figure 2: Projection of CO_2 emissions

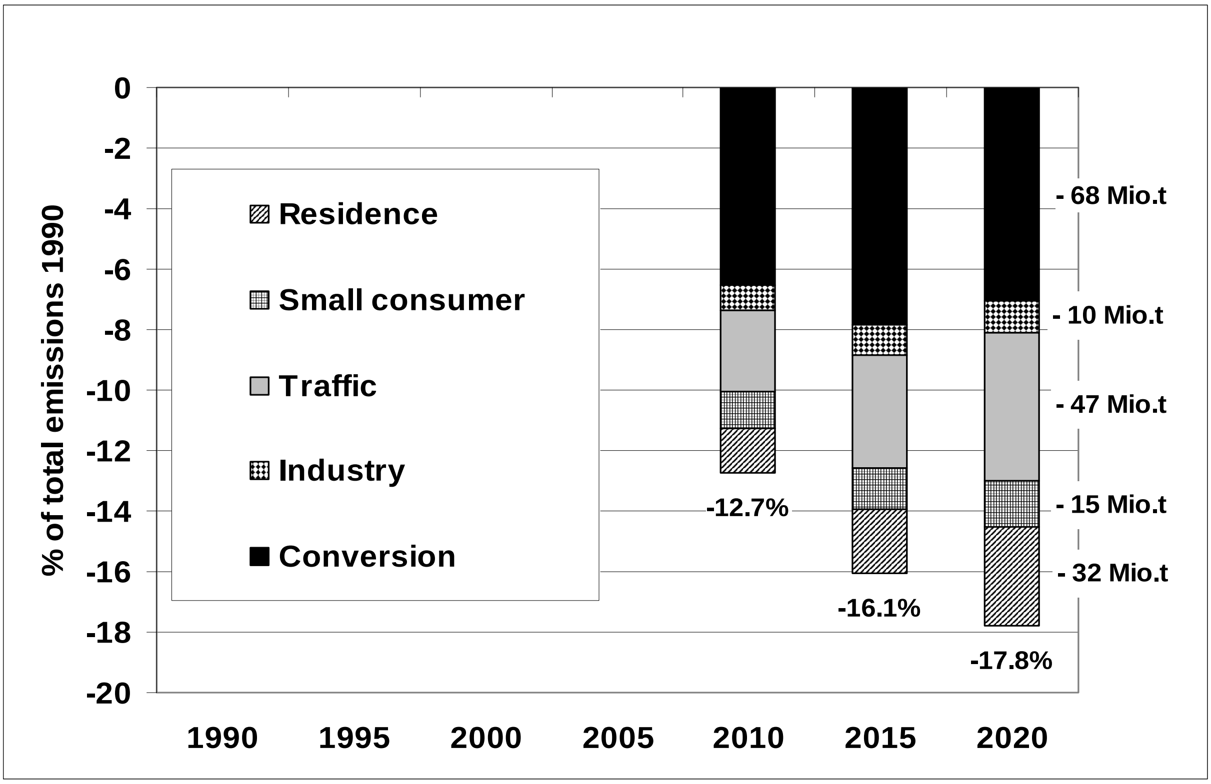

Figure 3: Sectorial change of CO_2 emissions

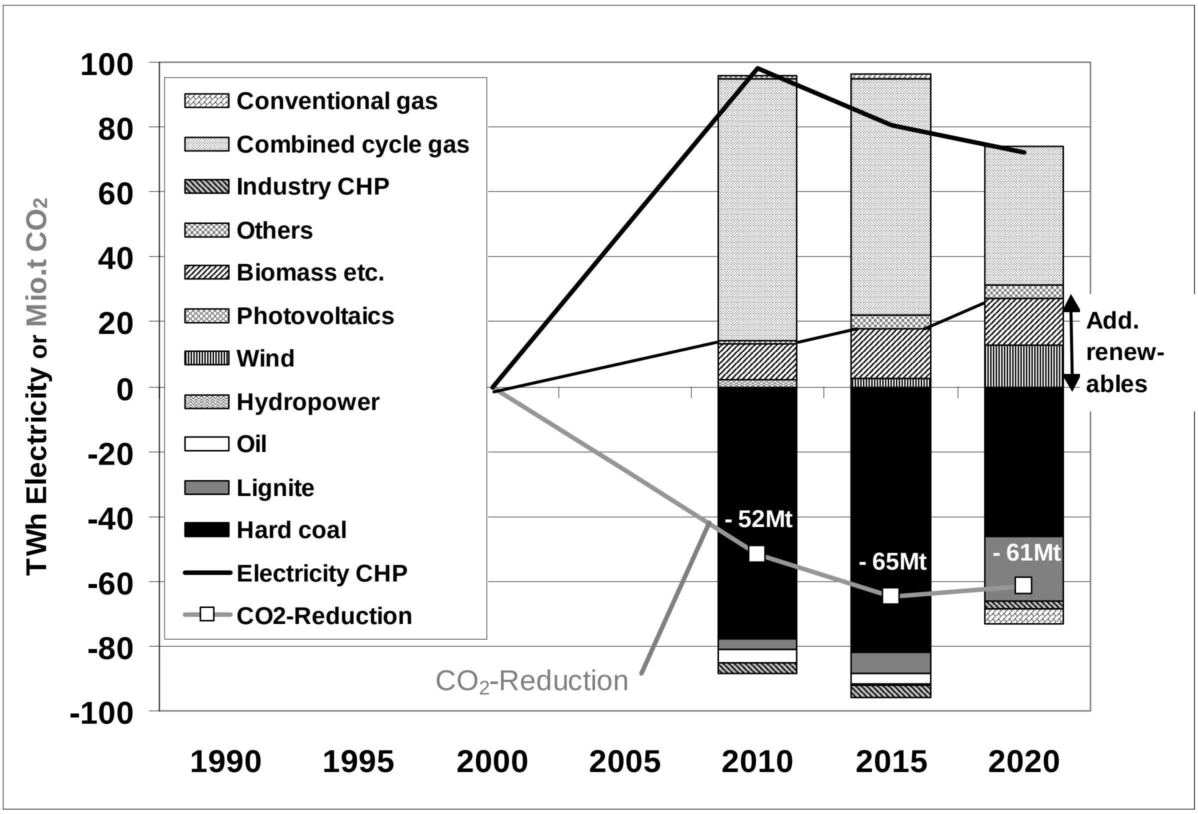

Figure 4: Changes of electricity production

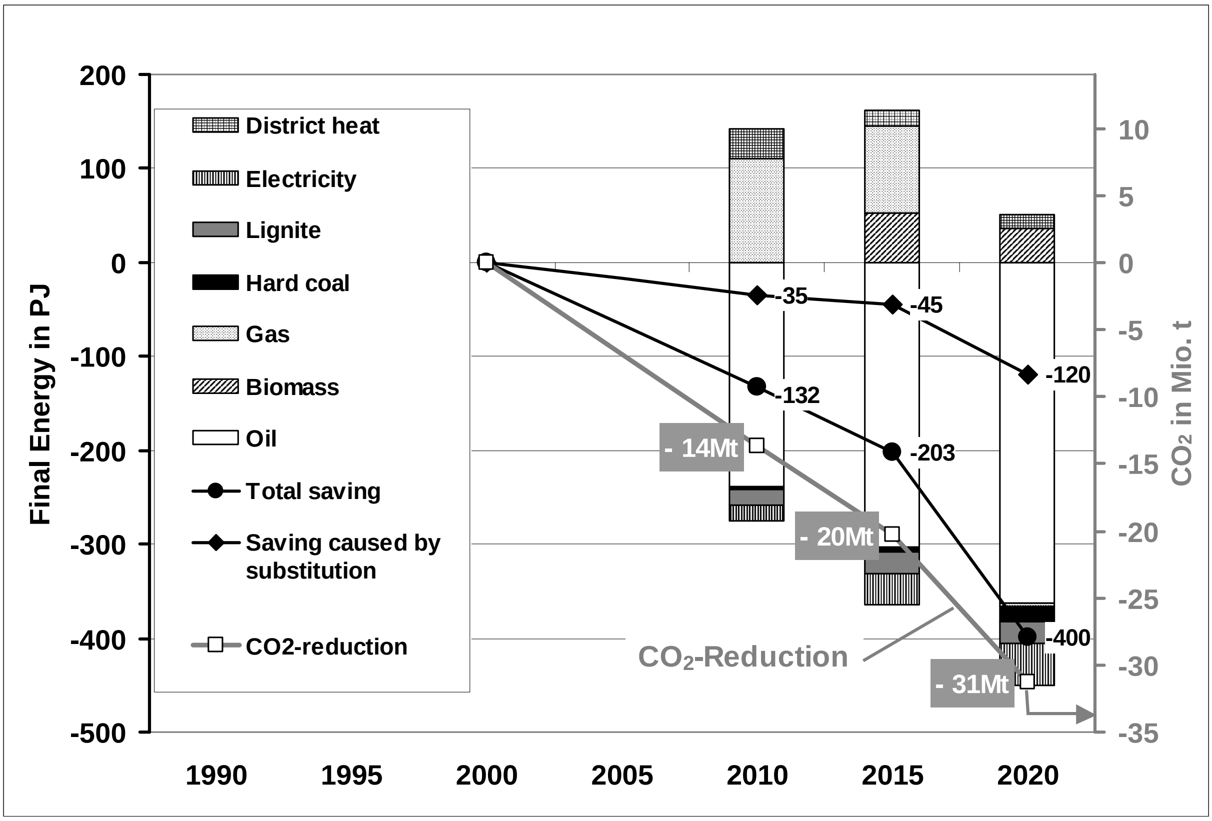

Figure 5: Changes in the residence sector

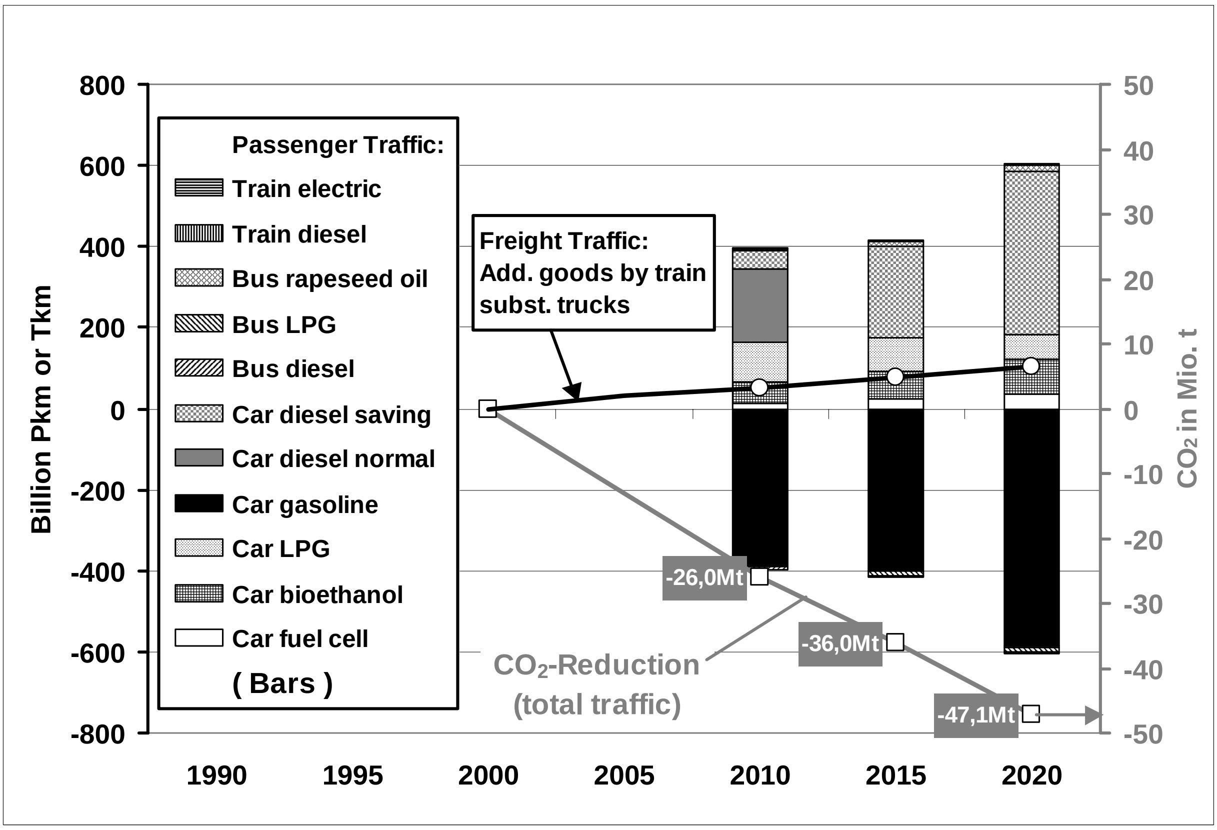

Figure 6: Structural changes in the traffic sector and corresponding CO_2 emissions

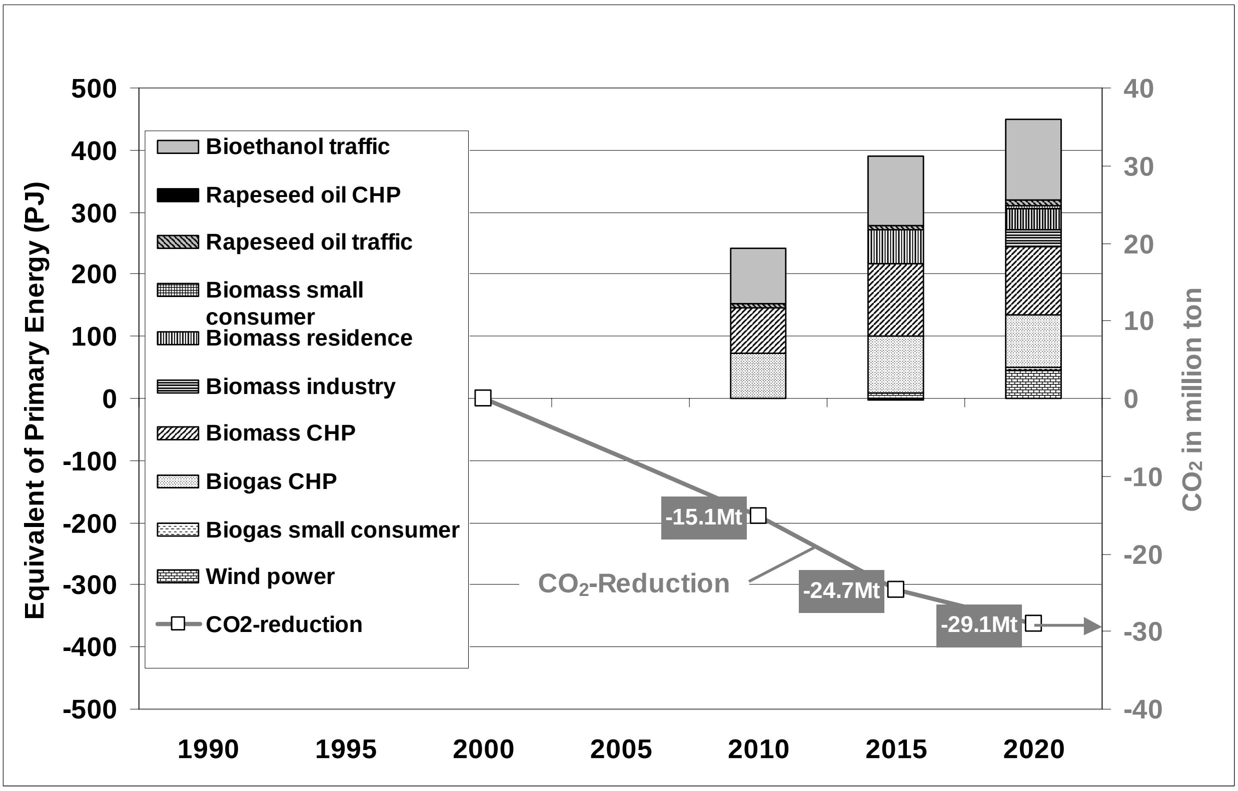

Figure 7: Additional use of renewable energy and corresponding CO_2 reduction

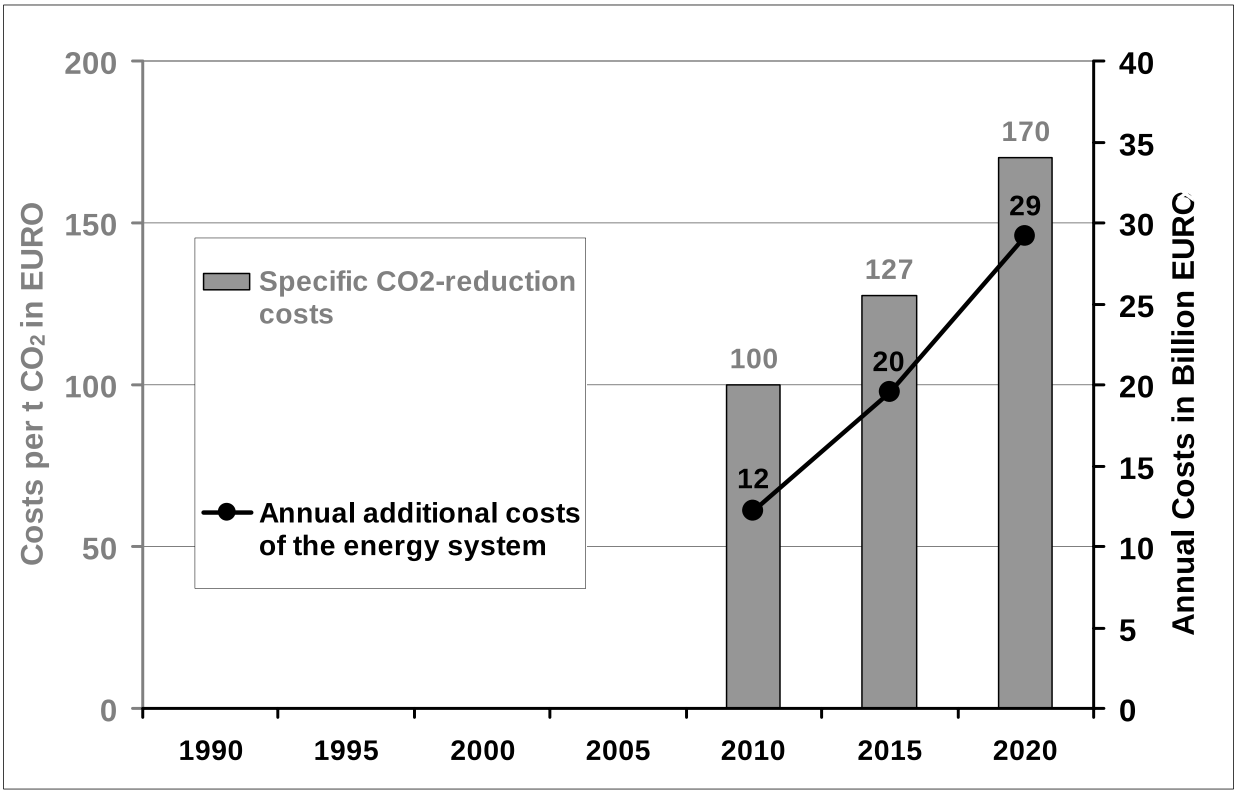

Figure 8: Costs of CO_2 reduction