CLIMATE CHANGE
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CO_2 Emission Factors for Fossil Fuels

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Umwelt Bundesamt

CLIMATE CHANGE 28/2016

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by

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Emissions Situation (Section I 2.6)

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Short description

Germany is obligated to report its national emissions of greenhouse gases, annually, to the European Union and the United Nations. Over 80 % of the greenhouse-gas emissions reported by Germany occur via combustion of fossil fuels. The great majority of the emissions consist of carbon dioxide. To calculate carbon dioxide emissions, one needs both the relevant activity data and suitable emission factors, with the latter depending on the applicable fuel quality and input quantities. In light of these elements' importance for emission factors, the German inventory uses country-specific emission factors rather than international, average factors. To determine such factors, one requires a detailed knowledge of the fuel compositions involved, especially with regard to carbon content and net calorific values.

The present publication provides an overview of the quality characteristics of the most important fuels used in Germany and of the CO_2 emission factors calculated on the basis of those characteristics. Since annual greenhouse-gas emissions have to be calculated back to 1990, the study also considers fuels that are no longer used today. To that end, archival data are used. Gaps in the data are closed with the help of methods for recalculation back through the base year.

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List of Abbreviations

AGEB	Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen)
BAFA	Federal Office for Economic Affairs and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle)
DBI	German fuel institute (Deutsches Brennstoffinstitut)
DDR	German Democratic Republic, GDR (Deutsche Demokratische Republik)
DEBRIV	Federal German association of all lignite producing companies and their affiliated organisations (Deutscher Braunkohlen Industrieverein)
DEHSt	German Emissions Trading Authority (Deutsche Emissionshandelsstelle)
DGMK	German society for petroleum and coal science and technology (Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V.)
ETS	Emissions Trading System
Eurostat	Statistical office of the European Union
GASAG	Berlin natural gas utility (Berliner Gaswerke AG)
GUS	Commonwealth of Independent States, CIS (Gemeinschaft Unabhängiger Staaten)
IPCC	Intergovernmental Panel On Climate Change
MTBE	Methyl *tert*-butyl ether
PAH	Polycyclic aromatic hydrocarbons (= polycyclische aromatische Kohlenwasserstoffe (PAK))
PIONA	Paraffins, Isoparaffins, Olefins, Naphthenes and Aromatics
UNFCCC	United Nations Framework Convention on Climate Change
VDKI	German Coal Importer Association (Verein der Kohlenimporteure)
W.E.G.	German federal association for natural gas, petroleum and geoenergy (Wirtschaftsverband Erdgas- und Erdölgewinnung (New name: Bundesverband Erdgas, Erdöl und Geoenergie e.V. (BVEG)))

1 Introduction

Combustion-related CO_2 emissions are calculated by multiplying the relevant fuel data, as obtained from statistics, by the applicable emission factors. The emission factors for this purpose depend primarily on the carbon content and net calorific value of the fuels involved. Over 80 % of all German greenhouse-gas emissions are calculated in this manner. For this reason, the quality of the factors is of central importance.

The CO_2 emission factors for reporting on greenhouse gases (cf. the tables in Chapter 7) are determined primarily on the basis of data, on measured fuel parameters, that are reported and anonymised in the context of emissions trading. Annual data are available on net calorific values, emission factors, fuel quantities and data quality. The data undergo thorough quality checks. For example, only factors from tier levels 3 or 4 enter into calculations. In every case, tier level 3 and 4 values are analysis values that are representative for the entire year. The two tier levels differ solely in terms of the applicable uncertainties. In the context of emissions trading, some substance streams are not uniquely named, and this leads to erroneous material allocations in connection with solid fuels. In the case of coal, such misallocations can be unambiguously identified via the net calorific value and then subsequently reallocated. Lignite and hard coal can be clearly and unambiguously differentiated via their net calorific values. Annually weighted averages are calculated from the quality-checked data. To check whether the so-determined factors are truly representative, the underlying fuel quantities are compared with the corresponding figures from the Energy Balance. In addition, care is taken to ensure the greatest possible consistency between net calorific values and emission factors. Ultimately, such work also supports quality assurance of emissions trading data.

Data from sources in addition to emissions trading were used as well. Furthermore, we evaluated relevant archive data, and we carried out measurements of our own. The recalculations back through the year 1990 were carried out with a range of widely differing procedures. In each case, the most suitable procedure for the specific situation was selected. This approach was designed to assure the consistency of the time series – and to provide the most realistic solutions possible. Finding well-documented archive data for the year 1990 proved to be a challenge, since documents for that year were available only in paper form, and housed at a range of different institutions. In addition, it was found that data were seldom kept for longer than 20 years. What is more, the qualities of the fuels used in the former GDR tended to differ – considerably, in some cases – from the qualities of the fuels used in the old German Länder. Since some of the terminology used in this connection in the former GDR was not used at all in statistics of the former Federal Republic of Germany (West Germany), the relevant fuels had to be assigned to fuel groups used in the latter country. For example, in the Energy Balance, "lignite tar" was placed in the meta-lignite (Hartbraunkohle) category. In the final analysis, the task of positively identifying such exotic fuels proved possible only with the help of experts on this subject. Due to the long time period involved, however, some of the pertinent experts had already retired. The scope of the task was limited by carrying out highly detailed considerations solely for the base year 1990. For the years 1990 – 1994, all relevant statistics are available, broken down by old and new German Länder. For interim years, a number of assumptions had to be made, since even less information was available for those years than was available for 1990. In addition, a great many installations were decommissioned in the new German Länder in the early 1990s. In some years, such closures led to sudden fuel changes.

2 Oxidation factors

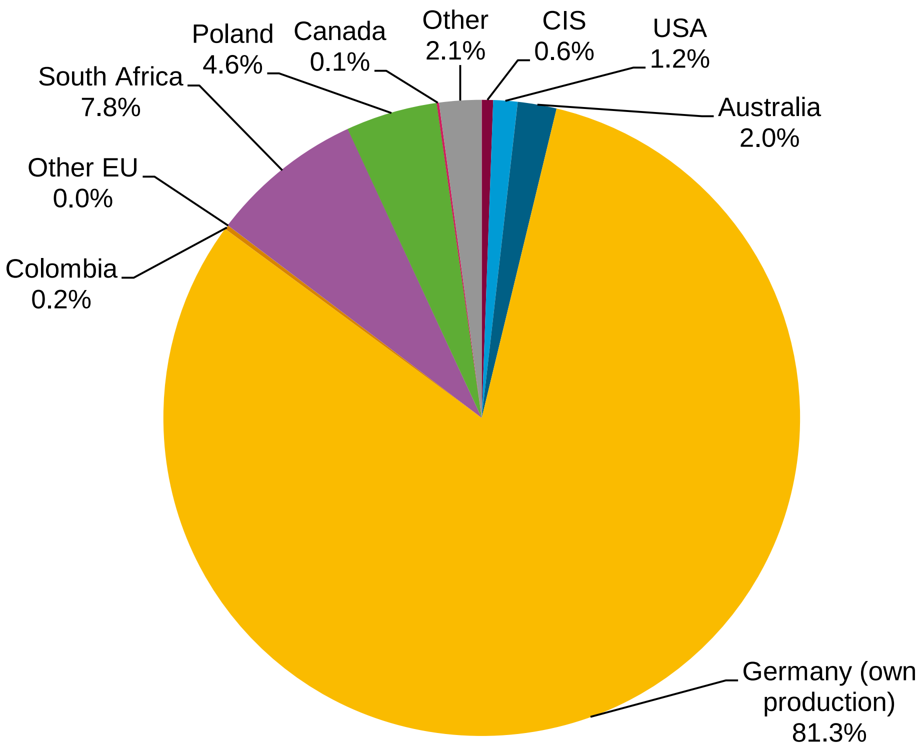
The 1996 IPCC Guidelines, which were the valid source for the calculation methods to be used for reporting through 2014, listed default values for oxidation factors. Those oxidation factors were calculated from the carbon content remaining in ash. The currently valid 2006 IPCC Guidelines work from a basis of complete fuel oxidation and no longer include that calculation step. In each case, they apply an oxidation factor of 1. The German Greenhouse-Gas-Emissions-Trading Act (Treibhausgas-Emissionshandelsgesetz) also specifies an oxidation factor of 1. For this reason, emissions trading data do not include data on carbon content remaining in ash. Neither do any other sources provide reliable and representative data for this area. For this reason, an oxidation factor of 1 is assumed. In the German greenhouse-gas inventory, pertinent calculations have always been based on assumed complete oxidation, due to the uncertainties in the data.

3 Hard coal

3.1 Grades of hard coal

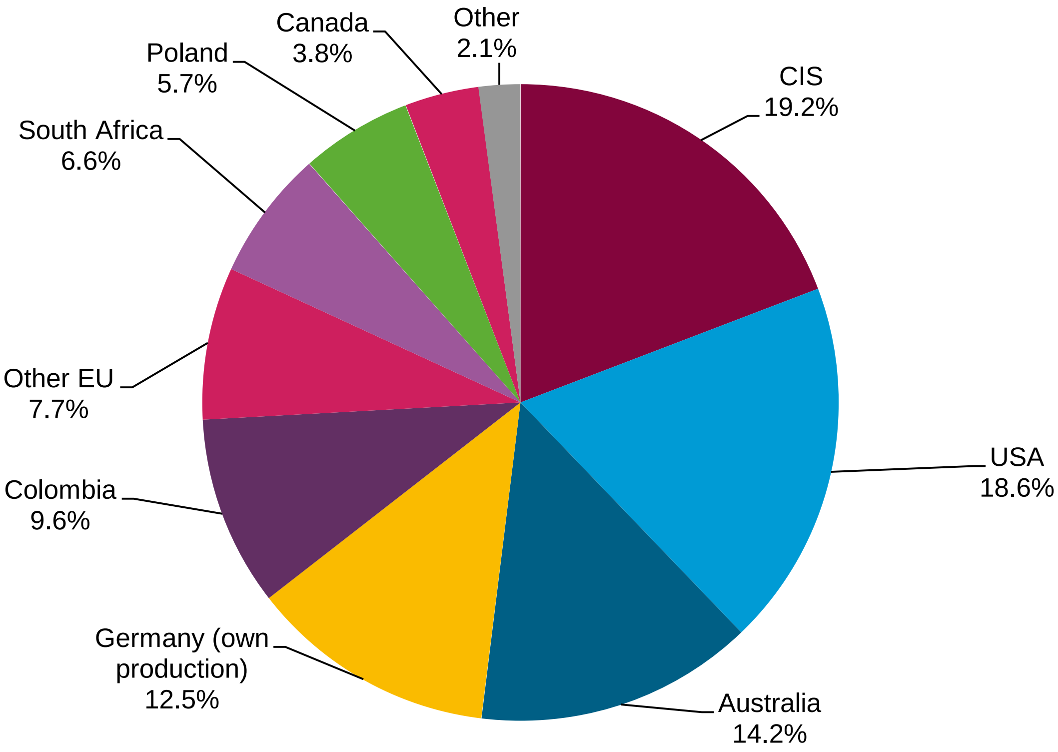
The quantities of hard coal used in Germany have been decreasing since 1990. At the same time, hard coal's share of Germany's primary energy consumption has hardly changed at all. In 2014, it amounted to about 13 %. On the other hand, the sources for Germany's hard-coal supply have changed considerably. Throughout the course of the time series, these changes have led to changes in average net calorific values and carbon content. The following figures provide an overview of the sources of Germany's hard-coal supply in 1990 and in 2014.

Figure 1: Origins of hard coal used in Germany in 1990



Source: VDKI 2015, AGEB 2016

Figure 2: Origins of hard coal used in Germany in 2014



Source: VDKI 2015, AGEB 2016

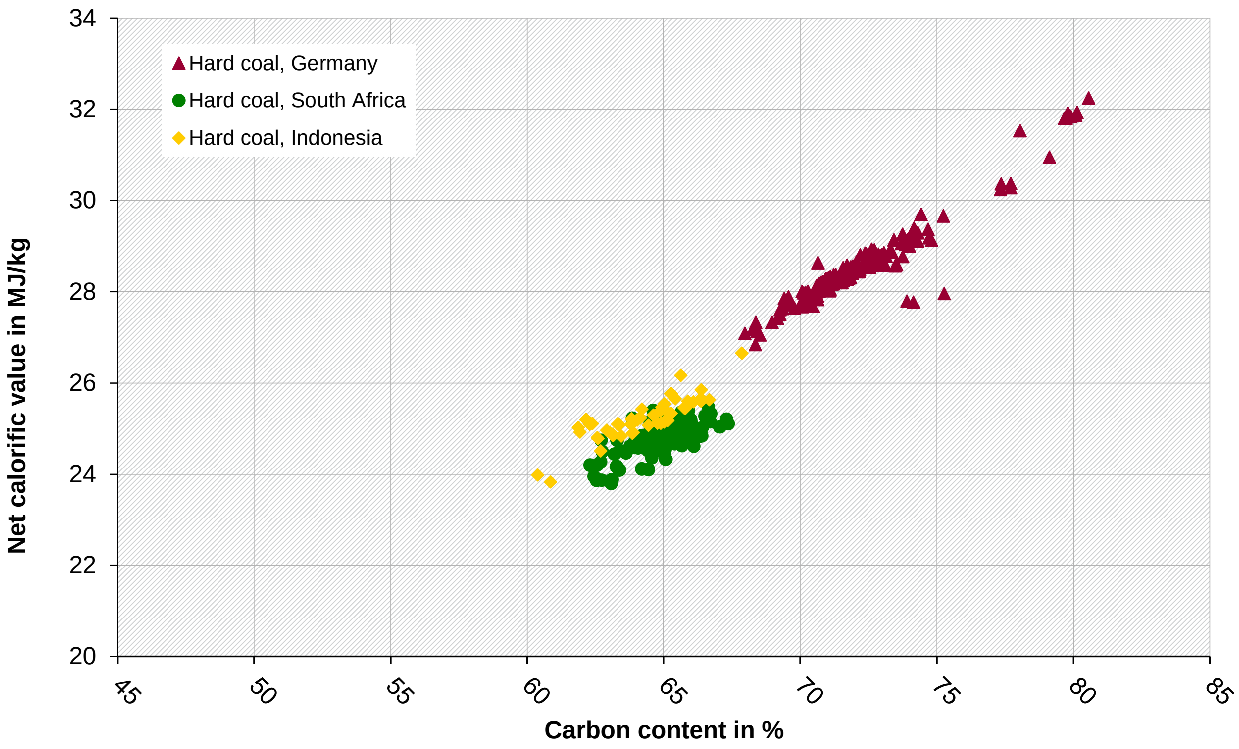
Whereas in 1990, the great majority of the hard coal used in Germany was mined within Germany itself, the country now imports most of its hard coal. And Germany's hard-coal mining sector will shut down completely in 2018. From that point on, Germany will use only imported hard coal.

The fraction of coal that Germany imports from South Africa and Poland has remained about the same since 1990. On the other hand, imports from Australia, the U.S., Colombia and the Commonwealth of Independent States (CIS) – primarily from Russia – have increased considerably. Imports from Canada and from other EU countries have also increased – although not to the same degree.

3.2 Net calorific values and carbon content

Coal-quality characteristics differ from mining region to mining region. In some cases, different open-pit mines within the same region will yield different grades of coal. At the same time, quality differences tend to be not as pronounced in hard coal as they are in lignite. The following figures show net calorific value / carbon ratios for various grades of hard coal. In each case, the carbon content figures and net calorific values refer to the original substance.

Figure 3: Calorific values & carbon content of hard coal from Germany, South Africa and Indonesia

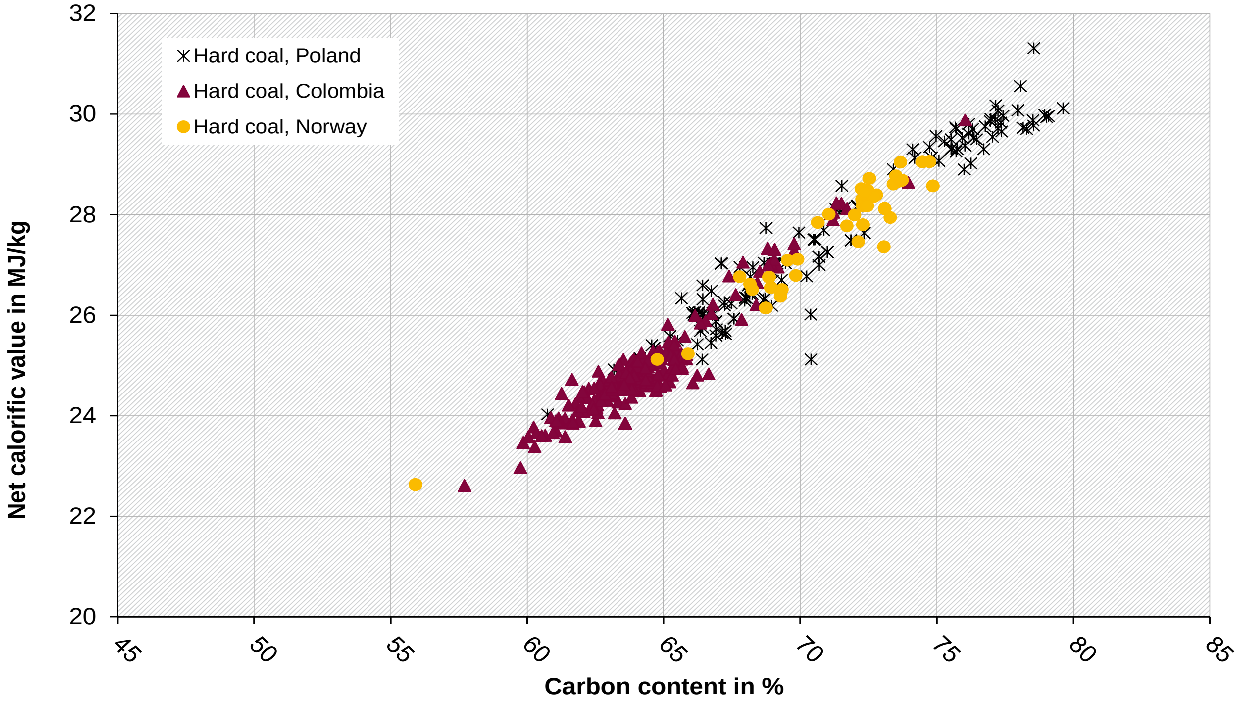


Source: Own figure, compiled from data of DEHSt (2015)

With the help of the figure, specific profiles can be derived for the different grades of hard coal produced in the countries shown. South African and Indonesian hard coals have very similar properties, whereas German hard coal has considerably different properties.

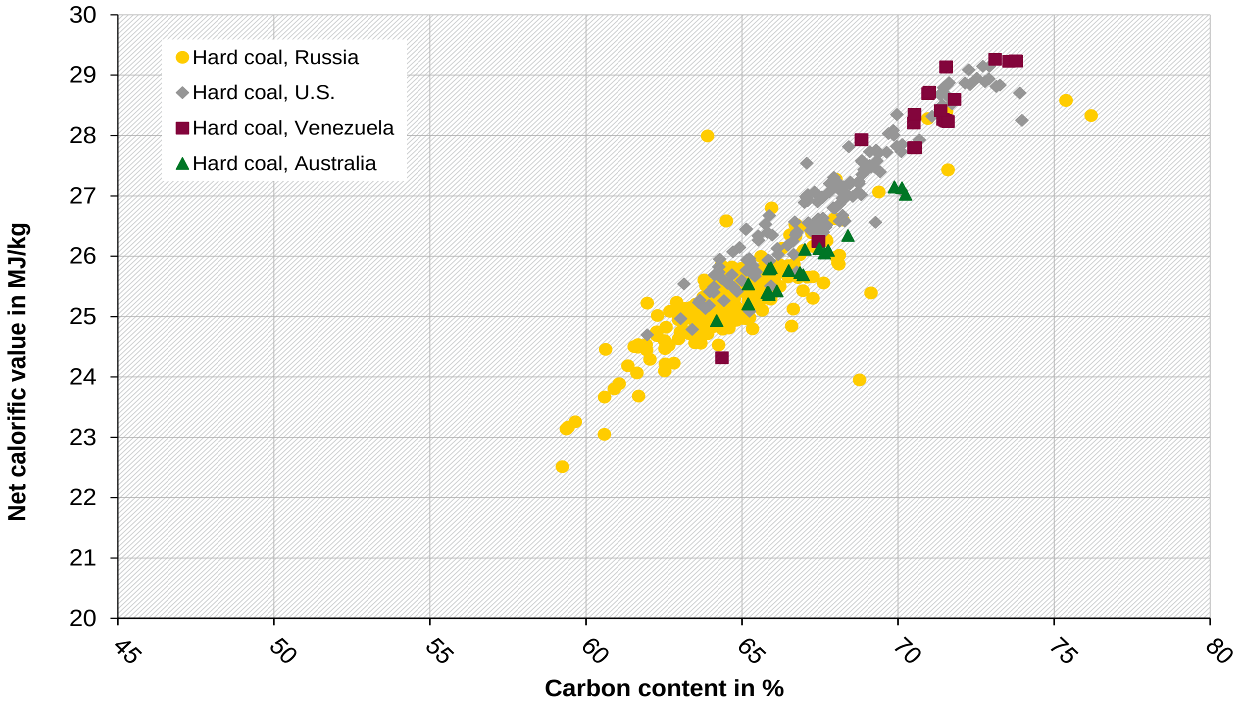
On average, German hard coal has higher net calorific values and carbon content levels. German hard coal is mined at depths greater than 1000 m, and under difficult geological conditions. While the coal so extracted is thus of high quality, it cannot be extracted at competitive prices. Originally, German hard coal was mined at sites near the city of Ibbenbüren, along the Saar and Ruhr rivers and near the city of Aachen. The last remaining mines along the Ruhr River and near Ibbenbüren will be closed at the end of 2018.

Figure 4: Net calorific values & carbon content levels of hard coal from Poland, Colombia and Norway



Source: Own figure, compiled from data of DEHSt (2015)

Figure 5: Net calorific values & carbon content levels of hard coal from Russia, the U.S., Venezuela and Australia

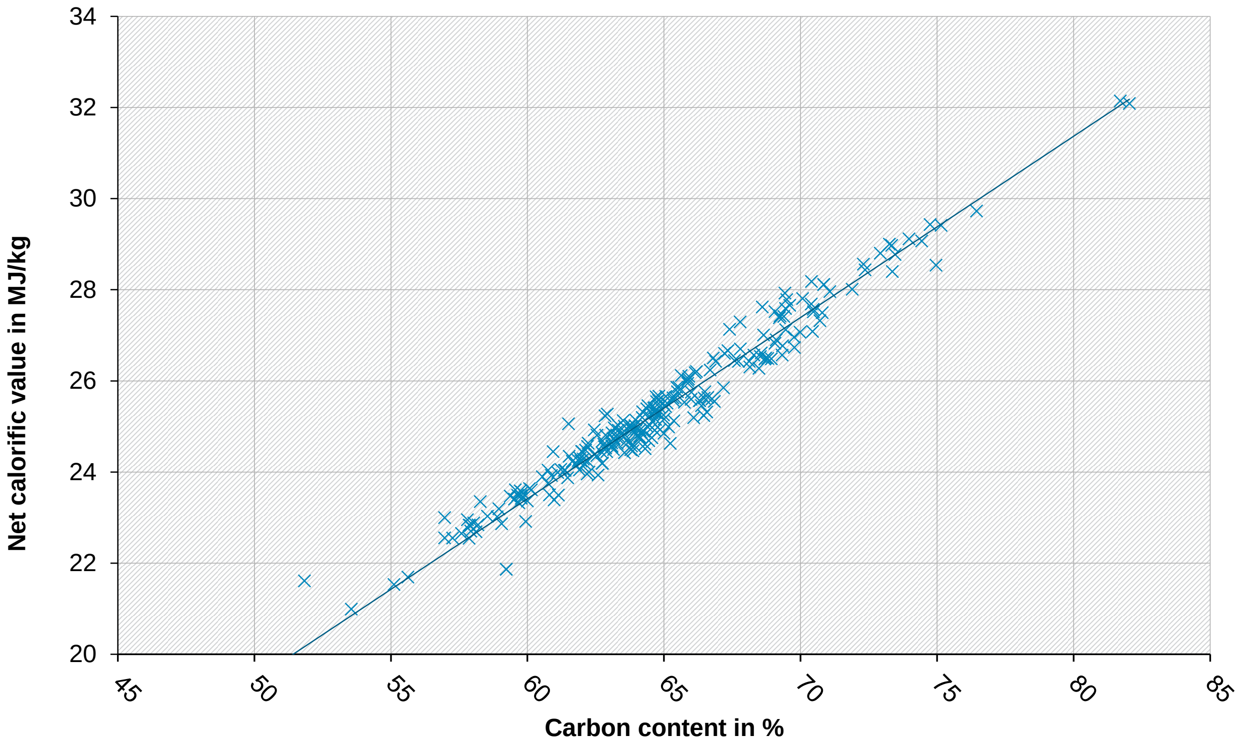


Source: Own figure, compiled from data of DEHSt (2015)

Most varieties of hard coal have a carbon content (with respect to the original substance) between 60 and 75 %. The average content, which can vary from year to year, ranges between 65 and 66 %. Hard coal within the lower range, up to a carbon content of about 56 %, and a net calorific value of no more than 22 MJ/kg, is referred to as low-grade coal. Hard coal within the upper range is of coking-coal quality. The highest carbon content, reaching values over 30 %, is found in anthracite coal.

Hard coal is commonly classified in terms of its fractions of volatile components. Coal classifications include flame coal (Flammkohle), gas flame coal (Gasflammkohle), gas coal (Gaskohle), fat coal (Fettkohle), forge coal (Esskohle), non-baking coal (Magerkohle) and anthracite (Anthrazit). Since hydrogen is among the volatile components in coal, this classification scheme cannot be directly applied to the evaluation carried out in the present study. For purposes of emission calculation, the carbon content and the lower heating value (net calorific value) are of central importance.

Figure 6: Net calorific values & carbon content levels of other types of hard coal



Source: Own figure, compiled from data of DEHSt (2015)

In addition to the substance streams that, on the basis of their designation, can be assigned to specific areas of origin, significant quantities of mixed coal and of coal of uncertain origin have to be considered. Data relative to those quantities were also evaluated. The "other hard coal" types of coal also exhibit a fixed net calorific value / carbon ratio. The hard coal that cannot be assigned to specific areas of origin basically falls onto the same ratio line as that formed by hard coal from known areas of origin. This relationship is particularly pronounced in hard coal, because sulphur and hydrogen content levels do not vary as much in hard coal as they do in other fuels. A fuel's sulphur and hydrogen content influences its net calorific value. Since these elements – logically enough – do not include any carbon, these parameters affect the slopes of the lines.

3.3 Calculation of CO_2 emission factors for hard coal

CO_2 emission factors and net calorific values were determined for all relevant coal fractions of known origin (Germany, South Africa, Australia, Indonesia, Colombia, Norway, Poland, Czech Republic, Russia, U.S. and Venezuela). In addition, weighted averages were calculated for the "other hard coal" fractions that cannot be assigned to specific areas of origin. Two different methods for calculating hard-coal emission factors for previous years of the time series were reviewed. In one method, a weighted average for each year was calculated using data for the individual areas of origin, along with import-stream data given in hard-coal statistics. In the other method, a weighted average was formed from all of the verified emission factors reported in emissions trading. Since the pertinent values differ only very slightly in most years (with differences ranging between 0.02 and 0.35 %), as of 2006 weighted emission factors for all hard coal reported in emissions trading (except that used in the iron & steel sector) can be used – regardless of the areas of origin involved. The recalculations back through 1990 are carried out by combining the origin-specific emission factors, as determined from emissions trading data, with the relevant import streams. This produces a consistent time series. Over the years, the weighted emission factor for hard coal increases slightly, from 93.1 t CO_2/TJ in 1990 to 94.3 t CO_2/TJ in 2011. As of that year, the factor then decreases slightly. All in all, the German values, on average, are slightly below the default value given by the 2006 IPCC Guidelines, 94.6 t CO_2/TJ.

Review of the individual values used in emissions trading shows that changes in the applicable regulations have considerably enhanced the quality of net calorific values and emission factors, especially those used as of 2008. In addition, the quantity of hard coal that can be clearly assigned to specific areas of origin has decreased considerably. For this reason, the most sensible approach is to form weighted averages that cover all hard coal, regardless of area of origin. This is the only way to ensure that the resulting emission factors are truly representative.

Inter-sectoral emission factors are calculated for hard coal. This ensures that the relevant total emissions are determined as precisely as possible. Apart from the fact that the calculations needed to produce sector-specific emission factors would be unreasonably laborious, the emissions trading sector and official statistics (which provide the basis for the national greenhouse-gas inventory) do not always agree in their emissions allocations to specific industrial sectors, and thus sector-specific calculation of emission factors, as a general basis, would necessarily lead to errors. In the present case, such an approach would make it impossible to assure the correctness of the resulting total-emissions data.

3.4 Coking coal, hard coal and hard-coal products of the steel industry

An exception is made for the iron and steel industry; sector-specific emission factors have been calculated for it. The coking coal data used by the iron and steel industry are not calculated on an inter-sectoral basis, since that coal can be unambiguously identified. Furthermore, few reliable net-calorific-value data are available. Although a formula for calculating net calorific values could be derived using the above figures, such a derivation would be too cumbersome in the present case. The relevant emissions can be calculated directly using the carbon-content data available from emissions trading and statistics on steel production, which are already available in natural units. To prevent double-counting, the pertinent coal is not included in calculation of emission factors for hard coal overall. For the iron & steel sector, the inventory gives only mass-related emission factors.

From the same data set, it was possible to calculate emission factors for hard-coal coke, hard-coal tar and benzene, all of which the Energy Balance combines under "Other hard-coal products."

For all other sectors in which hard-coal coke is used, a net-calorific-value-related CO_2 emission factor of 108.1 t CO_2/TJ was calculated. That value is somewhat higher than the IPCC default value of 107 t CO_2/TJ. Since hard-coal coke is a compound product of defined composition, with only slight quality fluctuations, an average is used for pertinent calculations. The annual substance-value fluctuations lie within the uncertainties range. With this in mind, an average covering a 9-year period was formed. The resulting value is reviewed on an annual basis. If any significant changes occur, the factor will be suitably adjusted.

3.5 Hard coal and hard-coal briquettes in small combustion plants

Since emissions trading data do not include hard-coal briquettes used in small combustion plants, Technische Universität Dresden, Faculty of Mechanical Science and Engineering, carried out analyses of its own for this area, in the framework of the project "Adjustment of methods used in German GHG-emissions inventories, to bring them into line with the revised 'UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the convention'" ("Methodische Anpassung der deutschen THG-Emissionsinventare an die überarbeiteten 'UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the convention.'") (Öko-Institut 2014), and at the Institute of Power Engineering (Institut für Energietechnik). The resulting values were carried back through the year 1990, since no representative values were available for the base year. In all likelihood, most of the hard-coal briquettes used at that time were German hard-coal briquettes. Today, only imported briquettes are used. Since the last German hard-coal-briquette factory was closed in 2007, it was not possible to analyze this fuel (German hard coal briquettes). On the other hand, hard-coal briquettes are a defined product whose carbon content and net calorific values vary only slightly. Consequently, the error that results from the relevant assumption is also very small.

The anthracite coal burned in households and in other small combustion plants was also studied. For anthracite, data from emissions trading are available. The CO_2 emission factors calculated from the emissions trading data are higher than those determined via the analyses. A mean value of 97.6 t CO_2/TJ was calculated from the combination of emission trading data and analysis results. That value is closer to the default value of 98.3 t CO_2/TJ given in the 2006 IPCC Guidelines.

The following table presents an overview of the results from the analyses.

Table 1: Analysis data for hard coal

Analysis parameter	Units	Egg coal, England	Anthracite, Ibbenbüren
Short analysis			
Water	[mass fraction]	2.415	0.340
Ash content, 815°C	[mass fraction]	5.610	2.760
Volatiles	[mass fraction]	10.820	4.505
Fixed carbon	[mass fraction]	81.155	92.395
Total	[mass fraction]	100.000	100.000
Higher heating value	[kJ/kg]	32,236.500	35,021.500
Net calorific value	[kJ/kg]	31,496.000	34,361.500
CO2-emission factor	[t CO2/TJ]	95.913	96.828

Analysis parameter	Units	Egg coal, England	Anthracite, Ib-benbüren
Elementary analysis			
Water	[mass fraction]	2.415	0.340
Ash content, 815°C	[mass fraction]	5.610	2.760
Carbon content	[mass fraction]	82.390	90.740
Hydrogen content	[mass fraction]	3.165	2.885
Nitrogen content	[mass fraction]	1.315	1.140
Oxygen content	[mass fraction]	3.325	1.380
Total sulphur	[mass fraction]	1.780	0.755
Total	[mass fraction]	100.000	100.000
C/H ratio	[kg C / kg H]	26.000	31.450
Total chlorine	[mass fraction]	0.260	0.105

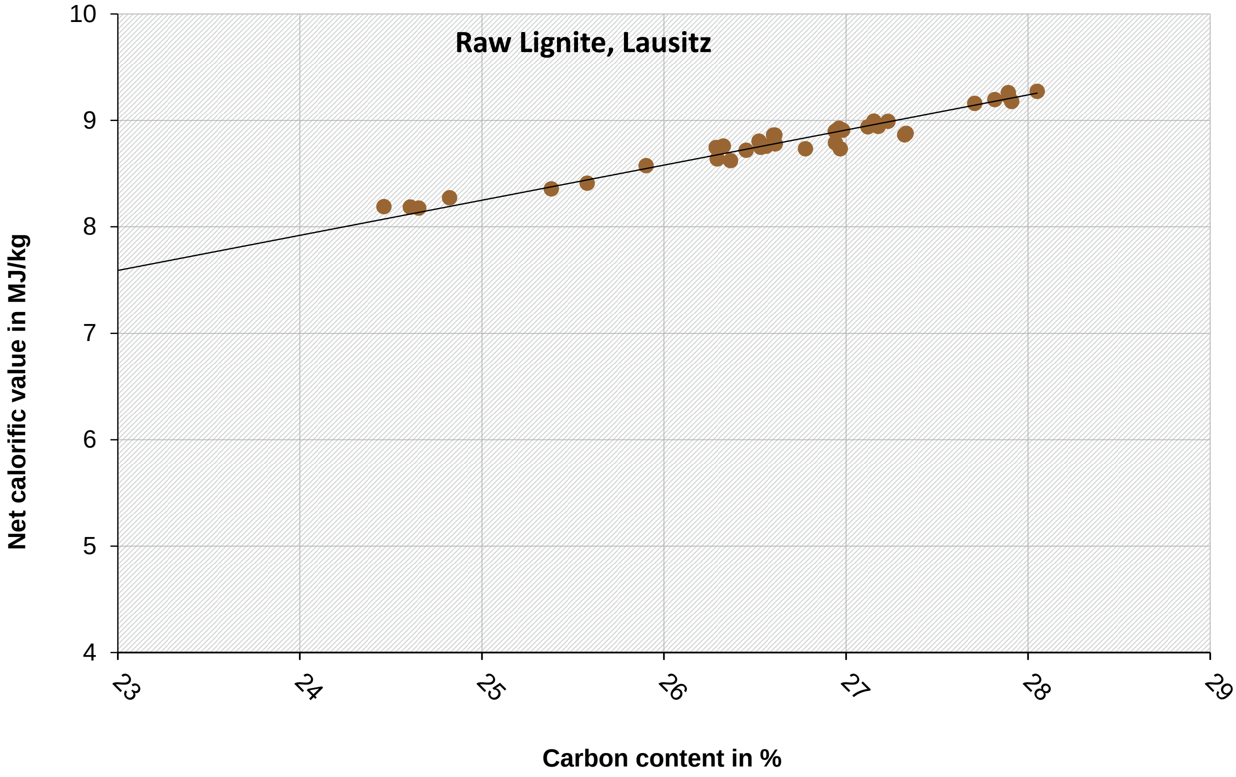
Source: TU Dresden 2014

4 Lignite

4.1 Raw lignite

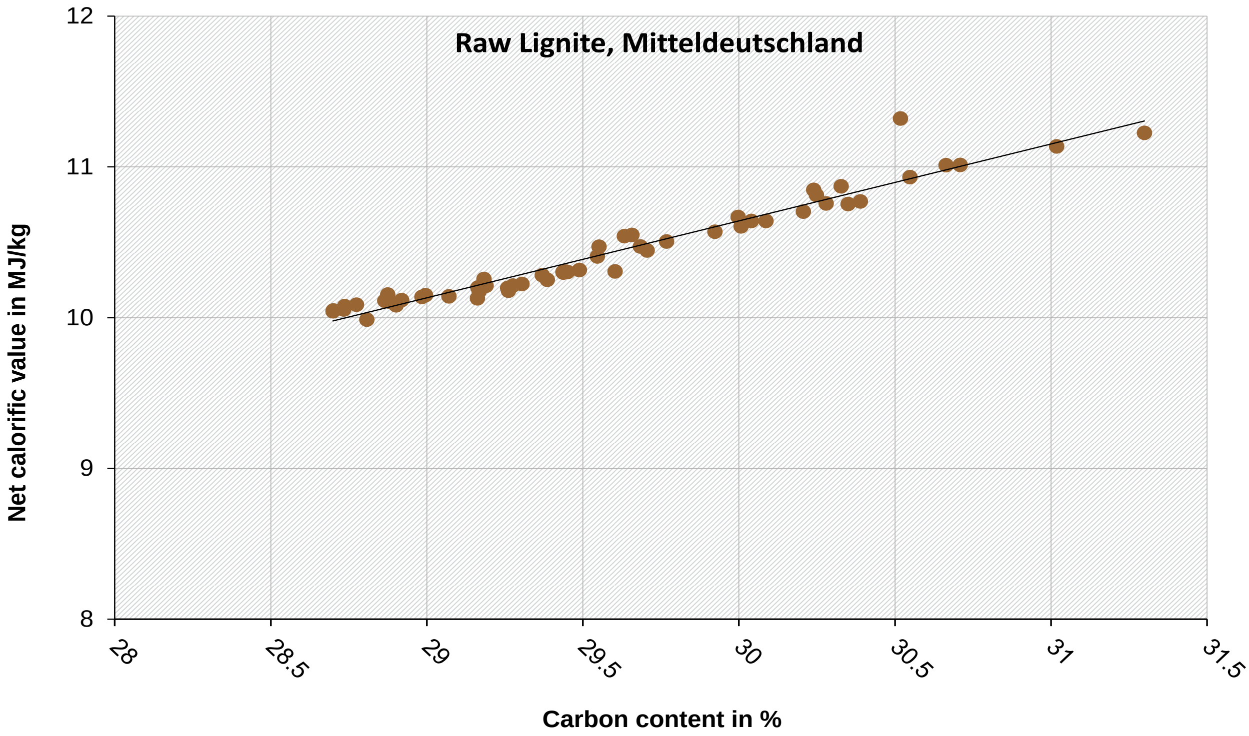
Deutschland is the world's largest lignite producer. The great majority of the raw lignite mined in the country is used directly, in power stations, while a small fraction of the lignite is used to make transformation products. The composition of raw lignite varies considerably more widely than does that of hard coal. Sulphur content is an important parameter. That parameter can differ greatly from mining district to mining district. Since sulphur content is of relevance to the net calorific value, it influences the net calorific value / carbon ratio. As a result, the data have to be evaluated on a mining-district-specific basis. When enough data are used, the mining-district-specific evaluation for lignite, like the evaluation for hard coal, shows a clear correlation between net calorific value and carbon content, as the following figures show.

Figure 7: Net calorific values & carbon content for raw lignite from the Lusatian (Lausitz) mining district



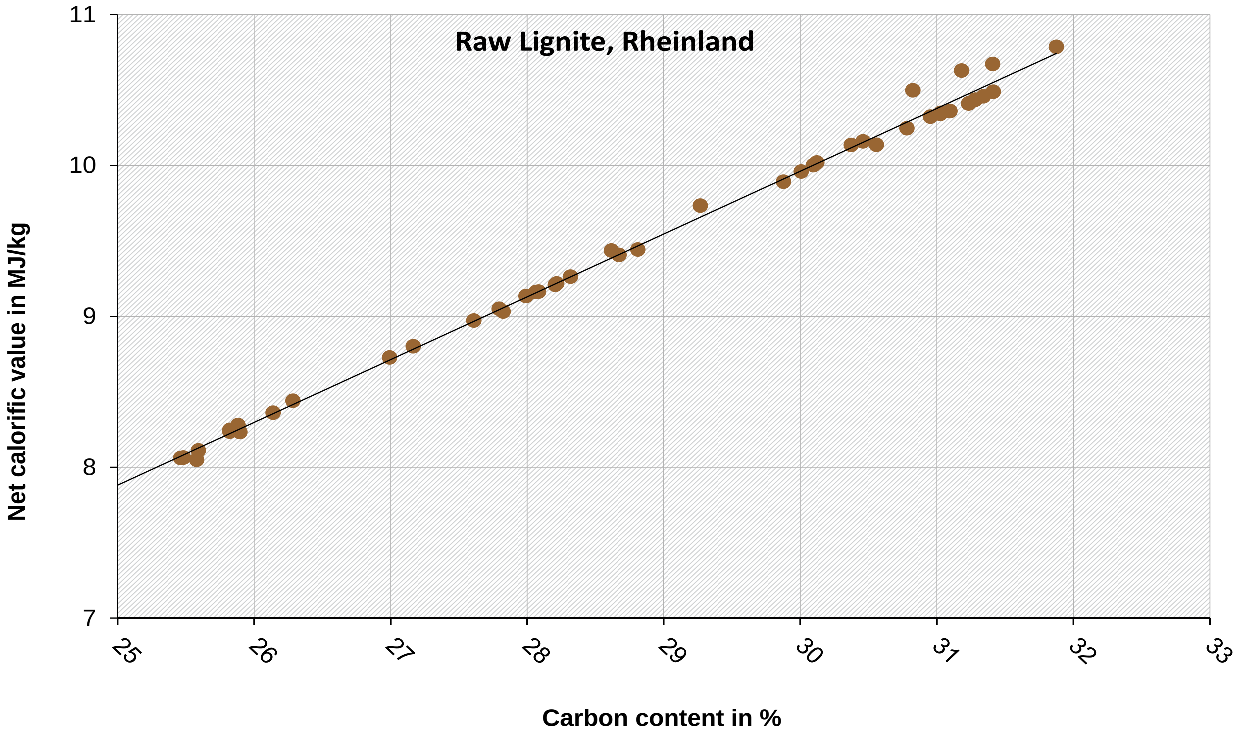
Source: Own figure, compiled from data of DEHSt (2015)

Figure 8: Net calorific values & carbon content for raw lignite from the central German (Mitteldeutschland) mining district



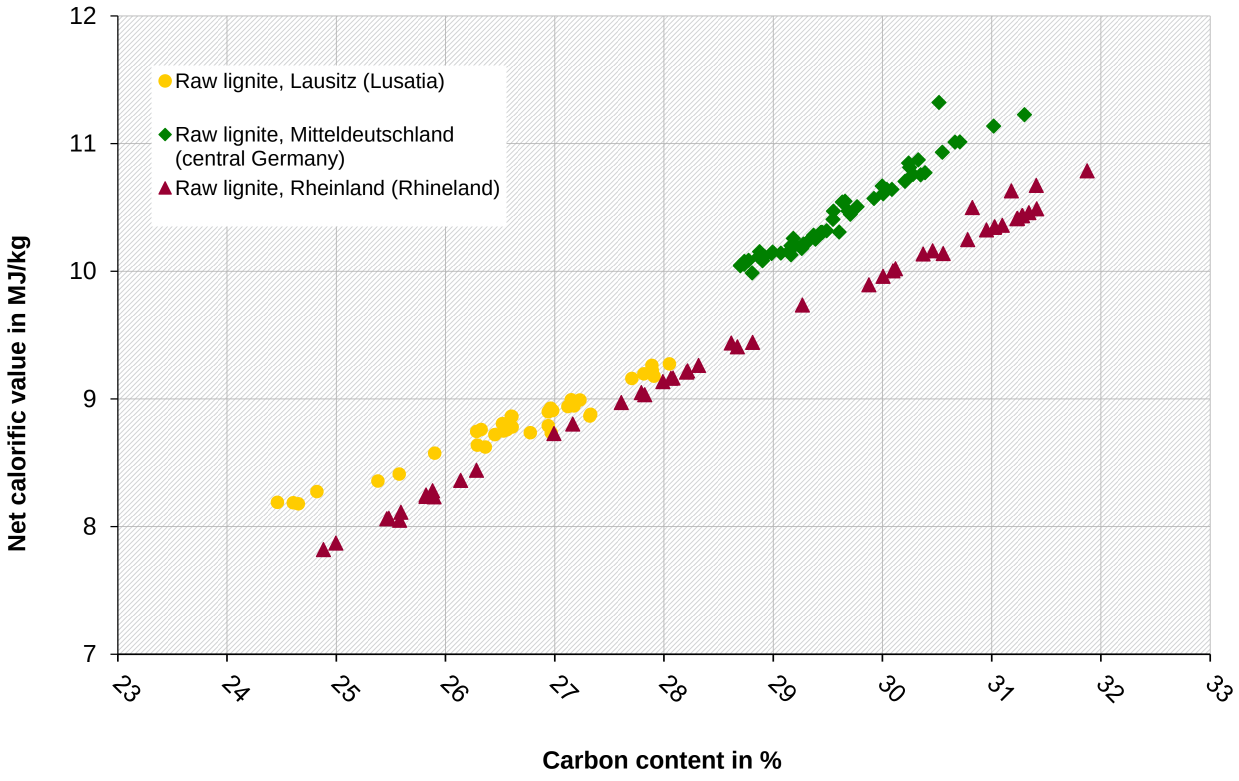
Source: Own figure, compiled from data of DEHSt (2015)

Figure 9: Net calorific values & carbon content for raw lignite from the Rhineland (Rheinland) mining district



Source: Own figure, compiled from data of DEHSt (2015)

Figure 10: Comparison of net calorific values & carbon content in raw lignite



Source: Own figure, compiled from data of DEHSt (2015)

The separate graphs for the different German lignite-mining districts can be clearly interpreted. The integrated graph, which summarizes the data for the most important German lignite-mining districts, highlights the differences between the individual profiles. The raw lignite from the two eastern German mining districts has a higher sulphur content, on average, than does coal from the Rhineland district. The highest sulphur content is seen in lignite from the central German (Mitteldeutschland) district. It amounts to 1.3 – 2.1 % (DEBRIV 2014). As a result, the net calorific values for that lignite are higher, on average, than those for lignite from the other two mining districts. Lignite from the Helmstedt mining district has an even higher sulphur content, ranging from 1.5 to 3.5 % (DEBRIV 2014). The quantities of coal used from that district are insignificant in comparison to the coal quantities sourced from the other districts, however. What is more, use of the open-pit mine and the remaining coal deposits in the Helmstedt mining district is expected to continue only until 2017.

4.2 Determination of emission factors back through 1990

For the period as of 2005, annual, mining-district-specific emission factors can be calculated from emissions trading data. Since lignite quality levels have changed since 1990, the currently used emission factors cannot simply be carried backward. In particular, a number of coal pits were closed in the new German Länder in the early 1990s, and this influenced the mining-district-specific average. The pertinent changes are reflected in the development of net calorific values, which are available on a mining-district-specific basis for the period as of 1990. The data are provided to the Federal Environment Agency (UBA) by the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations.

Thanks to the good correlation between net calorific values and carbon fractions, a suitable formula can be derived for nearly every mining district. With the help of the so-produced formulae, and the net calorific values known for the relevant years, it was possible to calculate the pertinent carbon content data and, subsequently, the energy-related CO_2 emission factors. This, in turn, made it possible to re-calculate the data back though 1990 and, thus, to produce a consistent time series. Certain uncertainties arise in that a number of small-scale mines were in operation in 1990 that produced coal with different sulphur content levels. The pertinent data cannot now be generated after the fact, however. And enquiries submitted to local mining museums produced no new findings. In 1990, very little carbon analysis was carried out, because carbon had not yet become an important issue. Only a few individual analyses were carried out, and they are not necessarily representative. For example, for lignite from the state of Hesse, which was mined until 2003, only net-calorific-value data are available. For the relevant recalculations, a mean sulphur content was assumed. It lies between the content levels for lignite from the central German (Mitteldeutschland) and Rhineland mining districts. That coal plays an insignificant role in terms of quantity, however. The relevant emission factor changed sharply between 1991 and 1992, because two power stations in that mining district were decommissioned that had been temporarily fired with low-grade coal.

As a result, the energy-related CO_2 emission factors for Rhineland raw lignite have decreased slightly since 1990. While a CO_2 factor of 114.8 t CO_2/TJ was calculated for 1990, the corresponding value given in the emissions trading sector for the year 2014 is 113.1 t CO_2/TJ. In the intervening years, the emission factors fluctuated between 113.9 and 113.0 t CO_2/TJ. For raw lignite from the central German mining district, the resulting factor for 1990 is 105.7 t CO_2/TJ. In 2014, a value of 102.8 t CO_2/TJ was reported. In the intervening years, the emission factors fluctuated between 104.0 and 102.8 t CO_2/TJ. With regard to the Lusatian mining district, the emission factor calculated for 1990, 111.2 t CO_2/TJ, happens to be identical with the value determined for 2014, from emissions trading data. Throughout the time series, the CO_2 emission factors vary between 112.0 and 109.9 t CO_2/TJ. The 1986 annual report of the former GDR's coal industry includes some analysis data for various open-pit mines in the Lusatian mining district. Those data are incomplete, however; only ash, water and sulphur content were measured. Fortunately, other sources (Mohry 1986) yielded supplementary data on levels of hydrogen, nitrogen and oxygen, thereby making it possible to calculate carbon content. Boie's formula was used to check whether the result of the analysis-data calculation agrees with the measured net calorific value. The result indeed shows good agreement. In addition, the formula determined for raw lignite from the Lusatian mining district was used, in combination with the known net calorific value, to calculate a carbon-content level. That result also agrees well with the analysis results.

Due to the small number of measurements involved, and to the measurements' wide fluctuation, it was not possible to calculate a net calorific value / carbon ratio for raw lignite from the Helmstedt mining district. For this reason, an average was determined, from the emissions trading data for the period 2005 – 2013, and that value was carried backward through 1990. That value has been retained as a fixed value. It will not be recalculated each year, even though in future emissions trading data will cover an even larger number of years. In the final analysis, such recalculation would not yield any new findings for the year 1990. What is more, coal mining in the Helmstedt mining district is expected to be terminated in 2017. Consequently, only a small number of new values are now expected. The calculations show that the CO_2 emission factors have increased from 98.7 to 101.1 t CO_2/TJ. Raw lignite from the Helmstedt mining district has the highest net calorific value – and, thus, the lowest energy-related CO_2 emission factor.

For inputs of raw lignite in district heating stations, a weighted emission factor was calculated from lignite inputs for the public electricity supply. For the areas of industry and residential, institutional and commercial (small consumers), a weighted emission factor, reflecting the distribution of the various mining districts, was calculated from sales statistics of the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations (Deutscher Braunkohlen Industrie Verein). For inputs for the public electricity supply, emission factors of 110.8 – 111.7 t CO_2/TJ result throughout the time series. Those values are considerably higher than the default value given in the

2006 IPCC Guidelines, 101.0 t CO_2/TJ. Therefore, the default value is probably not representative of the real situation. Use of the default value for the German inventory would underestimate CO_2 emissions by about 15 million t CO_2.

4.3 Lignite briquettes

For the period as of 2005, the emission factors for lignite briquettes are determined on the basis of emissions trading data. From those data, year-specific and mining-district-specific averages were formed. Then, weighted averages were calculated from them, with the help of sales statistics (DEBRIV). The emissions trading data cannot be used directly, since they do not completely cover the areas covered by the report. The residential, institutional and commercial (small consumers) sectors do not participate in emissions trading. To ensure that the fuel grades involved are closely comparable, the analyses of ETS data were compared with our own analyses of briquettes from the residential sector. The results show good agreement. The following figure provides an overview of the analysis results.

Table 2: Analysis data for lignite briquettes

Analysis parameter	Units	"Rekord" brand briquettes, Lusatian mining district	Briquettes, Rhineland district
Short analysis			
Water	[mass fraction]	13.180	14.350
Ash content	[mass fraction]	4.875	3.250
Volatiles	[mass fraction]	45.990	43.190
Fixed carbon	[mass fraction]	35.955	39.210
Total	[mass fraction]	100.000	100.000
Gross calorific value	[kJ/kg]	21,304.500	21,982.000
Net calorific value	[kJ/kg]	20,124.000	20,811.000
CO2-emission factor	[t CO2/TJ]	98.478	99.036
Elementary analysis			
Water	[mass fraction]	13.180	14.350
Ash content	[mass fraction]	4.875	3.250
Carbon content	[mass fraction]	54.045	56.210
Hydrogen content	[mass fraction]	3.905	3.850
Nitrogen content	[mass fraction]	0.655	0.700
Oxygen content	[mass fraction]	22.700	21.250
Total sulphur	[mass fraction]	0.640	0.390
Total	[mass fraction]	100.000	100.000
C/H ratio	[kg C / kg H]	13.850	7.350
Total chlorine	[mass fraction]	0.030	0.035

Source: TU Dresden 2014

While lignite briquettes are a standardised product, subject to specific quality criteria, they can still differ from mining district to mining district, depending on the carbon and sulphur content of the raw lignite they are made from. The pertinent recalculation back through the year 1990 proved to be considerably more complicated than the calculation for raw lignite. Only for Rhineland lignite briquettes was it possible to calculate an average CO_2 emission factor, from the ETS data for 2005 – 2013, that can also be used for the years 1990 – 2004. At the beginning of the 1990s, a great many briquette factories in the new German Länder were closed, and this had a considerable impact on fuel quality. No briquettes are now produced from raw lignite from the Central German (Mitteldeutschland) mining district, due to that lignite's high sulphur content. Consequently, no current measurements are available for such briquettes, and thus archive data had to be used. The available analysis data consisted of data of Mohry, dating from 1986, and data from the 1986 edition of the "Jahresbericht der Kohleindustrie der DDR" ("Annual report of the coal industry of the GDR"). Analysis data from the "Ernst Thälmann" Ingenieursschule für Bergbau und Energetik in Senftenberg (now the Brandenburg University of Technology Cottbus-Senftenberg) were also used. Gaps in the analyses were closed via calculations of our own. In the process, a nitrogen / oxygen ratio of 1:30 was assumed. This made it possible to calculate the lacking nitrogen-content data. The results were verified by also calculating the net calorific value from the individual data. The calculated and measured net calorific values show excellent agreement, as the following table shows.

Analysis parameter	Units	Braunkohlenkombinat Bitterfeld (Bitterfeld lignite production combine)	Briquette factory, Espenhain	Braunkohlenkombinat Senftenberg (Senftenberg lignite production combine)
Water content	[mass fraction]	19.100	15.100	19.300
Ash content, 815°C	[mass fraction]	11.400	13.430	5.470
Carbon content	[mass fraction]	49.973	51.673	50.360
Hydrogen content	[mass fraction]	4.000	4.000	4.000
Nitrogen content	[mass fraction]	0.397	0.437	0.650
Oxygen content	[mass fraction]	11.900	13.100	19.500
Total sulphur	[mass fraction]	3.230	2.260	0.720
Net calorific value (analysis)	[kJ/kg]	19.720	20.190	18.800
Net calorific value (calculated)	[kJ/kg]	19.760	20.220	18.821
Emission factor, t CO_2/TJ	[t CO2/TJ]	92.919	93.843	98.220
Analysis parameter	**Units**	**Gaskombinat (gas production combine), Schwarze Pumpe**	**Briquette factory, Lauchhammer**	**Briquettes, Lusatian mining district**
Water content	[mass fraction]	18.600	14.900	12.910
Ash content, 815°C	[mass fraction]	6.610	5.100	5.650
Carbon content	[mass fraction]	51.013	54.903	54.290
Hydrogen content	[mass fraction]	3.500	4.000	4.370
Nitrogen content	[mass fraction]	0.627	0.657	0.850
Oxygen content	[mass fraction]	18.800	19.700	21.300
Total sulphur	[mass fraction]	0.850	0.740	0.630
Net calorific value (analysis)	[kJ/kg]	18.650	20.440	20.553
Net calorific value (calculated)	[kJ/kg]	18.684	20.490	20.501
Emission factor, t CO_2/TJ	[t CO2/TJ]	100.294	98.489	96.854

Source: Jahresbericht 1986 der Kohleindustrie (Annual coal-industry report for 1986); Ingenieursschule für Bergbau und Energetik "Ernst Thälmann"; own calculations

It emerged that the previous assumption regarding the carbon content of briquettes from the Central German (Mitteldeutschland) district was much too high. As a result, the emission factor that had been used for 1990 was also too high. That value has now been downwardly corrected, by a suitable degree.

In calculation of the averages, it was ensured that the resulting emission factors agreed with the net calorific values published by DEBRIV. This made it possible to calculate an annual CO_2 emission factor for each mining district. And from those factors, in turn, it was possible, with the help of the sales statistics available from DEBRIV, to calculate annual, weighted CO_2 emission factors. This produced a consistent time series for the period as of 1990.

The weighted CO_2 emission factors for lignite briquettes in Germany range from 98.3 to 99.8 t CO_2/TJ. The values are somewhat higher than the default value of 97.5 t CO_2/TJ. Presumably, the briquette samples on which the default value was based had a higher sulphur content or lower water content. That relationship is suggested by the fuel data listed above. On average, lignite briquettes from the central German (Mitteldeutschland) district have lower energy-related CO_2 emission factors.

4.4 Lignite dust and fluidised bed coal

With regard to lignite dust and fluidised-bed coal, the data situation is considerably simpler, since all mining districts supply data to the emissions trading sector. On the other hand, it is not possible to derive a fixed net calorific value / carbon ratio from the available data. For this reason, for purposes of recalculation back through 1990, averages from 2005, and from 2008 – 2013, were used, depending on data quality. In an approach similar to that used for raw lignite and briquettes, a weighted CO_2 emission factor was also calculated for lignite dust and fluidised-bed coal, with the help of sales statistics (DEBRIV). For the period as of 2005, the CO_2 emission factors available from emissions trading were inserted directly into the calculations. Then, weighted factors were calculated in the usual manner, with the help of mining-district-specific sales statistics. The annual values range between 97.6 and 98.1 t CO_2/TJ. They are thus close to the default value, 97.5 t CO_2/TJ.

4.5 Lignite coke

Lignite coke is currently produced in only one mining district. Hearth furnace coke is used primarily as a feedstock. Since the pertinent fuel quality fluctuates only very slightly, an average was formed from the ETS data for 2008 – 2013 and then used for the recalculations back through 1990. For the new German Länder, only one data source was available. That source consists of analyses carried out by the [former] "Ernst Thälmann" engineering school for mining and energy technology ("Ingenieursschule für Bergbau und Energetik 'Ernst Thälmann'"), located in Senftenberg. It seems plausible that the fuel from the new German Länder, in comparison to coke from the Rhineland district, had a considerably lower carbon content and considerably higher ash content and sulphur content. Logically enough, the emission factor calculated for the new German Länder is also lower. Unfortunately, the data do not indicate whether the coke involved was high-temperature lignite coke or low-temperature lignite coke. In the former GDR, both production processes were used.

The emission factor calculated for 2014, from emissions trading data, is 109.3 t CO_2/TJ, which is close to the average calculated for 2005 – 2013, 109.6 t CO_2/TJ. Over the years, the values of the factor fluctuate only slightly, between 109.3 and 109.8 t CO_2/TJ. The 2006 IPCC Guidelines do not list a default value for lignite coke.

4.6 Meta-lignite

For the period as of 2008, the CO_2 emission factors for meta-lignite can be generated from ETS data. Only very small quantities of meta-lignite, imported from the Czech Republic, are now used in Germany. To make it possible to calculate the pertinent emission factors back through 1990, the applicable carbon / net-calorific-value ratio was determined from the available emissions trading data. It was then possible, with the help of the net calorific values known from lignite statistics (DEBRIV), to produce a consistent time series.

4.7 Other lignite products

In the former GDR, the lignite-coking process also yielded lignite tar. Unfortunately, no data for the year 1990 were available for lignite tar. As an alternative, analysis data from the research report Vertrag Nr. (contract number) 7220-EB/106 (DEBRIV 1980) were used. The material values given by the original source refer to water-free and ash-free samples. They were converted in keeping with the original substance. Lignite tar has not been used since 1991.

The material values for lignite tar oil, which was used in some refineries in the former GDR, were obtained from a data set of the [former] "Ernst Thälmann" engineering school for mining and energy technology ("Ingenieursschule für Bergbau und Energetik 'Ernst Thälmann'"), located in Senftenberg. The analysis data for lignite semi-coke were also obtained from the same data source.

Table 3: Analysis data for other lignite products

Analysis parameter	Units	Lignite tar	Lignite tar oil	Lignite semi-coke
Water content	[mass fraction]	16.500	0.000	29.100
Ash content	[mass fraction]	0.140	0.000	1.800
Carbon content	[mass fraction]	68.889	84.000	61.570
Hydrogen content	[mass fraction]	8.028	11.000	1.310
Oxygen content	[mass fraction]	6.194	4.300	3.420
Nitrogen content	[mass fraction]	6.194	0.000	1.000
Sulphur content	[mass fraction]	0.250	0.700	1.800
Net calorific value	[kJ/kg]	30.456	39.170	22.526
Emission factor	[t CO2/TJ]	82.937	78.631	100.220

Source: DEBRIV 1980; Ingenieursschule für Bergbau und Energetik "Ernst Thälmann"; own calculations

The lignite products listed above are very uncommon, and they are no longer used. For this reason, the IPCC Guidelines do not provide any default values for them.

4.8 Peat

The data records of the [former] "Ernst Thälmann" engineering school for mining and energy technology ("Ingenieursschule für Bergbau und Energetik 'Ernst Thälmann'"), located in Senftenberg, also included analyses of peat. The net calorific value for that substance agrees with the value used in the Energy Balance. In the Energy Balance, fuel peat has been reported within the section on meta-lignite. Pursuant to the 2006 IPCC Guidelines, peat is reported as a fossil fuel.

Table 4: Analysis data for peat

Analysis parameter	Units	Peat, fresh	Peat, air-dried
Water content	[mass fraction]	85.000	25.000
Ash content	[mass fraction]	0.900	4.500
Carbon content	[mass fraction]	8.290	41.450
Hydrogen content	[mass fraction]	0.800	4.020
Oxygen content	[mass fraction]	4.710	23.550
Nitrogen content	[mass fraction]	0.240	1.200
Sulphur content	[mass fraction]	0.060	0.280
Net calorific value	[kJ/kg]	0.986	14.930
Emission factor	[t CO2/TJ]	308.133	101.797

Source: Ingenieursschule für Bergbau und Energetik "Ernst Thälmann"

Peat is no longer used in Germany as a fuel. The pertinent CO_2 emission factor has been applied to the 1990 – 2007 time series. The default value given in the 2006 IPCC Guidelines, 106 t CO_2/TJ, is higher than the national value. As the above table shows, the values can fluctuate widely, however – primarily as a function of the substance's water content. Since the net calorific values given in the Energy Balance agree with the net calorific value resulting from the analysis, the CO_2 factor may also be assumed to agree.

5 Petroleum

5.1 Crude oil and naphtha

In Germany, crude oil and naphtha are not used in combustion systems. Consequently, emissions trading data do not include carbon-content figures for these raw materials. And no other sources provide analysis values. For this reason, we have used the default values given in the 2006 IPCC Guidelines. The factors are used solely for the Reference Approach and for obtaining the transformation balance for refineries. The possibility of determining national CO_2 emission factors for crude oil was considered, in various ways. While refinery operators regularly test crude-oil mixtures for quality, carbon content is not among the parameters they test for. As a result, additional analyses would have to be carried out. In a range of discussions with the Association of the German Petroleum Industry (Mineralölwirtschaftsverband), it emerged that it would be impossible to obtain the number of samples needed to determine a representative average for a year. Many different types of crude oil are used in Germany. They are pumped through pipelines as mixtures. Different petroleum types are mixed in keeping with applicable prices and quality requirements. The number of different types of crude oil processed in the country's refineries has increased considerably in recent years. And mixtures' fractions of the different types differ widely from year to year. This additionally complicates the task of producing and analyzing time series.

5.2 Gasolines

For calculation of the CO_2 emission factors for gasolines, an extensive evaluation was carried out of research report 502-1 of the German Society for Petroleum and Coal Science and Technology (DGMK), "Composition of gasolines from German refineries" ("Zusammensetzung von Ottokraftstoffen aus deutschen Raffinerien" (DGMK 2002)). As part of that study, samples from a total of 14 German refineries were analyzed. "…In the gasoline grades Normal [regular], Super [mid-grade/plus] and Super Plus [premium], the [carbon] content was determined, in the form of individual values, for hydrocarbons with three to six carbon atoms in their molecules, for selected aromatics with up to 12 carbon atoms and for some oxygen-containing compounds. …at the same time, in complementation of these measurements, and in keeping with draft DIN EN 14517 (PIONA), the sum totals of paraffins, naphthenes, cyclic and acyclic olefins and aromatics were determined, in each case for all components with the same carbon number. In contrast to the approach used for the individual measurements, these measurements also covered, in addition to nonaromatic hydrocarbons with three to six carbon atoms, nonaromatic hydrocarbons with up to ten carbon atoms…." [DGMK research report 502-1 p. 7]

The carbon content was calculated using the averages of the individual measurements on hydrocarbons with three to six carbon atoms and aromatics with up to 12 carbon atoms, for the fuel grades Normal [regular], Super [mid-grade/plus] and Super Plus [premium]. The relevant values are listed in tables 1-4 of DGMK research report 502-1. Of the polycyclic aromatic hydrocarbons, only the substances fluorene, phenanthrene and anthracene were covered, because all other PAHs were present in such low concentrations that they would have no impact on the total-carbon-content calculation. Even the three PAHs mentioned, which had the highest concentrations of all the PAHs present, had virtually no impact on the calculation result. The individual measurements were supplemented with the "PIONA" measurements for hydrocarbons with more than 7 carbon atoms. This approach yielded a total coverage level of 99 – 100%, depending on the fuel grade concerned. The following table provides a complete overview of the analysis results.

Table 5: Analysis data for the various grades of gasoline

Components	Units	Normal [regular]	Super [midgrade/plus]	Super Plus [premium]
MeOH	% by weight	0.010	0.060	0.120
propane	% by weight	0.070	0.060	0.060
propene	% by weight	0.010	0.010	<0.01
n-butane	% by weight	3.090	3.300	3.210
i-butane	% by weight	1.550	1.560	1.550
1-butene	% by weight	0.200	0.250	0.150
trans-butene-2	% by weight	0.370	0.480	0.320
cis-butene-2	% by weight	0.330	0.360	0.220
i-butene	% by weight	0.210	0.250	0.200
1,3-butadiene	% by weight	0.010	0.010	0.010
TBA	% by weight	0.020	0.020	0.030
n-pentane	% by weight	4.820	3.850	3.020
2,2-dimethylpropane	% by weight	0.010	0.020	0.020
i-pentane	% by weight	10.500	10.960	11.270
cyclopentane	% by weight	0.950	0.820	0.640
1-pentene	% by weight	0.300	0.230	0.070
trans-2-pentene	% by weight	0.950	0.750	0.270
cis-2-pentene	% by weight	0.440	0.350	0.150
2-methylbutene-1	% by weight	0.620	0.480	0.180
3-methylbutene-1	% by weight	0.110	0.080	0.040
2-methylbutene-2	% by weight	1.360	1.090	0.410
2-methylbutandiene-1,3	% by weight	0.030	0.020	0.010
trans-1,3-pentadiene	% by weight	0.030	0.020	0.010
cis-1,3-pentadiene	% by weight	0.010	0.010	<0.01
cyclopentene	% by weight	0.560	0.370	0.170
MTBE	% by weight	0.140	2.300	10.020
n-hexane	% by weight	2.820	1.820	1.100
2,2-dimethylbutane	% by weight	2.380	1.940	2.180
2,3-dimethylbutane	% by weight	1.380	1.160	1.210
2-methylpentane	% by weight	4.760	3.520	2.370
3-methylpentane	% by weight	2.710	1.860	1.180
methylcyclopentane	% by weight	2.060	1.410	0.880
cyclohexane	% by weight	1.460	0.710	0.410
1-hexene	% by weight	0.090	0.070	0.010
trans-3-hexene	% by weight	0.110	0.110	0.020
cis-3-hexene	% by weight	0.040	0.040	0.010
trans-2-hexene	% by weight	0.110	0.110	0.020
cis-2-hexene	% by weight	0.130	0.120	0.030
3-methylpentene-1	% by weight	0.050	0.040	0.010
4-methylpentene-1	% by weight	0.050	0.040	0.010
cis-4-methylpentene-2	% by weight	0.040	0.020	<0.01
2,3-dimethylbutene-1	% by weight	0.030	0.030	<0.01

Components	Units	Normal [regular]	Super [mid-grade/plus]	Super Plus [premium]
trans-4-methylpentene-2	% by weight	0.020	0.030	0.010
2-methylpentene-1	% by weight	0.170	0.150	0.050
2-ethylbutene-1	% by weight	0.020	0.020	<0.01
2-methylpentene-2	% by weight	0.280	0.250	0.060
cis-3-methylpentene-2	% by weight	0.150	0.130	0.040
trans-3-methylpentene-2	% by weight	0.250	0.200	0.060
2,3-dimethylbutene-2	% by weight	0.070	0.050	0.010
3-methylcyclopentene	% by weight	0.070	0.090	0.020
4-methylcyclopentene	% by weight	0.030	0.020	0.010
cyclohexene	% by weight	0.040	0.040	0.010
1-methylcyclopentene	% by weight	0.270	0.240	0.070
benzene	% by weight	0.880	0.860	0.660
toluene	% by weight	10.820	11.960	12.520
ethylbenzene	% by weight	2.230	2.790	2.330
m-xylene	% by weight	4.200	5.400	5.120
p-xylene	% by weight	1.820	2.330	2.270
o-xylene	% by weight	2.320	3.020	3.030
styrene	% by weight	0.040	0.060	0.010
i-propylbenzene	% by weight	0.210	0.320	0.290
n-propylbenzene	% by weight	0.680	0.880	1.030
3-phenylpropene-1	% by weight	<0.01	0.010	<0.01
3-ethyltoluene	% by weight	1.930	2.490	2.800
4-ethyltoluene	% by weight	0.850	1.130	1.280
1,3,5-trimethylbenzene	% by weight	0.830	1.130	1.270
alpha-methylstyrene	% by weight	0.010	0.010	<0.01
2-ethyltoluene	% by weight	0.710	0.900	1.040
cis-propylbenzene	% by weight	0.010	0.010	<0.01
m-methylstyrene	% by weight	0.020	0.010	0.010
o-methylstyrene	% by weight	0.010	0.010	<0.01
1,2,4-trimethylbenzene	% by weight	2.770	3.730	4.340
p-methylstyrene	% by weight	0.010	0.010	<0.01
trans-propenylbenzene	% by weight	0.040	0.020	0.010
1,2,3-trimethylbenzene	% by weight	0.610	0.790	0.930
indane (benzocyclopentane)	% by weight	0.590	0.470	0.410
indene (benzocyclopentadiene)	% by weight	0.100	0.060	0.030
tert-butylbenzene	% by weight	0.010	<0.01	<0.01
i-butylbenzene	% by weight	0.040	0.040	0.050
sec-butylbenzene	% by weight	0.040	0.040	0.050
n-butylbenzene	% by weight	0.080	0.080	0.090
1-methyl-4-isopropylbenzene	% by weight	0.020	0.030	0.080
1,3-diethylbenzene	% by weight	0.140	0.140	0.160
1-methyl-3-n-propylbenzene	% by weight	0.300	0.340	0.380
1,4-diethylbenzene	% by weight	0.060	0.060	0.060
1-methyl-4-n-propylbenzene	% by weight	0.120	0.130	0.150

Components	Units	Normal [regular]	Super [midgrade/plus]	Super Plus [premium]
1,3-dimethyl-5-ethylbenzene	% by weight	0.320	0.370	0.420
1,2-diethylbenzene	% by weight	0.030	0.030	0.020
1-methyl-2-n-propylbenzene	% by weight	0.110	0.120	0.130
1,4-dimethyl-2-ethylbenzene	% by weight	0.210	0.240	0.270
1-methyl-3-isopropylbenzene	% by weight	0.070	0.080	0.100
1,2-dimethyl-4-ethylbenzene	% by weight	0.340	0.400	0.460
1-methyl-2-isopropylbenzene	% by weight	0.020	0.010	0.010
1,3-dimethyl-4-ethylbenzene	% by weight	0.190	0.220	0.250
1,2-dimethyl-3-ethylbenzene	% by weight	0.070	0.080	0.100
1,2,4,5-tetramethylbenzene	% by weight	0.190	0.240	0.280
1,2,3,5-tetramethylbenzene	% by weight	0.270	0.340	0.400
1,2,3,4-tetramethylbenzene	% by weight	0.120	0.130	0.140
5-methylindane	% by weight	0.130	0.100	0.090
tetralin	% by weight	0.020	0.020	0.020
naphtalene	% by weight	0.280	0.230	0.220
2-methylnaphtalene	% by weight	0.100	0.110	0.110
1-methylnaphtalene	% by weight	0.050	0.050	0.050
2,6-dimethylnaphtalene	% by weight	<0.01	0.010	0.010
1,3-butadiene	% by weight	0.007	0.010	0.006
2-methylbutadiene-1.3	% by weight	0.032	0.021	0.010
trans-pentadiene-1.3	% by weight	0.026	0.019	0.007
cis-pentadiene-1.3	% by weight	0.013	0.009	0.003
cyclopentadiene	% by weight	0.054	0.040	0.017
methylcyclopentadiene (a)	% by weight	0.012	0.011	0.001
methylcyclopentadiene (b)	% by weight	0.008	0.007	0.001
dicyclopentadiene (a)	% by weight	0.020	0.012	0.002
dihydrodicyclopentadiene	% by weight	0.423	0.235	0.024
tetrahydrodicyclopentadiene	% by weight	0.253	0.125	0.067
paraffins (7 C-atoms)	% by weight	6.194	5.123	4.433
paraffins (8 C-atoms)	% by weight	3.503	4.053	6.600
paraffins (9 C-atoms)	% by weight	1.129	0.909	0.852
paraffins (10 C-atoms)	% by weight	0.352	0.270	0.218
naphthenes (7 C-atoms)	% by weight	1.534	1.164	0.616
naphthenes (8 C-atoms)	% by weight	0.786	0.579	0.293
naphthenes (9 C-atoms)	% by weight	0.195	0.150	0.043
naphthenes (10 C atoms)	% by weight	0.098	0.066	0.025
acyclic olefins (7 C atoms)	% by weight	0.944	0.671	0.209
acyclic olefins (8 C atoms)	% by weight	0.652	0.569	0.135
acyclic olefins (9 C atoms)	% by weight	0.106	0.114	0.027
acyclic olefins (10 C atoms)	% by weight	0.054	0.033	0.018
cyclic olefins (7 C atoms)	% by weight	0.274	0.264	0.037
cyclic olefins (8 C atoms)	% by weight	0.276	0.458	0.138
cyclic olefins (9 C atoms)	% by weight	0.062	0.127	0.016
cyclic olefins (10 C atoms)	% by weight	0.051	0.048	0.032

Components	Units	Normal [regu-lar]	Super [mid-grade/plus]	Super Plus [pre-mium]
paraffins (> 10 C-atoms)	**% by weight**	**0.667**	**0.667**	**0.649**
fluorene	**% by weight**	**0.001**	**0.002**	**0.002**
phenanthrene	**% by weight**	**0.002**	**0.003**	**0.003**
anthracene	**% by weight**	**0.001**	**0.001**	**0.002**
sulphur	**% by weight**	**0.002**	**0.002**	**0.001**
Total	**% by weight**	**99.024**	**99.720**	**99.996**
Emission factor	**t CO2/t**	**3.183**	**3.185**	**3.141**

Source: DGMK 2002

For calculation purposes, the measuring limit was applied for the few values that lie below that limit. The same evaluation and calculation were carried out with the help of the data from the preceding study, which was published in 1994. The results are presented in the following table.

Table 6: Comparison of CO_2 emission factors

	Units	Normal [regu-lar]	Super [mid-grade/plus]	Super leaded	Super Plus [pre-mium]
DGMK 2002	[t CO_2/TJ]	3.183	3.185	-	3.141
DGMK 1994	[t CO_2/TJ]	3.179	3.188	3.193	3.156
Difference	**[%]**	**0.129**	**-0.100**		**-0.475**

Source: own calculations, on the basis of the DGMK studies of 2002 and 1994

The discrepancies are very small – less than 0.5 %. The values for leaded "Super" fuel, which has not been sold since 2002, differ only slightly from those for unleaded "Super" fuel. The discrepancy lies within the natural fluctuation range for the fuels, and is thus within the applicable uncertainties range. We thus refrained from listing leaded "Super" fuel separately. And, consequently, for leaded gasoline, which was still being sold in small quantities in the early 1990s, we have used the same emission factor that we have used for unleaded gasoline. In general, the available measurement technology has improved since the DGMK study of 1994, especially with the result that individual components with three to six carbon atoms can now be measured with greater sensitivity. Furthermore, for the DGMK study of 2002, as part of separate measurements on the fuel grades "Normal" [regular], "Super" [mid-grade/plus] and "Super Plus" [premium], selected diolefins and PAHs were also studied. For the aforementioned reasons, the data in the DGMK study of 2002 can be expected to be of higher quality overall. For this reason, the results from the DGMK study of 2002 were used for the inventory. Since the discrepancies between the values for 1994 and those for 2002 are very small, no real trend emerges.

The following figures show the compositions of the various gasoline grades and the fluctuation range for the pertinent emission factors. The highest and lowest emission factors, and the most important influencing parameters, are marked in each case.

Table 7: Composition of "Normal" [regular] gasoline grades

Components	Paraffins	Naph-thenes	Acyclic ole-fins	Cyclic ole-fins	Aromatics	Oxygen com-pounds	Emission factor
Units	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[t CO_2/t]
Mean	**45.30**	**7.004**	**8.781**	**1.513**	**37.140**	**0.295**	**3.183**
Refinery 1	46.81	8.160	9.040	0.820	35.180	0.010	3.181
Refinery 2	46.30	6.090	10.890	0.965	35.790	0.010	3.182
Refinery 3	42.03	7.090	17.280	3.260	30.400	0.010	3.176
Refinery 4	51.30	3.125	2.265	0.420	42.900	0.010	3.190
Refinery 5	41.63	9.500	5.510	0.100	41.250	2.020	3.182
Refinery 6	48.29	4.750	6.100	1.205	39.580	0.075	3.188
Refinery 7	49.66	5.370	8.930	1.080	35.040	0.010	3.178
Refinery 8	41.24	15.030	4.800	2.755	36.020	0.165	3.184
Refinery 9	40.45	7.245	11.895	1.165	39.270	0.010	3.190
Refinery 10	52.06	6.475	11.215	1.265	28.680	0.320	3.160
Refinery 11	52.03	5.975	10.205	1.095	30.630	0.095	3.166
Refinery 12	41.64	4.735	4.415	0.945	48.120	0.185	3.206
Refinery 13	49.24	7.430	3.675	1.290	37.200	1.205	3.175
Refinery 14	31.53	7.085	16.710	4.820	39.900	0.010	3.202

Source: DGMK 2002; own calculations

Table 8: Composition of "Super" [mid-grade/plus] gasoline grades

Components	Paraffins	Naph-thenes	Acyclic ole-fins	Cyclic ole-fins	Aromatics	Oxygen com-pounds	Emission factor
Units	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[t CO_2/t]
Mean	**40.23**	**4.880**	**7.438**	**1.532**	**43.441**	**2.543**	**3.186**
Refinery 1	46.61	2.760	4.940	0.350	43.900	1.525	3.190
Refinery 2	36.44	3.590	13.700	1.695	44.630	0.010	3.207
Refinery 3	32.22	3.980	15.725	1.780	46.300	0.010	3.211
Refinery 4	47.20	1.960	1.855	0.415	47.250	1.365	3.194
Refinery 5	33.29	11.190	5.890	0.110	42.190	7.340	3.173
Refinery 6	37.42	4.490	5.730	1.530	49.980	0.885	3.210
Refinery 7	39.77	3.190	11.685	1.745	43.660	0.010	3.202
Refinery 8	46.35	2.840	5.030	2.895	42.420	0.525	3.191
Refinery 9	44.40	5.245	8.840	3.155	36.340	2.065	3.169
Refinery 10	46.56	4.215	8.040	2.030	35.840	3.325	3.160
Refinery 11	49.07	4.415	6.610	1.040	37.140	2.015	3.169
Refinery 12	41.61	7.235	4.745	1.190	45.300	0.010	3.206
Refinery 13	38.94	7.610	2.460	0.810	45.230	4.995	3.175
Refinery 14	23.32	5.595	8.885	2.700	47.990	11.515	3.152

Source: DGMK 2002; own calculations

Table 9: Composition of "Super Plus" [premium] gasoline grades

Components	Paraffins	Naph-thenes	Acyclic ole-fins	Cyclic ole-fins	Aromatics	Oxygen com-pounds	Emission factor
Units	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[% by weight]	[t CO_2/t]
Mean	**33.95**	**2.900**	**2.759**	**0.429**	**44.332**	**10.487**	**3.144**
Refinery 1	36.26	1.720	2.390	0.210	49.970	9.465	3.159
Refinery 2	44.74	2.205	0.860	0.035	44.870	7.365	3.156
Refinery 3	-	-	-	-	-	-	-
Refinery 4	28.55	1.245	1.320	0.235	44.140	8.705	3.160
Refinery 5	27.71	8.490	1.800	0.085	46.720	13.955	3.132
Refinery 6	33.29	1.810	3.685	1.200	49.190	6.795	3.176
Refinery 7	31.64	2.275	4.155	0.320	47.380	7.625	3.170
Refinery 8	31.21	1.700	0.090	0.205	43.480	13.955	3.121
Refinery 9	41.60	3.035	2.515	0.210	34.430	13.440	3.102
Refinery 10	32.14	2.720	8.175	0.780	39.400	10.820	3.132
Refinery 11	45.67	2.310	0.720	0.185	32.380	10.435	3.111
Refinery 12	30.69	3.265	4.455	0.900	48.670	8.015	3.172
Refinery 13	28.55	3.335	1.495	0.655	48.400	13.745	3.136
Refinery 14	29.36	3.595	4.205	0.555	47.290	12.005	3.143

Source: DGMK 2002; own calculations

The discrepancies listed above are higher, on average, than the discrepancies between the DGMK studies of 2002 and 1994. For this reason, the discrepancies may be assumed to lie within the natural fluctuation ranges for the relevant grades of gasoline. The largest factors that influence the CO_2 emission factors have been marked in colour. For regular gasoline, the concentration of aromatics is the primary factor that determines the size of the CO_2 emission factor. On average, aromatics have higher carbon content levels than paraffins do. In general, the concentrations of aromatics found in a gasoline depend primarily on whether basic chemical compounds are also produced on the premises of the refinery that produced the gasoline. In cases in which such compounds are produced on the premises, producers seek to maximize the quantities of aromatics that are provided to chemical production processes. The concentrations of aromatics vary only slightly in "Super" [premium] grades of gasoline. The CO_2 factors in such gasoline are determined primarily by the levels of oxygen compounds (MTBE) found in the gasoline. In the case of "Super Plus" [premium], the concentrations of aromatics and of oxygen compounds both play a role.

At the time the measurements were carried out, no biofuels were being added to conventional fuels. Measurements including biofuels would distort the results, since biofuels contain ethanol, which contains oxygen. Such measurements would thus low lower carbon content levels overall.

A weighted CO_2 emission factor has been calculated from the data on annual sales of the fuel grades "Normal" [regular], "Super" [mid-grade/plus] and "Super Plus" [premium] (Official Mineral Oil Statistics). No figures for the new German Länder are available for the year 1990. That lack is compensated by applying to the year 1990 the breakdown for the various fuel grades as it was in 1991. In the interest of consistency, an energy-related CO_2 emission factor was calculated from the calculated mass-related emission factor and the net calorific value used in the Energy Balance. The so-determined emission factors hardly vary at all over the years. A surprisingly low emission factor results for only one year – 2011. Following the introduction of the fuel "E10" (which included a biofuel fraction of up to 10% in "Super" [mid-grade/plus]), considerably more "Super Plus" [premium] was purchased.

The energy-related emission factor remained constant over the years, at about 73.1 t CO_2/TJ. The default value of 69.3 t CO_2/TJ given in the 2006 IPCC Guidelines is too low. Use of the default value in the German inventory would yield a result that would be too low by about 3 million t CO_2.

5.3 Diesel fuel

The basis used for calculating the emission factor for diesel fuel is DGMK research report 583: "The composition of diesel fuels from German refineries, 1999-2002" ("Zusammensetzung von Dieselkraftstoffen aus Deutschen Raffinerien 1999-2002"). That study graded summer and winter samples from 13 refineries. From the analysis results, an average for the summer grades and an average for the winter grades were calculated. The following figure shows the slight differences that emerged between the grades.

Table 10: Composition of diesel fuels in summer

Components	Carbon	Hydrogen	Emission factor
Units	[% by weight]	[% by weight]	[t CO_2/t]
Average	**86.32**	**13.577**	**3.165**
Refinery 1	86.30	13.700	3.164
Refinery 2	86.20	13.700	3.161
Refinery 3	86.30	13.600	3.164
Refinery 4	86.30	13.600	3.164
Refinery 5	86.40	13.600	3.168
Refinery 6	86.40	13.500	3.168
Refinery 7	86.20	13.700	3.161
Refinery 8	86.20	13.800	3.161
Refinery 9	86.60	13.300	3.175
Refinery 10	86.20	13.600	3.161
Refinery 11	86.30	13.500	3.164
Refinery 12	86.50	13.400	3.172
Refinery 13	86.30	13.500	3.164

Source: DGMK research report 583; own calculations

Table 11: Composition of diesel fuels in winter

Components	Carbon	Hydrogen	Emission factor
Units	[% by weight]	[% by weight]	[t CO_2/t]
Average	**86.40**	**13.488**	**3.168**
Refinery 1	86.40	13.500	3.168
Refinery 2	86.40	13.300	3.168
Refinery 3	86.20	13.700	3.161
Refinery 4	86.20	13.700	3.161
Refinery 5	86.40	13.600	3.168
Refinery 6	86.20	13.400	3.161
Refinery 7	86.20	13.700	3.161
Refinery 8	86.50	13.500	3.172

Components	Carbon	Hydrogen	Emission factor
Refinery 9	86.30	13.600	3.164
Refinery 10	86.40	13.400	3.168
Refinery 11	86.50	13.500	3.172
Refinery 12	86.70	13.200	3.179
Refinery 13	86.30	13.500	3.164
Refinery 14	86.60	13.500	3.175
Refinery 15	86.70	13.400	3.179
Refinery 16	86.40	13.300	3.168

Source: DGMK research report 583; own calculations

The values fluctuate throughout a very narrow range overall. On the one hand, the grades of fuel produced by the various different refineries differ only very slightly. On the other, the differences between summer and winter grades of diesel fuel are also slight. Nonetheless, it is possible to calculate a weighted emission factor, from these data, that takes account of both summer and winter grades of fuel. In Germany, the availability of "winter diesel" is governed by law. Petrol stations are legally required to sell "winter diesel" from 15 November to 28 February. In addition, a conversion phase has to be taken into account, with the result that the usage period for "winter diesel" amounts to about 4 months. Accordingly, diesel vehicles run with "summer diesel" for a total of 8 months of the year. Applying this distribution, a weighted emission factor was calculated from the analysis results relative to "summer diesel" and "winter diesel." While the study did take account of calorific values, such values were available for only a few samples. And those samples cannot be unambiguously allocated to the various elementary analyses. It was possible to calculate net calorific values from the analysis data, however. The results show excellent agreement with the measured net calorific values. In addition, the values agree well with the net calorific values given in the Energy Balance. The calculation yields an energy-related CO_2 emission factor of about 74.0 t CO_2/TJ. That value agrees very well with the default value given in the 2006 IPCC Guidelines, 74.1 t CO_2/TJ.

5.4 Refinery gas

For refinery gas, a mass-related CO_2 emission factor was calculated from emissions trading data. Since the annual fluctuations are slight, a factor was used that remains constant for all of the years concerned. It was synthesised from the averages for the year 2005 – 2013. While the net calorific values given in the emissions trading sector exhibit only slight annual fluctuations, the net calorific values used in the Energy Balance do vary – considerably, in part. They differ from the emissions trading data. The default net calorific value given for energy statistics, at 42.4 MJ/kg of refinery gas, is considerably lower than the average calculated from emissions trading data, 47.6 MJ/kg. A plausible explanation for the annual fluctuations, and for the discrepancy with the emissions trading data, is that energy statistics reflect the fact that the numbers of operators using the low default net calorific value vary from year to year. In the interest of consistency, and in order to prevent underestimation of the CO_2 emissions, the inventory is prepared using the net calorific values used in the Energy Balance. The emission factor is then suitably adjusted. As a result, the energy-related emission factor fluctuates considerably, from 54.6 to 65.4 t CO_2/TJ. The default emission factor given by the 2006 IPCC Guidelines is 57.6 t CO_2/TJ, although the Guidelines give a high net calorific value of 49.5 MJ/kg that would normally be expected to lead to a lower default emission factor. Overall, the national emission factors are within the 95 % confidence interval for the default values.

5.5 LP gas

To make it possible to calculate CO_2 emission factors for LP gas, first the carbon content levels of butane and propane were calculated, via molar weights. The applicable fractions for the two components are published in the annual reports of the German Liquid Petroleum Gas Association (Deutscher Verband Flüssiggas). That association also provided the data for the period back through 1990. Weighted, mass-related emission factors are calculated annually from the applicable fractions for the two components. Those factors are then divided by the pertinent net calorific values used in the Energy Balance. The mass-related emission factors hardly vary at all over the years. The net calorific values given in the Energy Balance fluctuate more widely from year to year. Here again, the calorific-value fluctuations seen in energy statistics can be plausibly attributed to inconsistencies in use of the default calorific values given in the statistics. Identical net calorific values are used for propane and butane in each case. Via the calculation method chosen, these fluctuations in net calorific values are transferred to the energy-related CO_2 emission factor. The emission factors for LP gas that are published in the National Inventory Report apply only to energy-related consumption. The data for feedstock use differ, since the mixtures chosen for such use tend, on average, to contain more butane than propane. The mixtures chosen for energy-related use tend to contain more propane than butane. For energy-related consumption, which is of relevance for emissions reporting, weighted emission factors of 64.0 to 66.6 t CO_2/TJ were calculated. The default value given by the 2006 IPCC Guidelines, 63.1 t CO_2/TJ, is slightly lower than the averages for Germany as a whole. In all likelihood, the mixture on which the default value is based contained other substances, in addition to propane and butane, whose specific emission factors are lower than those for propane and butane.

5.6 Other petroleum products and residual substances

The CO_2 emission factors for light fuel oil, petroleum coke, heavy fuel oil and "other petroleum products" are calculated from emissions trading data. The relevant averages for the years 2005 – 2013 were carried backward through 1990.

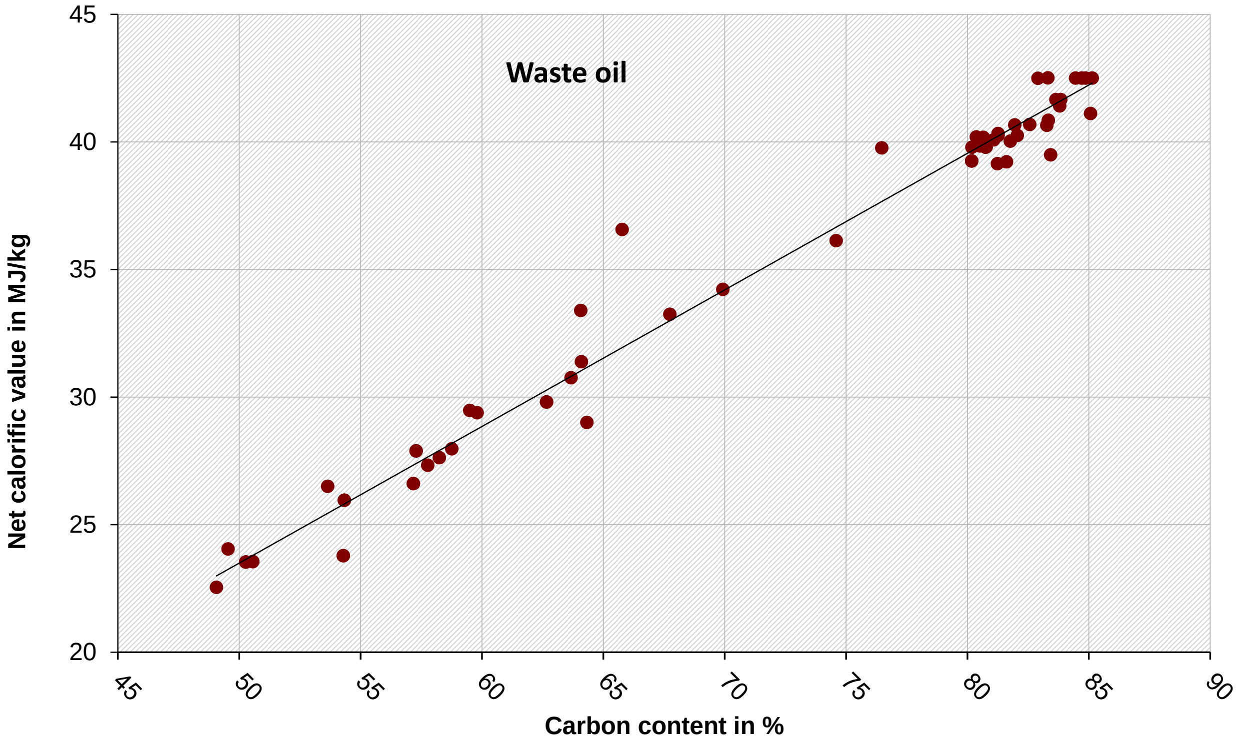
For light fuel oil, an average emission factor of 74.0 t CO_2/TJ was calculated. As expected, it is the same as the emission factor for diesel fuel. In addition, it agrees with the default value, 74.1 t CO_2/TJ.

Over the years concerned, the national emission factors for petroleum coke vary from 94.6 to 95.7 t CO_2/TJ. Overall, the values are somewhat lower than the default value given in the 2006 IPCC Guidelines, 97.5 t CO_2/TJ. Nonetheless, the values lie within the 95 % confidence interval. The national values have been calculated from quality-assured individual values. In addition, the fuel allocations have been checked for correctness.

It is somewhat difficult to differentiate between heavy fuel oil and "other petroleum products." In the Mineral Oil Statistics, "other petroleum products" are defined as residual substances from refineries, and the pertinent emission factor is calculated accordingly. And in the Energy Balance, the oils listed in the column "heavy fuel oil" include heavy fuel oils and other residual oils. The majority of heavy fuel oils are used in international shipping, and residual oils are used in chemical processing (non-energy-related consumption). Heavy fuel oil, meeting the applicable standards, continues to be used in conventional combustion processes in industry, on a considerably smaller scale. For that heavy fuel oil, annual, weighted emission factors of 79.0 – 81.3 t CO_2/TJ were determined. In comparison to those levels, the default value given in the 2006 IPCC Guidelines, 77.4 t CO_2/TJ, seems somewhat too low. The national factors for "other petroleum products" differ only slightly from the corresponding values for heavy fuel oil. They are slightly higher, on average, and range from 82.1 to 82.9 t CO_2/TJ. In this light, the default value given in the 2006 IPCC Guidelines for "Other petroleum products," 73.3 t CO_2/TJ, seems considerably too low. In this context, the Guidelines combine various substances, such as aromatics, tar, propylene, sulphur and fats, that differ considerably in terms of their chemical properties. For example, pure sulphur has a carbon content of 0, while benzene and toluene have carbon contents > 90%. The pertinent net calorific values also vary considerably. In general, it would be useful to separately list the substances that the Guidelines combines, because such combination can lead to marked misinterpretations and underestimations.

In Germany, only very small quantities of waste oil are used in combustion processes. For the most part, such oil is reprocessed, i.e. it is used for substance recovery. For this reason, only a limited quantity of data can be generated from emissions trading data. The substance values for waste oil vary, depending on the oil's origin. Nonetheless, a clear correlation between carbon content levels and calorific values emerges, as the following figure shows:

Figure 11: Calorific values and carbon content of waste oil



Source: Own figure, compiled from data of DEHSt (2015)

Presumably, the sulphur content levels of the waste oil considered here do not vary so widely. Otherwise, the values in the figure would show greater scattering.

6 Gases

Some gaseous fuels are grouped with the solid fuels, in keeping with the IPCC definitions of the fuels, and with the Guidelines' emphasis on the solid-fuel origins (including production origins) of the relevant gaseous fuels. This applies for coke-oven and town gas, for blast furnace gas and basic oxygen furnace gas and for fuel gas. The other produced gases are grouped with the liquid fuels, since these gases occur primarily in chemical industry processes – in non-energy-related consumption of naphtha and other petroleum products. These classifications play a necessary role in ensuring that the Reference Approach produces meaningful results.

6.1 Coke oven gas, blast furnace gas and basic oxygen furnace gas

Germany is a leading steel producer. Its production of coke oven gas, blast furnace gas and basic oxygen furnace gas is thus high, as one would expect. Blast furnace gas and basic oxygen furnace gas are normally combusted as mixtures. Natural gas is sometimes added, depending on the quality of the gas. Virtually all of the blast furnace gas produced by the steel industry is used for energy generation. Only a very small fraction of this gas is flared off.

The CO_2 emission factors for coke oven gas, blast furnace gas and basic oxygen furnace gas are determined with the help of emissions trading data. For relevant recalculations back through 1990, averages were calculated from the emissions trading data for the period 2005 – 2013. Those values were then used for the years 1990 – 2004. The emission factors calculated for coke oven gas vary only slightly – between 40.3 and 41.8 t CO_2/TJ. The national values are slightly below the default value given by the 2006 IPCC Guidelines – 44.4 t CO_2/TJ – but they are within that value's 95% confidence interval.

Since in energy statistics blast furnace gas and basic oxygen furnace gas are reported only as a gas mixture, a weighted emission factor is calculated from a) the emission factors determined individually for the two gases and b) the quantities of blast furnace gas and basic oxygen furnace gas that are produced. Undoubtedly, the mixing ratios used in the various utilization areas can differ. Combustion of blast furnace gas and basic oxygen furnace gas is covered only partially by emissions trading data, and the calculation method used ensures that the total emissions are calculated correctly. For it to be possible to compare the national factors with the default values in the 2006 IPCC Guidelines, blast furnace gas and basic oxygen furnace gas have to be considered separately. For blast furnace gas, the annual average emission factors (implied emission factors), calculated for the entire installations sector, vary from 254.9 to 272 t CO_2/TJ. The net calorific values range from 3.3 to 3.6 MJ/m^3. The default emission factor given in the 2006 IPCC Guidelines, at 260 t CO_2/TJ, lies within the range covered by the national factors. In Germany, the annual implied emission factors for basic oxygen furnace gas range from 188.6 to 195.1 t CO_2/TJ. The average net calorific values vary from 8.1 to 8.5 MJ/m^3. The default emission factor given in the 2006 IPCC Guidelines, at 182 t CO_2/TJ, is lower than the German values and thus seems somewhat too low.

6.2 Town gas

Town gas was used in Germany until 1996. In the Energy Balance, it is grouped with coke oven gas. The data situation is similar to that for combustion of blast furnace gas and basic oxygen furnace gas – no data are available on the fractions of coke oven gas and town gas found in the gas mixtures used. For this reason, a weighted emission factor was calculated here as well, via the figures for production of coke oven gas and town gas. The values for town gas were obtained from Berliner Gaswerke AG (GASAG – the Berlin natural gas utility) and DBI Gas- und Umwelttechnik GmbH Leipzig (DBI GUT). Detailed analyses are available for the years 1989 through 1991. The following table provides an overview of the different grades of gas used.

Table 12: Composition of the different components in town gas, by origin

	Units	Coal gasification	High-temperature lignite coking	Coal-dust gasification	Pressurized natural gas reforming	Pressurized oil cracking
Oxygen	[% by vol.]	0.060	0.160	0.000	0.120	0.120
Nitrogen	[% by vol.]	1.380	11.360	3.700	1.810	1.000
Carbon dioxide	[% by vol.]	4.240	3.570	17.400	2.500	2.910
Hydrogen	[% by vol.]	55.670	47.360	40.100	60.660	47.950
Carbon monoxide	[% by vol.]	21.190	21.780	38.800	34.420	47.550
Methane	[% by vol.]	17.000	15.260	0.000	0.510	0.440
Ethene	[% by vol.]	0.370	0.380	0.000	0.000	0.000
Propane	[% by vol.]	0.020	0.030	0.000	0.000	0.000
Propene	[% by vol.]	0.020	0.030	0.000	0.000	0.000
n-butane	[% by vol.]	0.050	0.070	0.000	0.000	0.000
Ethane	[% by vol.]	0.000	0.000	0.000	0.000	0.000
n-pentane	[% by vol.]	0.000	0.000	0.000	0.000	0.000
Net calorific value	[MJ/m³]	15.100	13.710	9.240	11.090	11.360
Emission factor	[t CO2/TJ]	56.620	59.965	119.812	66.387	88.126

Source: DBI GUT 2014a

These different gases were combined to form mixtures of relatively constant quality. Data on the relevant gas-fraction mixing ratios for summer and winter grades of gas are also available from DBI Gas- und Umwelttechnik GmbH Leipzig (DBI GUT). The following mixture is considered representative for summer grades, with respect to the fractions seen at the national level: 62.5 % gas from coal gasification, 25 % gas from high-temperature lignite gasification and 12.5% gas from coal-dust gasification. This yields a CO_2 emission factor of 65.36 t CO_2/TJ. The following mixture is considered representative for winter grades: 44.74 % gas from coal gasification, 17.9 % gas from high-temperature lignite gasification, 16.11 % gas from pressurised natural-gas reforming, 5.59 % gas from pressurised oil cracking, 8.95 % gas from coal-dust gasification and 6.71 % nitrogen. This yields an implied CO_2 emission factor of 62.4 t CO_2/TJ. The emission factors have been suitably weighted. The compositions of such mixtures vary considerably at the regional level, since the gases were sometimes also used separately. The calculation as described is used to obtained a national average. In comparison to the calculated CO_2 factors, the default emission factor given in the 2006 IPCC Guidelines, 44.4 t CO_2/TJ, seems too low. On the other hand, it has been a long time since town gas was used in Europe.

6.3 Fuel gas

The values for fuel gas, which was used exclusively in the former GDR, were obtained from a data set of the [former] "Ernst Thälmann" engineering school for mining and energy technology ("Ingenieursschule für Bergbau und Energetik 'Ernst Thälmann'"), located in Senftenberg. The following table covers a number of different gases:

Table 13: Analysis data for lignite gases used in the former GDR

	Units	Lignite-based "winkler" gas	Lignite-based generator gas	Lignite-based carbonisation gas	Lignite-based water gas
Carbon dioxide	[% by vol.]	5.500	3.700	19.000	13.800
Carbon monoxide	[% by vol.]	22.500	30.000	11.600	38.000
Hydrogen	[% by vol.]	12.600	10.700	11.000	26.500
Nitrogen	[% by vol.]	55.700	53.500	45.500	21.500
Methane	[% by vol.]	0.700	2.000	11.600	0.600
Other hydrocar-bons	[% by vol.]	0.000	0.000	0.800	0.000
Oxygen	[% by vol.]	0.000	0.000	0.500	0.000
Net calorific value [MJ/m³]	[MJ/m³]	4.459	5.665	7.277	7.879
Emission factor	[t CO2/TJ]	126.701	123.990	118.439	130.972

Source: Ingenieursschule für Bergbau und Energetik "Ernst Thälmann"; own calculations

The term "fuel gas" is not clearly defined. Since this gas was used primarily in mine-mouth power plants, it may be assumed to have been a lignite-based gas. The composition of such gas can vary widely, however. Consequently, the applicable emission factors can also differ widely. They lie within the range 118.6 to 131 t CO_2/TJ. In the interest of applying a conservative approach, to ensure that the base-year emissions are not overestimated, the lowest emission factor is used for inventory preparation. The 1989 Energiewirtschaftlicher Jahresbericht (1989 edition of an annual report for the energy sector) gives a net calorific value of 5.3 MJ/Nm^3 for "other gas," a figure that points to a higher emission factor. Since in the Energy Balance coke oven gas, town gas and fuel gas are reported as a group, the net calorific values for the individual gases involved can no longer be determined.

Other residual gases are used primarily in the chemical industry. This term refers both to high-caloric gases, with high hydrogen fractions, and to low-caloric flare gases with high nitrogen fractions. The pertinent emission factor was calculated from emissions trading data for the chemical industry. In the process, an average for the years 2008 – 2013 was obtained. Energy statistics and emissions trading use considerably different calorific-value figures, but the relevant quantities, given in cubic meters, show good agreement. For this reason, an emission factor was calculated that is based on that natural unit. In the interest of consistency, calculations for purposes of inventory preparation use the net calorific value given in energy statistics.

For **mine gas**, a methane-content figure is calculated from the quantity of methane used, as given by the Gesamtverband Steinkohle (GVSt) hard-coal-mining association, and the total quantity, expressed in cubic meters, given in the Energy Balance. A CO_2 emission factor is then calculated via the relevant gas composition. Statistical differences are seen in some years. In the interest of applying a conservative approach, the calculation is carried out with the lowest methane-content figure. On the whole, the methane content in the so-utilised gas can be expected to decrease somewhat. For this reason, the values are reviewed annually. The 2006 IPCC Guidelines do not give a default emission factor for mine gas.

6.4 Natural gas and associated gas

For petroleum gas, data were available from emissions trading. In Germany, petroleum gas is used only in connection with natural-gas production. Until 1994, petroleum gas was listed separately in the Energy Balance as a fuel. As of 1995, the Energy Balance has presented combined data on natural gas and associated gas. Since the quantities of natural gas recorded in the context of emissions trading are not representative, and since default emission factors are frequently used, the firm of DBI Gas- und Umwelttechnik GmbH Leipzig (DBI GUT) carried out analyses of its own, via the following project: "Measurements of natural-gas quality at various points in the network, for derivation and verification of implied emission factors and net calorific values for natural gas" ("Messungen der Erdgasqualität an verschiedenen Stellen im Netz zur Ableitung bzw. Verifizierung von durchschnittlichen Emissionsfaktoren und Heizwerte von Erdgas" (2014)). In the project, measurements were taken throughout Germany, at a total of 32 different locations. The measurement sites were selected so as to ensure that all important imported gases, and the country's own production, would be covered. In addition, a mixture distributed in Germany was analysed. In cases involving border handover points in which it was not possible to take measurements, alternative measurement sites were found.

Table 14: Analysis data for natural gas L

	Units	Netherlands, winter	Netherlands, summer	Germany, winter	Germany, summer
Helium	[mol%]	0.05786	0.05787	0.05487	0.04889
Hydrogen	[mol%]	0.00000	0.00000	0.00000	0.00000
Oxygen	[mol%]	0.00200	0.02198	0.00100	0.00699
Nitrogen	[mol%]	13.20306	11.89412	11.66730	11.23674
Carbon dioxide	[mol%]	0.91300	0.73146	0.76550	0.53382
Carbon monoxide	[mol%]	0.00000	0.00000	0.00000	0.00000
Methane	[mol%]	82.92466	85.30374	85.10016	86.58319
Ethane	[mol%]	2.44735	1.69909	2.00772	1.47382
Ethene	[mol%]	0.00000	0.00000	0.00000	0.00000
Propane	[mol%]	0.29519	0.18362	0.21809	0.06493
Propene	[mol%]	0.00000	0.00000	0.00000	0.00000
i-butane	[mol%]	0.04515	0.02857	0.03649	0.01256
n-butane	[mol%]	0.05024	0.03203	0.04183	0.01119
Neopentane	[mol%]	0.00615	0.00450	0.00550	0.00410
i-pentane	[mol%]	0.01220	0.00822	0.01288	0.00394
n-pentane	[mol%]	0.01153	0.00761	0.01192	0.00265
i-hexane	[mol%]	0.00921	0.00622	0.01035	0.00302
n-hexane	[mol%]	0.00456	0.00301	0.00602	0.00127
i-heptane	[mol%]	0.00609	0.00370	0.00932	0.00161
n-heptane	[mol%]	0.00192	0.00114	0.00370	0.00044
i-octane	[mol%]	0.00326	0.00178	0.00831	0.00095
n-octane	[mol%]	0.00068	0.00057	0.00398	0.00012
Benzene	[mol%]	0.00527	0.00972	0.02257	0.00873
Toluene	[mol%]	0.00052	0.00073	0.00643	0.00088
Ethylbenzene	[mol%]	0.00009	0.00009	0.00152	0.00008
m, p-xylene	[mol%]	0.00001	0.00011	0.00234	0.00007
o-xylene	[mol%]	0.00000	0.00013	0.00220	0.00000
Gross calorific value	[MJ/m³]	35.25756	35.49946	35.80461	35.65066
Net calorific value	[MJ/m³]	31.80846	32.01544	32.29877	32.14516
Emission factor	[t CO2 /TJ]	55.90181	55.62934	55.76198	55.41216

Source: DBI GUT 2014b

Table 15: Analysis data for natural gas H

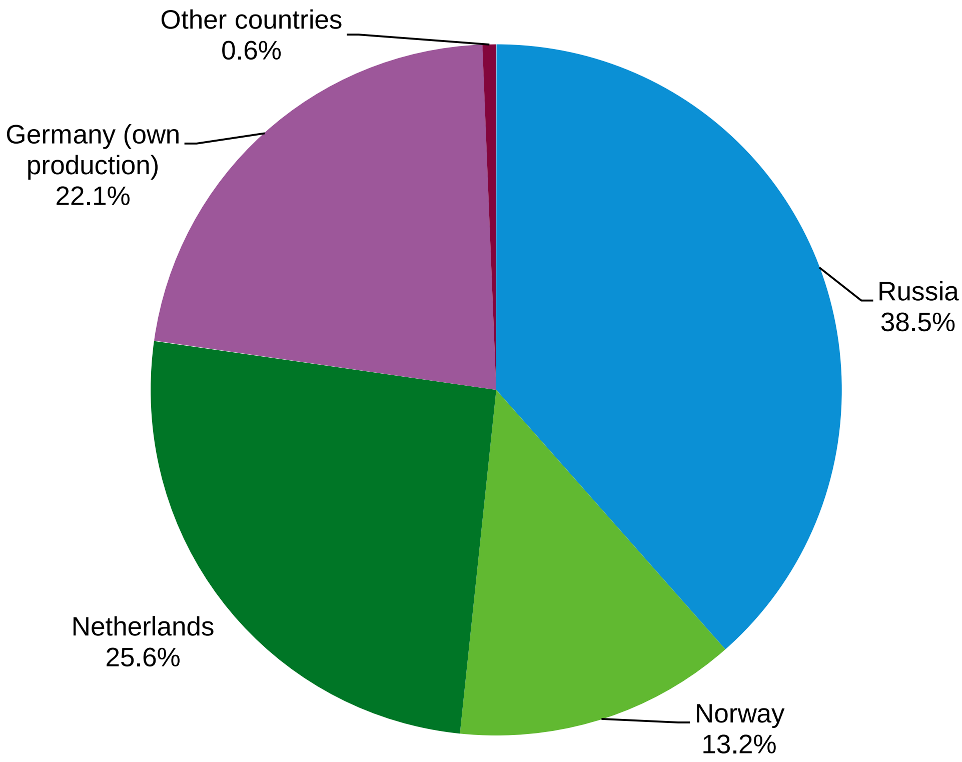
	Units	Norway, winter	Norway, summer	Russia, winter	Russia, summer	Denmark, summer
Helium	mol%	0.01795	0.02294	0.02294	0.02294	0.03088
Hydrogen	mol%	0.00000	0.00000	0.00000	0.00000	0.00000
Oxygen	mol%	0.00998	0.00000	0.00000	0.00000	0.00000
Nitrogen	mol%	1.15469	1.17550	0.82557	0.66778	0.16749
Carbon dioxide	mol%	1.11328	1.67775	0.07324	0.12639	1.00493
Carbon monoxide	mol%	0.00000	0.00000	0.00000	0.00000	0.00000
Methane	mol%	92.95818	90.94302	97.26253	96.60166	87.92253
Ethane	mol%	4.10166	5.08850	1.39408	1.96520	6.83474
Ethene	mol%	0.00000	0.00000	0.00000	0.00000	0.00000
Propane	mol%	0.43806	0.87704	0.30531	0.43763	2.33819
Propene	mol%	0.00000	0.00000	0.00000	0.00000	0.00000
i-butane	mol%	0.07966	0.07623	0.05038	0.07659	0.36923
n-butane	mol%	0.05924	0.09196	0.04689	0.07059	0.73655
Neopentane	mol%	0.00220	0.00079	0.00094	0.00137	0.00784
i-pentane	mol%	0.01613	0.01722	0.00711	0.01139	0.18272
n-pentane	mol%	0.01210	0.01417	0.00512	0.00822	0.20814
i-hexane	mol%	0.01089	0.00571	0.00195	0.00345	0.07296
n-hexane	mol%	0.00654	0.00391	0.00124	0.00207	0.05977
i-heptane	mol%	0.01024	0.00249	0.00135	0.00251	0.02840
n-heptane	mol%	0.00075	0.00041	0.00016	0.00023	0.01180
i-octane	mol%	0.00550	0.00083	0.00060	0.00114	0.00877
n-octane	mol%	0.00051	0.00011	0.00010	0.00017	0.00211
Benzene	mol%	0.00121	0.00113	0.00028	0.00032	0.00981
Toluene	mol%	0.00051	0.00024	0.00014	0.00022	0.00252
Ethylbenzene	mol%	0.00021	0.00000	0.00002	0.00005	0.00022
m, p-xylene	mol%	0.00023	0.00006	0.00005	0.00007	0.00020
o-xylene	mol%	0.00028	0.00000	0.00000	0.00000	0.00018
Gross calorific value	[MJ/m³]	40.63784	40.95824	40.17810	40.53254	44.58987
Net calorific value	[MJ/m³]	36.67763	36.98431	36.23026	36.55986	40.35322
Emission factor	t CO2/TJ	56.11740	56.62425	55.16382	55.31522	57.25707

Source: DBI GUT 2014b

The fluctuation range covered by the CO_2 emission factors for the various grades of gas is very narrow. And the values vary only very slightly overall, as the overviews show.

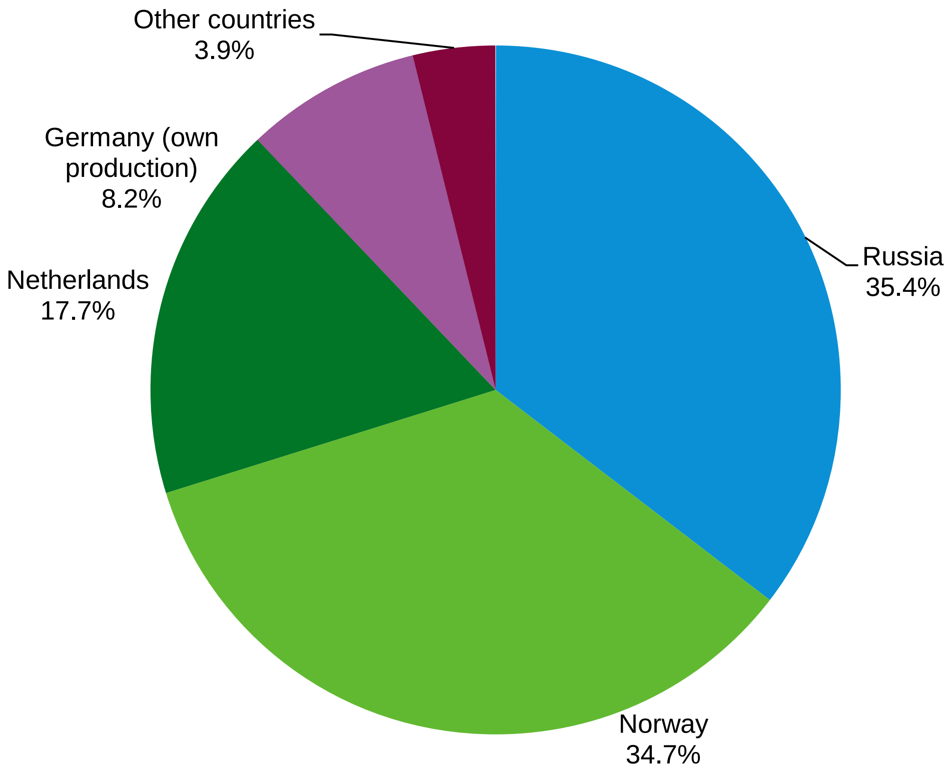
As with the other fuels, no sector-specific emission factors are determined for natural gas. In the present case, the data would not support determination of such a factor. For this reason, weighted emission factors have been determined at the national level. The relevant calculation is based on the measurements taken, on the import streams and on the country's own production. The country's own production includes a small fraction of petroleum gas. The pertinent figures are published in the annual reports of the Wirtschaftsverband Erdöl- und Erdgasgewinnung (WEG) German oil and gas industry association. That fraction has also been taken into account in the calculation. The country's own production levels, and the import streams, have changed considerably since 1990, as the following two figures show.

Figure 12: Origins of natural gas, 1990



Source: BAFA 2015, Eurostat 2016

Figure 13: Origins of natural gas, 2014



Source: BAFA 2015, Eurostat 2016

The country-specific emission factors calculated with regard to the various areas of origin exhibit virtually no fluctuation. The values range from 55.7 t CO_2/TJ to 55.9 t CO_2/TJ. The emission factors lie within the range of the default CO_2 emission factor given in the 2006 IPCC Guidelines – 56.1 t CO_2/TJ for natural gas.

7 Selected fuel-related CO_2 emission factors

The following list is an excerpt from the *List of CO_2 emission factors derived for emissions reporting [covering fuel-related emissions]* that is published annually in the *National Inventory Report (NIR)* and separately on our website for *Topic-related greenhouse-gas emissions (Themenseite Treibhausgas-Emissionen)* [1].

Table 16: CO_2 emission factors – fuel-related emission factors (excerpt; last revision: 15 April 2016)

	Units	1990	1995	2000	2005	2010	2014
Coal							
Hard coal (Steinkohle)							
Raw hard coal (power stations, industry)	t CO2/TJ	93.1	93.1	93.5	93.9	94.0	93.6
Hard-coal briquettes	**t CO2/TJ**	**95.9**	**95.9**	**95.9**	**95.9**	**95.9**	**95.9**
Hard-coal coke (not including iron & steel)	**t CO2/TJ**	**108.1**	**108.1**	**108.1**	**108.1**	**108.1**	**108.1**
Hard-coal coke: iron & steel	t CO2/t	3.29	3.26	3.23	3.19	3.18	3.21
Anthracite (heat market for households, commerce, trade, services)	t CO2/TJ	97.6	97.6	97.6	97.6	97.6	97.6
Low-grade hard coal, *old German Länder (states)*	t CO2/TJ	95.2					
Coking coal, *Germany*	t CO2/t	2.96	2.93	2.90	2.87	2.86	2.89
Hard coal: iron & steel	t CO2/t	2.92	2.92	2.92	2.95	2.89	2.96
Other hard-coal products	**t CO2/t**	**3.30**	**3.30**	**3.30**	**3.30**	**3.29**	**3.32**
Hard-coal tar	t CO2/t	3.27	3.27	3.27	3.28	3.27	3.31
Benzene	t CO2/t	3.38	3.38	3.38	3.38	3.38	3.36
Lignite (Braunkohle)							
Raw lignite							
Public district heating stations, *Germany*	t CO2/TJ		111.7	110.8	111.1	110.7	110.9
Old German Länder	*t CO2/TJ*	113.8					
New German Länder	*t CO2/TJ*	110.0					
Industry, commerce, trade, services, *Germany*	t CO2/TJ		106.0	109.8	108.2	106.3	103.8
Old German Länder	*t CO2/TJ*	114.7					
New German Länder	*t CO2/TJ*	107.7					
Public power stations; District:							
Rhineland	t CO2/TJ	114.8	113.9	113.1	113.2	113.3	113.1
Helmstedt	t CO2/TJ	98.7	98.7	98.7	98.7	96.7	101.1
Hesse	t CO2/TJ	112.2	103.2	103.5	NO	NO	NO
Lusatian mining district	t CO2/TJ	111.2	111.3	111.5	111.2	110.6	111.2
Central German mining district	t CO2/TJ	105.7	103.9	102.9	104.0	103.4	102.8

[1] https://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen (cf. the "Reports & Data" (Berichte & Daten) section in the central column)

	Units	1990	1995	2000	2005	2010	2014
Lignite briquettes, *Germany*	t CO2/TJ		98.3	99.0	99.3	99.0	99.6
Old German Länder	*t CO2/TJ*	99.5					
New German Länder	*t CO2/TJ*	96.6					
Lignite tar, *new German Länder*	t CO2/TJ	82.9					
Lignite tar oil, *new German Länder*		78.6					
Lignite dust and fluidised bed coal, *Germany*	t CO2/TJ		97.6	98.1	98.1	98.0	98.1
Old German Länder	*t CO2/TJ*	98.3					
New German Länder	*t CO2/TJ*	96.1					
Lignite coke, *Germany*	t CO2/TJ		109.6	109.6	109.6	109.6	109.6
Old German Länder	*t CO2/TJ*	109.6					
New German Länder	*t CO2/TJ*	100.2					
Peat *old German Länder, Germany*		101.8	101.8	101.8	101.8	NO	NO
Meta-lignite	t CO2/TJ	96.4	96.4	96.5	NO	94.9	95.6
Petroleum							
Crude oil *)	t CO2/TJ	73.3	73.3	73.3	73.3	73.3	73.3
Petrol	t CO2/TJ	73.1	73.1	73.1	73.1	73.1	73.1
Naphtha, *Germany *)*	t CO2/TJ		73.3	73.3	73.3	73.3	73.3
*Old German Länder *)*	*t CO2/TJ*	73.3					
*New German Länder *)*	*t CO2/TJ*	73.3					
Kerosene *)	t CO2/TJ	73.3	73.3	73.3	73.3	73.3	73.3
Avgas *)	t CO2/TJ	70.0	70.0	70.0	70.0	70.0	70.0
Diesel fuel, *Germany*	t CO2/TJ		74.0	74.0	74.0	74.0	74.0
Old German Länder	*t CO2/TJ*	74.0					
New German Länder	*t CO2/TJ*	74.0					
Light fuel oil, *Germany*	t CO2/TJ		74.0	74.0	74.0	74.0	74.0
Old German Länder	*t CO2/TJ*	74.0					
New German Länder	*t CO2/TJ*	74.0					
Heavy fuel oil	t CO2/TJ	79.8	79.8	79.8	79.6	79.7	81.3
Petroleum	t CO2/TJ	74.0	74.0	74.0	74.0	74.0	74.0
Petroleum coke (not including coke burn-off in catalyst regeneration)	t CO2/TJ	94.8	94.8	94.8	94.8	94.6	95.7
LP gas, *Germany (energy-related consumption)*	t CO2/TJ		65.3	64.4	65.3	65.3	65.5
Old German Länder	*t CO2/TJ*	65.6					
New German Länder	*t CO2/TJ*	65.6					
Refinery gas, *Germany*	t CO2/TJ		56.9	56.7	57.0	65.4	61.2
Old German Länder	*t CO2/TJ*	54.6					
New German Länder	*t CO2/TJ*	54.6					
Other petroleum products, *Germany*	t CO2/TJ		82.1	82.1	82.1	82.5	82.7
Old German Länder	*t CO2/TJ*	82.1					
New German Länder	*t CO2/TJ*	82.1					
Used oil	t CO2/t	75.7	75.7	75.7	75.7	75.7	75.7
Lubricants *)	t CO2/TJ	73.3	73.3	73.3	73.3	73.3	73.3
Gases							

	Units	1990	1995	2000	2005	2010	2014
Coke oven gas, *Germany*	t CO2/TJ		41.0	41.0	40.7	40.3	41.2
Old German Länder	*t CO2/TJ*	41.0					
New German Länder	*t CO2/TJ*	43.6					
Coke-oven and town gas, *Germany*	t CO2/TJ		42.6				
Old German Länder	*t CO2/TJ*	43.2					
New German Länder	*t CO2/TJ*	58.3					
Blast furnace gas and basic oxygen furnace gas, *Germany*	t CO2/TJ		257.1	258.7	252.9	259.7	256.8
Old German Länder	*t CO2/TJ*	264.6					
New German Länder	*t CO2/TJ*	264.6					
Fuel gas, *new German Länder*	t CO2/TJ	118.4					
Other residual gases, *Germany*	t CO2/1000 m^3	1.77	1.77	1.77	1.77	1.77	1.77
Natural gases							
Natural gas, *Germany*	t CO2/TJ		55.8	55.8	55.9	55.9	55.9
Old German Länder	*t CO2/TJ*	55.7					
New German Länder	*t CO2/TJ*	55.5					
Associated gas	t CO2/TJ	61.9	61.9	61.9	61.9	61.9	61.9
Mine gas	t CO2/TJ	68.1	68.1	68.1	68.1	68.1	68.1

*) Default values

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