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A baseline scenario of future consumption expenditure of Germany and its impact on greenhouse gas emissions

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Contents

1 Introduction

Climate change induced by the emission of greenhouse gases (GHG) is one of the major threats to human livelihood (IPCC 2014). In order to reduce global warming to a modest level, the United Nations Framework Convention on Climate Change decided on maximising global temperature rise to 2°C compared to pre-industrial levels (UNFCCC 2015). Therefore, Germany as one the world's largest emitters of GHG has committed to reduce its GHG-emissions by at least 55% in 2030 compared to 1990 (Bundesministerium für Umwelt 2016). There exist different mitigation strategies aiming at reducing GHG-emissions by transforming German economy (Biesbroek et al. 2010). In order to asses these strategies, methodologies are required to identify appropriate strategies and optimise them. Several modelling approaches and scenarios have been developed and applied on different scales ranging from individual countries, regions to the world to give insights into how we may reach this climate stabilization goal (Loulou and Labriet 2008; Nordhaus and Yang 1996).

However, many of the methods applied have shortcomings in terms of mass balance, comprehensiveness (e.g. looking only at the energy sector), and/or level of detail of the economic network (Ackerman et al. 2009; Pindyck 2013). As multi-regional Input-Output (IO) analysis inherently deals with these issues it is seen as a proper tool to assess the widespread impacts and feedbacks of public policy actions (De Koning et al. 2016). As a first step to quantify these repercussions there is a need for a baseline scenario on which further scenarios can be constructed on.

Against this backdrop, in this project work I want to construct a baseline scenario of future consumption expenditure of Germany. The scenario is based on past trends of final demand[1] of German households, the government, non-profit organisations serving households (NPISH) and investment demand (gross fixed capital formation, GFCF). Given the time-frame of this work I assume technologies, energy mixes, general efficiency and productivity constant.

Based on the scenario I calculate future GHG-emissions for the period 2015 to 2045 in a 10-year-interval using a multi-regional IO model. The following questions are addressed:

1. What is the overall trend of GHG-emissions associated with final demand of Germany?

[1] Both terms 'consumption expenditure' and 'final demand' are used interchangeably

2. What are the local dynamics of these GHG-emissions?
3. What are the dynamics regarding industrial sectors?

2 Material and Methods

2.1 The Data

The 2013-release of environmentally extended multi-regional IO tables from the World Input-Output Database (WIOD) forms the basis for this work (Timmer et al. 2015). WIOD offers a time-series of yearly IO tables for the period from 1995 to 2011 covering 40 countries and one model for the rest of the world (RoW, in the following also referred to as *country*). Per country 35 industries are represented. A list of the countries and the industries can be found in table 1 and 2 in the annex. Besides, WIOD provides yearly satellite accounts for the period 1995 to 2009 for GHG-emissions, as well as the use of energy, land, water, and resources.

In the following matrices (capital letters) and vectors are represented as bolt characters. The IO table for the year t consist of a 1435x1435 (35 industries in 41 countries) matrix $\boldsymbol{Z_t}$ representing all flows between industries in the different countries, a 1x1435 vector $\boldsymbol{x_t}$ representing the absolute output of the industries, and a 4x1435 $\boldsymbol{Y_t}$-matrix representing final demand by (1) households, (2) non-profit organisations serving households (NPISH), (3) government and (4) investment (GFCF). For these four sectors final demand is given for each of the 35 industries in each of the 41 countries. Therefore, each coefficient of $\boldsymbol{Y_t}$ represents the final demand by *one* sector for products of *one* industry in *one* country in the year t.

As the unit of $\boldsymbol{Z_t}$, $\boldsymbol{x_t}$ and $\boldsymbol{Y_t}$ is US$ they are converted to Euro according to the exchange rates the makers of WIOD used for converting national values into US$ (see table 3 in the annex).

2.2 The Input-Output model

The IO model applied here follows the general framework of multi-regional environmental-extended IO models (see Miller and Blair 2009). In order to build a model for calculating GHG-emissions we first have to determine the coefficient matrix $\boldsymbol{A_t}$ which represents the inter-industry flows relative to the output $\boldsymbol{x_t}$:

$$A_t = Z_t * \hat{X}_t^{-1} \tag{1}$$

where $\boldsymbol{\hat{X}_t}^{\boldsymbol{-1}}$ is a square matrix with $1/x_{tn}$ (n represents the industry in a country) on the main diagonal and zeros elsewhere.

Afterwards the Leontief inverse matrix $\boldsymbol{L_t}$ is calculated, with the help of which the entire industrial output for a given final demand $\boldsymbol{Y_t}$ can be determined:

$$L_t = (I - A_t)^{-1} \tag{2}$$

with **I** being the identity matrix with the same dimension as $\boldsymbol{A_t}$.

Next to the IO tables I use WIOD's satellite accounts for the emission of the GHGs CO_2, CH_4, N_2O which are the main drivers of anthropogenic induced climate change (Forster et al. 2007). These accounts are stored in the matrix $\boldsymbol{E_t}$ which describes the absolute emissions for each industry in each country. By multiplying $\boldsymbol{E_t}$ with $\boldsymbol{\hat{X}_t}^{\boldsymbol{-1}}$ we get the so-called stressor matrix $\boldsymbol{S_t}$ which contains the relative emissions per unit of output:

$$S_t = E_t * \hat{X}_t^{-1} \tag{3}$$

In order to obtain the total emissions $\boldsymbol{b_t}$ we multiply $\boldsymbol{S_t}$ with the Leontief inverse matrix $\boldsymbol{L_t}$ and final demand $\boldsymbol{Y_t}$:

$$b_t = S_t * L_t * Y_t \tag{4}$$

The global warming potential of the emissions of CH_4 and N_2O are then weighted according to the 5th Assessment Report of the IPCC based on a time horizon of 100 years (Myhre et al. 2013). With CO_2 used as a reference with a value of 1, CH_4 has a global warming potential of 34, and N_2O of 298. Accordingly, in this work *GHG-emissions* represent the emissions of CO_2, CH_4 and N_2O in CO_2-equivalents (CO_2eq) associated with consumption expenditure of Germany.

2.3 The Scenario

The scenario in this work includes the following assumptions: (1) No increase in productivity over time, (2) no changes in technologies, (3) no efficiency improvements regarding emissions per produced unit, (4) the sector-wise final demand follows the trend of the period 1995 to 2011. Due to these assumptions, the likelihood of this scenario as such is not very high. The intention of this work rather is to show global economic and environmental effects in a hypothetical scenario where only one set of parameters (that is to say final demands of households, government, investment) are changed.

Assumptions (1) and (2) ensue from constant $\boldsymbol{L_t}$. Here, the most up-to-date matrix $\boldsymbol{L}$ from 2011 is taken for all future years. Assumption (3) ensues from constant $\boldsymbol{S_t}$. I use the latest available $\boldsymbol{S}$-matrix from 2009 for all future years. Regarding assumption (4) all final demand coefficients are extrapolated following these steps:

1. for each coefficient time-series for the period of 1995 to 2011 are created
2. linear models with linear time impact are fitted for each time-series
3. with the help of the fitted models predictions for each coefficient are made for the years 2015, 2025, 2035 and 2045. Predicted values of < 0 are set to 0.
4. based on these predictions new $\boldsymbol{Y_t}$-matrices are constructed for each future year

With the help of the new $\boldsymbol{Y_t}$ future GHG-emissions are computed using equation (4).

3 Results

3.1 Evaluation of the Scenario

From 1995 to 2011 total final demand of Germany increased from 1691 to 2287 billion €, which is equivalent to a total growth of 35 % and a average annual growth rate of 2 % (see figure 1 and table 4 in the annex). In the scenario total final demand in 2045 is 3480 billion € which means an increase by 106 % compared to 1995 and 52 % compared to 2011, respectively. The average annual growth rate in the period 2015 to 2045 is 1.6 %.

Regarding the share of each sector a small increase of the household sector from 55 % in 1995, to 57 % in 2011 and to 60 % in 2045 can be observed. This increase is accompanied by a light decrease of the GFCF sector from 22 % in 1995, to 20 % in 2011 and to 16 % in 2045, while the shares of the government and NPISH sectors stay relatively constant.

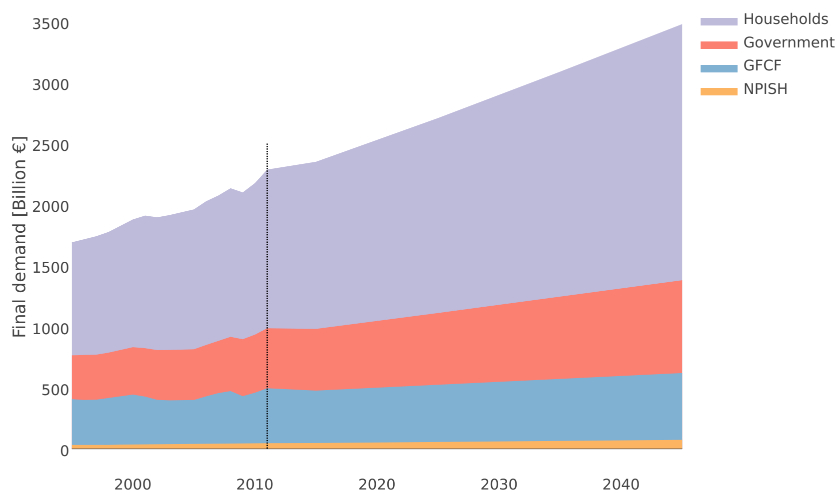

Figure 1: Final demand of Germany by households, government, NPISH and GFCF. The dashed line marks the border between data and extrapolations.

3.2 Total GHG-emissions

Despite this increase, total GHG-emissions caused by German consumption decreased in the period 1995 to 2011 from 1326 to 857 Gt CO_2eq (i.e. 35 %, see figure 2 and table 5 in the annex). In the scenario, however, emissions would increase to 2161 Gt CO_2eq in 2045 , which means an increase of 63 % (compared to 2015), or 152 % (compared to 2011). The proportions of each GHG in total emissions stay relatively constant.

3.3 Regional distribution of GHG-emissions

The amount of GHG-emissions associated with German final demand which have actually arisen in Germany decreased in the period 1995 to 2011 by 44 % from 709 to 399 Gt CO_2eq (see figure 3 for the relative proportions and table 6 in the annex for absolute numbers). While in 1995 54 % of all German consumption-based GHG-emissions occurred in Germany, this number declined to 46 % in 2011. By contrast, German consumption-based GHG-emissions arising in China increased by 29 % from 59 Gt CO_2eq in 1995 to 76 Gt CO_2eq in 2011. As absolute GHG-emissions associated with German consumption expen-

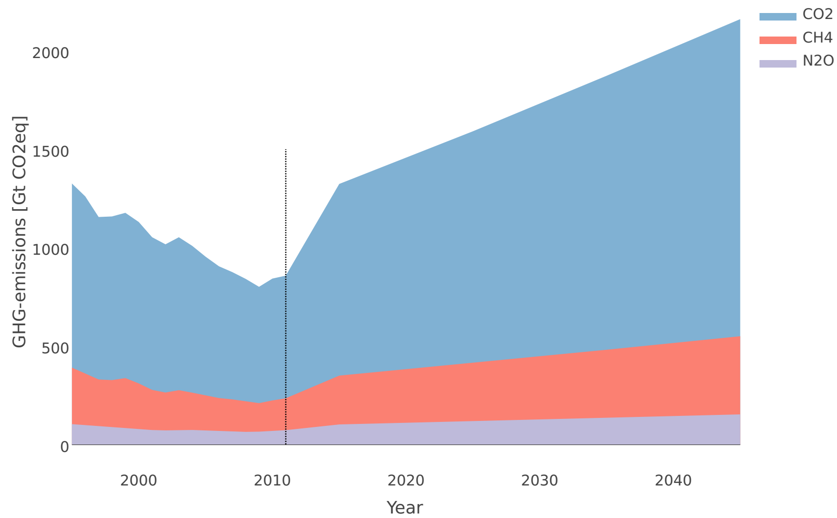

Figure 2: GHG-emissions associated with total final demand of Germany according to type of GHG. The dashed line marks the border between data and the results from the scenario model.

diture declined during this period of time, the Chinese share almost doubled from 4.5 % to 8.9 %. Moreover, the proportion of consumption-based GHG-emissions of Germany arising in the RoW and Asia increased in the period 1995 to 2011 from 10.6 % to 15.8 %, and 3.2 % to 5.8 %, respectively. By contrast, the share of Russia declines from 10 % in 1995 to 6.3 % in 2011. In the case of Europe (without Germany) and North America the respective proportions stay relatively constant.

In the scenario these trends continue. In 2045 only 35 % of all GHG-emissions associated with German final demand occur in Germany, while the share of China rises to 17 %. The share of the RoW further increases to 19 % in 2045, while the increase of the Asian share flattens off compared to the period 1995 to 2011. The proportions of consumption-based GHG-emissions of Germany occurring in Europe (without Germany), North America and Russia stay relatively constant.

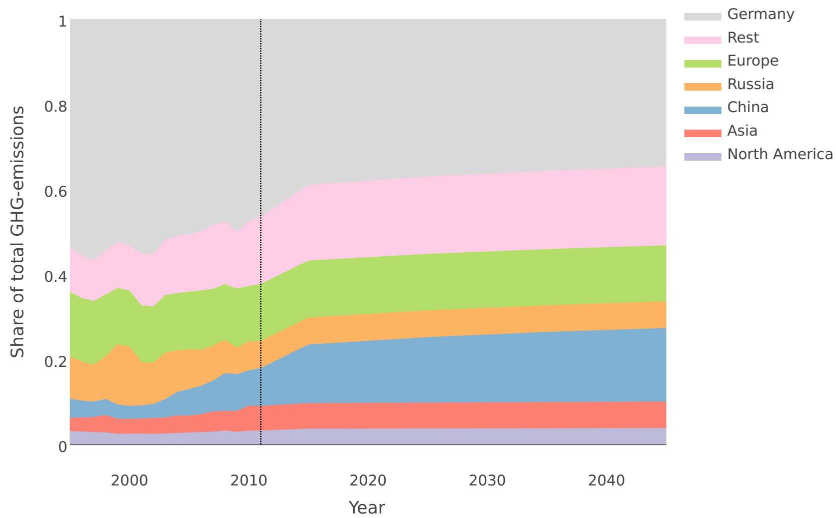

Figure 3: Share of GHG-emissions associated with total final demand of Germany according to the region where they arise. The dashed line marks the border between data and the results from the scenario model.

3.4 Distribution of GHG-emissions according to industrial sectors

The industrial sector with the highest share of GHG-emissions associated with German final demand is 'Electricity, gas and water supply' (32.7 % in 1995), followed by 'Agriculture, hunting, forestry and fishing' (14.9 %), 'Mining and quarrying' (8.4 %), 'Basic metals and fabricated metal' (6.8 %) and 'Chemicals and chemical products' (5.4 %). Despite some small fluctuations these proportions stayed relatively constant until 2011 (see figure 4 for the relative proportions and table 7 in the annex for absolute numbers).

In the scenario the overall pattern stays the same, only a small increase by the sector 'Electricity, gas and water supply' (from 32.1 % in 2011 to 36.6 % in 2045) can be observed, accompanied by a light decline of the share of 'Other'-sectors (from 30.9 % in 2011 to 27.8 % in 2045) .

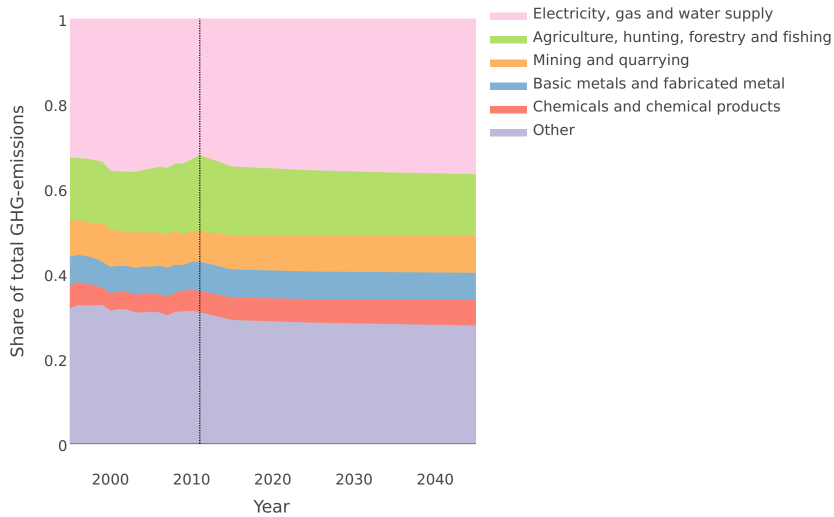

Figure 4: Share of GHG-emissions associated with total final demand of Germany according to the industrial sector from which they arise. The dashed line marks the border between data and the results from the scenario model.

4 Discussion

The scenario constructed in this project work is based on unrealistic assumptions and covers a long time span of 30 years. Therefore, the scenario is no *forecast* but rather a future simulation in a controlled environment (Pauliuk and Hertwich 2016). However, the results reveal some interesting insights into the dynamics of consumption-based GHG-emissions of Germany. First, the course of total GHG-emissions (figure 2) indicates a competition between growing final demand (which is equivalent to GDP when adding the net exports) and gains in efficiency and productivity (Guan et al. 2008). Despite constant growing demand, a steady decline of GHG-emissions can be observed until 2011. As emissions are a product of final demand ($\boldsymbol{Y}$), the inter-industry network ($\boldsymbol{L}$) and the relative emissions per unit of output ($\boldsymbol{S}$, see equation 4), decreasing emissions with increasing final demand imply improvements in (1) efficiency (i.e. less waste per produced unit, represented by $\boldsymbol{S}$) and/or in (2) productivity (i.e. less input per produced unit, represented by $\boldsymbol{L}$). Suppressing (1) and (2) under still growing final demand consequently leads to increased emissions, which explains the rise in GHG-emission in this scenario in the period from 2015 to 2045.

Secondly, a shift of the place of origin can be observed from Germany mainly to China and the RoW. This finding is in concordance with Peters et al. 2011 who reported an increase of net emission transfers via international trade from developing to developed countries from 1990 to 2008. Likewise, Kanemoto et al. 2014 found that the reduction of domestic emissions in developed countries are often not due to changes in consumption patterns, but rather the result of a burden-shift of emission-intensive goods and activities. The findings in this work, namely the constant shares of the emission-intensive industrial sectors (figure 4) together with the above mentioned local emissions-shifts, confirm this finding.

Another conspicuousness is the kink that appears in 2015 in figure 1 and 2. This can be explained by the fact that for the years 2012 to 2014 there is no data behind the plot. Instead, the last 'real' data point in 2011 is connected to the first scenario calculation in 2015. From 2015 to 2045 all curves grow linearly as it was to be expected from a scenario based on linear extrapolation.

One important assumption made in this work is that the trends of the final demand coefficients develop *linearly*. However, for the demand of many products and technologies a sigmoid trend has been observed, which would imply a logistic growth curve that saturates over time (Mahajan and Muller 1979). Wilting et al. 2008 for instance assumed for their baseline scenario annual change per coefficient to decrease by 10 % every year.

The baseline scenario of final consumption expenditure of Germany developed here can be the starting point for the construction of a sounder and more comprehensive scenario, which also includes future trends of efficiency and productivity (De Koning et al. 2016; Wilting et al. 2008). Therefore, analogous to the extrapolation of final demand matrices applied here, future matrices $\boldsymbol{S}$ and $\boldsymbol{L}$ can be developed based on past trends.

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Annex

Table 1: List of countries included in WIOD 2013-release and the corresponding regions.

Country	Region
Australia	Rest
Austria	Europe (without Germany)
Belgium	Europe (without Germany)
Bulgaria	Europe (without Germany)
Brazil	Rest
Canada	North America
China	China
Cyprus	Europe (without Germany)
Czech Republic	Europe (without Germany)
Germany	Germany
Denmark	Europe (without Germany)
Spain	Europe (without Germany)
Estionia	Europe (without Germany)
Finland	Europe (without Germany)
France	Europe (without Germany)
United Kingdom	Europe (without Germany)
Greece	Europe (without Germany)
Hungary	Europe (without Germany)
Indonesia	Asia (without China)
India	Asia (without China)
Ireland	Europe (without Germany)
Italy	Europe (without Germany)
Japan	Asia (without China)
Korea	Asia (without China)
Lithuania	Europe (without Germany)
Luxembourg	Europe (without Germany)
Latvia	Europe (without Germany)
Mexico	Rest
Malta	Europe (without Germany)
Netherlands	Europe (without Germany)
Poland	Europe (without Germany)

Portugal	Europe (without Germany)
Romania	Europe (without Germany)
Russia	Russia
Slovak Republic	Europe (without Germany)
Slovenia	Europe (without Germany)
Sweden	Europe (without Germany)
Turkey	Asia (without China)
Taiwan	Asia (without China)
United States	North America
Rest of the World	Rest

Table 2: List of industrial sectors covered in WIOD 2013-release

	Industrial sectors
1	Agriculture, hunting, forestry and fishing
2	Mining and quarrying
3	Food, beverages and tobacco
4	Textiles and textile products
5	Leather, leather products and footwear
6	Wood and products of wood and cork
7	Pulp, paper, printing and publishing
8	Coke, refined petroleum and nuclear fuel
9	Chemicals and chemical products
10	Rubber and plastics
11	Other non-metallic mineral
12	Basic metals and fabricated metal
13	Machinery, not elsewhere classified
14	Electrical and optical equipment
15	Transport equipment
16	Manufacturing, not elsewhere classified; recycling
17	Electricity, gas and water supply
18	Construction
19	Sale and repair of motor vehicles and motorcycles; retail sale of fuel
20	Wholesale trade, except of motor vehicles and motorcycles
21	Retail trade and repair, except of motor vehicles and motorcycles;
22	Hotels and restaurants
23	Inland transport
24	Water transport
25	Air transport
26	Other supporting transport activities
27	Post and telecommunications
28	Financial intermediation
29	Real estate activities
30	Renting of machinery & equipment and other business activities
31	Public administration and defence; compulsory social security
32	Education
33	Health and social work
34	Other community, social and personal services
35	Private households with employed persons

Table 3: Exchange rates used for converting monetary values from US$ into €

Year	Exchange rate [US $ per 1 €]
1995	1.37
1996	1.30
1997	1.13
1998	1.11
1999	1.07
2000	0.92
2001	0.90
2002	0.95
2003	1.13
2004	1.24
2005	1.24
2006	1.26
2007	1.37
2008	1.47
2009	1.39
2010	1.33
2011	1.39

Table 4: Final Demand of Germany in Billions of Euro according to sectors. Values from 1995 to 2011 are from WIOD, 2015 to 2045 are own extrapolations

	Households	NPISH	Government	GFCF	total
1995	926.71	29.45	358.94	375.57	1690.67
1996	950.62	27.35	368.96	370.78	1717.71
1997	971.44	28.35	368.76	372.20	1740.75
1998	989.75	29.72	373.54	382.64	1775.65
1999	1016.77	32.22	384.26	395.32	1828.56
2000	1047.63	33.58	388.42	408.78	1878.41
2001	1087.63	34.03	396.52	391.77	1909.95
2002	1088.91	35.39	407.81	363.68	1895.80
2003	1106.37	37.08	412.79	357.93	1914.17
2004	1128.62	37.51	412.09	358.68	1936.90
2005	1147.27	36.38	415.42	361.76	1960.83
2006	1178.54	36.25	421.08	391.64	2027.51
2007	1190.09	36.62	429.92	417.85	2074.48
2008	1218.57	37.23	444.51	433.84	2134.15
2009	1204.10	39.13	466.61	390.10	2099.94
2010	1242.82	40.90	475.78	416.94	2176.43
2011	1301.00	43.91	491.70	450.41	2287.02
2015	1370.38	45.24	505.77	429.62	2351.01
2025	1598.41	53.88	590.22	466.90	2709.41
2035	1845.23	62.53	675.34	506.51	3089.61
2045	2099.98	71.18	760.58	547.83	3479.57

Table 5: GHG-emissions by German consumption in Gt CO_2-eq. Values from 1995 to 2011 are from WIOD, 2015 to 2045 are results from the model

	CO2	CH4	N2O	Total
1995	935.37	287.05	103.14	1325.56
1996	898.20	263.75	97.99	1259.94
1997	825.33	239.06	90.93	1155.32
1998	831.40	240.30	86.51	1158.20
1999	839.54	255.04	81.94	1176.52
2000	820.13	233.28	76.69	1130.10
2001	775.59	203.87	73.18	1052.64
2002	752.95	192.24	71.42	1016.61
2003	776.96	201.69	73.88	1052.53
2004	745.80	189.54	73.48	1008.82
2005	703.95	178.83	71.00	953.77
2006	669.33	167.49	68.21	905.03
2007	646.60	161.07	67.77	875.44
2008	620.84	156.34	63.85	841.03
2009	590.94	144.74	64.99	800.67
2010	618.99	155.49	68.01	842.50
2011	622.95	161.94	72.52	857.40
2015	973.81	247.99	101.56	1323.36
2025	1177.07	295.80	117.92	1590.79
2035	1391.78	345.78	135.16	1872.73
2045	1610.95	396.92	152.69	2160.56

Table 6: GHG-emissions associated with German final demand in Gt CO_2-eq according to region where they arise. Values from 1995 to 2011 are from WIOD, 2015 to 2045 are results from the model

	Rest	Europe	North America	China	Germany	Asia	Russia
1995	140.91	201.01	41.47	59.21	709.40	41.88	131.67
1996	124.82	188.34	38.84	49.44	701.39	41.50	115.61
1997	110.91	173.55	35.16	42.41	654.66	39.20	99.45
1998	121.50	166.26	32.67	43.69	629.73	47.19	117.15
1999	127.62	155.40	29.58	39.63	616.29	41.36	166.64
2000	119.86	149.31	29.27	34.51	601.09	38.53	157.54
2001	128.03	139.90	26.85	32.69	580.71	37.23	107.21
2002	126.06	134.20	25.23	34.86	560.63	36.51	99.12
2003	136.00	142.83	27.16	45.72	546.97	39.62	114.23
2004	135.66	135.82	26.30	56.47	514.09	41.97	98.52
2005	128.68	129.62	25.03	59.35	482.42	39.75	88.92
2006	126.92	125.83	24.86	60.62	451.21	39.45	76.15
2007	130.92	116.36	26.34	63.50	424.42	41.58	72.32
2008	124.41	110.06	27.33	74.85	399.59	38.87	65.92
2009	107.74	111.09	23.81	69.25	399.69	39.26	49.81
2010	127.59	109.82	27.19	70.15	401.01	49.48	57.26
2011	135.31	115.24	27.98	76.28	398.51	49.72	54.36
2015	235.59	177.41	48.88	182.32	515.71	79.66	83.80
2025	289.42	211.29	59.81	244.83	588.71	96.69	100.05
2035	344.87	247.19	71.24	308.77	667.87	115.40	117.38
2045	401.11	284.10	82.95	373.50	748.42	134.76	135.72

Table 7: GHG-emissions associated with German final demand in Gt CO_2-eq according to industry. Values from 1995 to 2011 are from WIOD, 2015 to 2045 are results from the model

	Electricity, gas and water supply	Agriculture, hunting, forestry and fishing	Mining and quarrying	Basic metals and fabricated metal	Chemicals and chemical products	Other
1995	433.50	197.51	111.54	89.77	71.42	421.81
1996	413.18	184.00	103.81	80.22	68.04	410.69
1997	380.75	171.78	93.00	74.95	59.57	375.28
1998	385.43	172.53	94.95	73.98	53.63	377.69
1999	396.68	168.36	108.40	71.09	48.58	383.42
2000	404.19	155.84	100.34	69.80	46.23	353.70
2001	378.31	148.82	85.62	63.54	43.41	332.93
2002	366.63	144.26	80.86	61.61	42.96	320.29
2003	379.24	150.92	87.47	65.94	44.00	324.95
2004	358.94	147.38	82.41	65.25	43.91	310.93
2005	336.69	144.03	76.53	60.21	40.81	295.50
2006	315.87	139.67	71.10	61.03	38.11	279.26
2007	307.60	137.99	67.57	58.75	39.11	264.42
2008	287.37	132.14	67.85	55.30	37.64	260.72
2009	272.73	135.28	56.27	48.05	38.46	249.87
2010	278.78	142.34	61.05	55.75	41.16	263.40
2011	275.22	154.33	61.07	58.83	43.14	264.82
2015	460.78	213.79	106.67	87.13	70.31	384.69
2025	567.97	246.04	132.96	103.43	88.03	452.35
2035	678.56	278.97	160.90	120.59	108.46	525.24
2045	790.84	312.44	189.32	138.32	129.27	600.37