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Research article

Environmentally extended input-output tables for Germany

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Abstract: Environmentally extended input-output tables have become a powerful database for the evaluation of environmental and economic policies. They comprise useful information of satellite systems that are fully integrated into national accounts. Included are gross fixed capital formation, capital stock, employment, energy, air emissions, global warming, acid deposition, tropospheric ozone formation, waste, sewage, and water. A special feature of the extended input-output tables is that the data include information on values and quantities. For the promotion of this approach, I show a summary of the extended input-output tables of Germany for 2009 and 2019 on one page. The larger tables with 65 products and 65 homogenous branches are available on request. Emission models of input-output analysis enable estimating the domestic emissions for final uses of products for consumption, gross capital formation, and exports. However, they also provide a first approximation of foreign emissions, which are required abroad for German imports. The two results combined give a rough assessment of the total emissions world-wide to produce goods and services for final uses of Germany. The results revealed for the reported years that Germany started decoupling economic growth from energy consumption. This is a real achievement. Despite modest real economic growth, Germany successfully reduced the emission of gases during these ten years. However, the trend for emissions of imports is different. The emissions abroad to produce German imports stagnated in the same period. The new database will help identify the major environmental problems and general trends of economic development. It may also encourage appropriate environmental policies for preserving the natural environment.

Keywords: input-output analysis; system of national accounts; supply and use tables; input-output tables; gross domestic product (GDP); satellite systems; energy consumption; emission of gases; emission models; energy and emission content of products; national emissions; world-wide emissions; environmental policies

JEL Codes: C67, E01, Q56

1. Introduction

Environmentally extended input-output tables have become a powerful database to evaluate environmental and economic policies. They comprise useful information of satellite systems, which are fully integrated into the national accounts (OECD/European Union, 2025). My objective of this paper is to compile extended input-output tables for Germany and analyze the structural change and environmental impacts. I compiled two extended input-output tables for 2009 and 2019 from the Genesis-online database of Destatis, the Statistical Office of Germany, and the database of Eurostat, the Statistical Office of the European Union. For this study, only official data was used, which was published on the website of Destatis and Eurostat.

2. System of national accounts

The National Accounts provide the main data for macroeconomic analysis. Supply and use tables and, consequently, input-output tables, with their deep look into products and industries, are important sources for economic analysis by bridging the gap between macroeconomic analysis and microeconomic analysis. Supply and use tables form a central part of the system of national accounts. They are commonly used to balance the system of national accounts.

The System of National Accounts 2025 (United Nations, 2025) is an update of the Systems of National Accounts 2008 (United Nations, 2009) retaining the basic theoretical framework. The European System of Accounts – ESA 2010 (European Commission, 2013) is an internationally compatible framework for a systematic and detailed description of an economy. Its structure is consistent with the international guidelines on national accounting, as outlined in the system of national accounts – 2008 SNA.

3. Supply and use tables and input-output tables

Supply and use tables are the main source to compile gross domestic products. In a globalized world, supply and use tables become more important than ever. They enable studying the rising interdependencies of industries in production. In general, supply and use tables provide the framework for checking the consistency of statistics on flows of goods and services and primary inputs obtained from statistical sources. In a final step, rectangular supply and use tables are transformed to symmetric input-output tables, which constitute the database for macroeconomic models.

Supply and use tables mainly serve statistical purposes. Moreover, it is international practice to compile gross domestic product from a system of supply and use tables.

Input-output tables are mainly used for analytical purposes such as impact analysis, macroeconomic models, price models, and productivity analysis. Input-output data also serve several other analytical purposes by linking other major statistics (employment, capital, energy, and environment) to the system of national accounts. In a second step, supply and use tables are transformed into input-output tables. For the European Union industry-by-industry input-output tables and product-by-product input-output tables with homogenous branches are available.

4. Projection of supply and use tables

For Eurostat, the author developed the Euro method for projecting supply and use tables, which was published in the Eurostat Manual (Eurostat, 2008, pp. 451–475). Ten years later, Valderas-Jaramillo et al. (2019) presented new variants for projecting supply and use tables. Temursho (2020) gave a critical assessment of the new methodology by comparing the results of the Euro-method with the results of the traditional GRAS procedure. Finally, Valderas-Jaramillo et al. (2021) gave recommendations for fair comparisons. Their conclusion was to use the SUT-RAS method (Temurshoev et al., 2013) when projections for industry output are available. However, when no projections for industry output are available, the Euro method should be applied for projecting supply, use, and input-output tables.

5. Input-output economics

In economics, an input-output model is a quantitative economic model that represents the interdependencies between sectors of a national economy. Wassily Leontief (1905–1999) was the founding father of input-output economics. In 1973, he was awarded the 5th Nobel Prize in Economics for his development of the input-output model (Leontief, 1986). Since, the input-output framework has been used for economic planning, forecasting, and regional development.

In 1931, Leontief emigrated to the USA and published his famous book in 1941 "The Structure of the American Economy, 1919–1929, An empirical application of equilibrium analysis" (Leontief, 1941). In 1966, his famous text book "Analysing an Industrial Economy: Input-Output Economics" (Leontief, 1966) was printed. Finally, in 1986, the second edition of his book "Input-Output Economics" (Leontief, 1986) was published.

Over the years, the theoretical structure of input–output analysis has been refined, and its applications have been widened. The "Input-Output Analysis" of Kurz, Dietzenbacher, and Lager (Kurz et al., 1998) was published in three volumes. They present an overview of this development and an assessment of the state of input-output analysis. It presents some of the most significant theoretical and empirical contributions of leading scholars to sectoral economic analysis.

The second edition by Ronald Miller and Peter Blair's classic textbook "Input-Output Analysis: Foundations and Extensions" is the best reference for students and scholars in input–output research and applications (Miller and Blair, 2009).

In 2017, Thijs ten Raa edited the "Handbook of Input-Output Analysis" (ten Raa, 2017) with 14 articles of leading experts in the field of input-output analysis.

Sangwon Suh edited the “Handbook of Input-Output Economics in Industrial Ecology” (Suh, 2009). The handbook covers an array of topics, including the history of industrial ecology and input-output economics. Included are material flow analysis, life cycle assessment, sustainable consumption, policy applications, energy and climate change, waste management, national accounts, and statistics.

Shmelev (2012) published the book Ecological Economics: Sustainability in Practice. Presented is the state of the art in ecological economics focused on the analysis of sustainability of global, national, and regional economic systems. It covers a range of key methods used in sustainability research like multicriteria decision aid, input-output analysis, and life cycle analysis. Contained are practical case studies on the most pressing topics of today: renewables, biodiversity, waste management, and sustainable business.

In 2021, Shmelev and Brook (2021) published the paper “Macro Sustainability across Countries: Key sector Environmentally Extended Input-Output Analysis”. They proposed a comparative sustainability assessment method using environmentally extended input-output analysis and multi-criteria decision aid. Using symmetric input-output tables and sectoral CO_2 emissions and employment data for six countries, linkage coefficients were calculated for 163 sectors in each country.

6. Extended input-output tables

Early versions of extended input-output tables were developed by Joerg Beutel and Heinz Mürdter at Ifo-Institute of Economic Research in Munich.

After the oil crises in 1973 and 1979, Joerg Beutel and Carsten Stahmer designed Input-Output Tables of Energy Flows (Beutel and Stahmer, 1982). The main idea of the new input-output tables was compiling input-output tables with separate matrices for energy consumption and production in values and quantities. Beutel also published an early approach of “Input-Output Analysis of Environmental Protection” (Beutel and Mürdter, 1984). The approach of the Input-Output Table of Energy Flows for 1975 (Beutel and Mürdter, 1984) were later adopted by the Statistical Office of Germany (Destatis).

Extended input-output tables play an important role as a database for studying sustainable development and the impact of environmental policies. They comprise useful information of satellite systems, which are fully integrated into the national accounts. A special feature of the tables is that the data include information on values and quantities.

The Joint Research Institute (JRC) of the European Union and OECD published the Handbook on Extended Supply and Use Tables and Extended Input-Output Tables (OECD/European Union, 2025). The publication connects national statistics accounts with trade and business data and bridges the gap between macroeconomic (national accounts) and microeconomic data (business statistics and trade statistics). It sets new international standards and presents methodological guidance on how to compile Extended Supply and Use Tables (ESUTs) and Extended Input-Output Tables (EIOTs).

For the Eurostat Manual of Supply, Use and Input-Output Tables, the author compiled an extended input-output table 1995 with satellite systems for Germany for (Eurostat, 2008). He also provided an extended input-output table 2009 of Germany for the new Handbook on Supply and Use tables and Input-Output Tables of the United Nations (United Nations, 2018). This explains, in detail, how supply and use tables can be transformed into input-output tables (Beutel, 2017).

In both cases, Germany was chosen to be the reference case for compiling extended input-output tables, as this country is advanced in developing satellite systems for the traditional set of input-output tables. Similar extended input-output tables were compiled with great success for Saudi Arabia, Kuwait, and Brunei Darussalam.

The large extended input-output tables of Germany for 2009 and 2019 comprise 65 products, 65 industries, and all satellite systems. Here, I aggregated the extended input-output tables to 6 products and 6 industries with the objective of showing the whole system on one page.

The large extended input-output tables with satellite systems are available upon request. The submitted Excel-files include a careful documentation of the data and the compilation procedure.

7. Extended input-output table 2009 for Germany

The extended input-output table includes the input-output tables for domestic production and imports and 7 satellite systems:

1. Input-output table (Mio. Euro);
2. Imports (Mio. Euro);
3. Gross fixed capital formation (Mio. Euro);
4. Capital stock (Mio. Euro);
5. Employment (1.000 Persons);
6. Energy (Petajoule);
7. Air emissions (1.000 tons);
8. Global warming, acid deposition and tropospheric ozone formation (1.000 tons);
9. Waste, sewage and water (1.000 tons, Mio. cbm).

The data was retrieved from the GENESIS-Online databank of the Federal Statistical Office of Germany (Destatis) and the Eurostat website. A constraint for an update of the extended input-output table for Germany was that information on energy for homogenous branches was available only until 2019.

A special feature of the extended input-output table is that the first four matrices contain only values (input-output table, imports, investment, capital), while the following five matrices comprise quantities (labour, energy, emissions, waste, sewage and water).

The extended input-output table of Germany for 2009 is presented in Table 1. It is the bird's-eye view of the economy on one page. The first part of the table comprises the traditional part of the national accounts. It includes the input-output table with net exports and the input-output table of imports.

7.1. Input-output table

The use of products (domestic and imported combined) is shown in rows 1–6 for homogeneous branches in columns 1–6 and for final uses in columns 7–12. To arrive at domestic output in column 13, total imports of products must be deducted in column 12. I opted for an input-output table showing exports and imports of goods and services and, consequently, net exports in one table. The format of net exports for the extended input-output table enabled me to properly identify the export and import of energy, a key variable to identify environmental problems and to assess climate change.

7.2. Import matrix

The import matrix identifies the use of imported goods and services in production and for final uses in the same format of the input-output table (Table 1).

Table 1. Extended input-output table 2009 with satellite systems.

No.	Products (CPC)	Input of homogeneous branches: Agricul-ture, forestry and fishing	Mining, manufac-turing, electri-city and water	Construc-tion	Trade, transport and communi cation	Finance and busi-ness servi-ces	Public and other servi-ces	Final uses: Private con-sump-tion	Govern-ment con-sump-tion	Gross fixed capital forma-tion	Chan-ges in inven-tories	Exports	Less imports	Output at basic prices
No.	Products (CPC)	1	2	3	4	5	6	7	8	9	10	11	12	13
	Input-output table (billions of Euro)													
1	Products of agricul., forestry, fishing	3	31		1	0	1	17		0	4	7	- 23	42
2	Mining, manufactured products, electricity and water	11	641	63	77	14	42	362	15	152	- 28	790	- 689	1 451
3	Construction work	1	11	18	8	28	10	5		153		1	0	234
4	Trade, transport and communication	4	148	18	212	42	42	323	17	41	6	112	- 57	907
5	Finance and business services	6	148	31	130	285	56	315	3	27	0	72	- 62	1 010
6	Public and other services	0	18	3	12	17	48	147	472	2	0	2	- 1	721
7	Products at basic prices	26	996	133	440	386	200	1 169	506	375	- 18	985	- 833	4 365
8	Taxes less subsidies on products	2	10	2	12	17	24	151	6	34		0		257
9	Products at purchasers' prices	27	1 007	135	452	402	224	1 319	513	409	- 18	984	- 833	4 622
10	Compensation of employees	6	308	69	294	191	364							1 232
11	Other net taxes on production	- 6	- 2	0	- 1	5	- 7							- 12
12	Consumption of fixed capital	8	79	5	60	160	63							375
13	Net operating surplus	7	60	25	101	252	77							523
14	Value added at basic prices	15	445	99	454	608	497							2 117
15	Input at basic prices	42	1 451	234	907	1 010	721							4 365
	Imports (billions of Euro)													
1	Products of agricul., forestry, fishing	1	11		0	0	1	8		0	1	2		23
2	Mining, manufactured products, electricity and water	4	246	15	21	3	12	112	8	57	30	179		689
3	Construction work	0	0	0	0	0	0	0		0				0
4	Trade, transport and communication	0	9	1	31	4	2	5	2	2	0	1		57
5	Finance and business services	0	16	1	6	24	5	3		2		6		62
6	Public and other services		0		0	0	1	0		0		0		1
7	Products at basic prices	5	283	17	58	31	21	128	9	61	31	189		833
	Gross capital formation (billions of Euro)													
1	Machinery and equipment	5	49	4	45	116	37							256
2	Buildings	2	20	2	19	82	28							153
3	Total	7	69	6	64	198	65							409
	Capital stock (billions of Euro)													
1	Machinery and equipment	104	646	51	484	532	241							2 058
2	Buildings	167	1 039	81	777	6 998	2 243							11 305
3	Total	271	1 685	132	1 261	7 530	2 484							13 363
	Employment (1.000 persons)													
1	Wage and salary earners	295	6 787	1 948	9 821	5 693	11 356							35 900
2	Self-employed	359	275	463	1 297	1 017	1 059							4 470
3	Total	654	7 062	2 411	11 118	6 710	12 415							40 370
	Energy (Petajoule)													
1	Coal and coal products	0	1 714	1	1	0	6	17			- 41	40	- 1 115	623
2	Brown coals, lignite products	0	1 617	0	0	0	1	21			- 9	24	- 3	1 651
3	Crude oil		4 294								- 7	5	- 4 172	119
4	Gasolines	3	91	4	25	20	15	868			4	248	- 182	1 096
5	Diesel fuels	106	123	79	476	93	74	387			0	355	- 342	1 351
6	Jet fuels				434		4				10	176	- 429	195
7	Heating oil, light	25	188	14	87	26	85	514			13	100	- 441	611
8	Fuel oil, heavy		336		17	0	0				- 13	217	- 131	425
9	Other petroleum products	2	1 190	101	35	2	3	48			- 1	161	- 382	1 158
10	Natural gas and other gases	12	1 797	12	125	49	184	936			228	465	- 3 083	726
11	Renewable Energy	6	1 178	5	45	7	6	299			1	18	- 10	1 554
12	Electric power, other energy	23	2 641	14	289	76	197	678			127	198	- 1 618	2 624
13	Total	178	15 167	230	1 535	273	574	3 767			311	2 006	- 11 909	12 134
	Air emissions (1.000 tons)													
1	Carbon dioxide (CO_2)	10 784	553 690	9 380	107 382	12 612	25 158	223 004						942 012
2	Methane (CH_4)	1 274	884	1	118	1	5	65						2 348
3	Nitrous oxide (N_2O)	99	47	0	3	0	1	3						153
4	Nitrogen oxides (NOx)	158	556	61	776	44	60	379						2 034
5	Sulfur dioxide (SO_2)	2	341	1	224	1	6	35						610
6	Organic compounds (NMVOC)	323	550	8	62	2	10	325						1 280
7	Ammonia (NH_3)	580	16	0	2	0	0	20						620
8	Particulate matter (PM_{10})	36	57	15	131	2	3	58						303
9	Hydroflurocarbons (HFC)	13	2 701	65	4 050	308	356	2 538						10 031
10	Perflurorocarbons (PFC)		383		23									406
11	Sulfur hexafluoride (SF_6)		2 340			603								2 943
12	Total	13 271	561 565	9 531	112 772	13 574	25 599	226 428						962 740
	Global warming, acid deposition and tropospheric ozone formation (1.000 tons)													
1	Greenhouse gases (1)	75 861	592 450	9 483	111 676	12 702	25 498	225 811						1 053 480
2	Acid deposition (2)	113	730	43	768	31	48	301						2 034
3	Tropospheric ozone formation (3)	1 756	1 990	69	956	47	75	769						5 662
	Waste, sewage and water													
1	Waste (1.000 tons)	804	122 849	194 098	4 945	5 510	3 931	36 033						368 171
2	Sewage (Mio. cbm)	21	26 970	38	173	193	137	3 118						30 650
3	Water from waterworks (Mio. cbm)	136	- 3 725	14	194	216	154	3 011						
4	Water from nature (Mio. cbm)	303	37 608	25	9	10	7	25						37 986

Note: Germany 2009 [ ] = Values [ ] = Quantities

(1) Carbon dioxide (CO_2 = 1), methane (CH_4 = 28) and nitrous oxide (NO = 298) were transformed with the documented factors to greenhouse gases in CO_2-equivalents.

(2) Sulfur dioxide (SO_2 = 1) and nitrogen oxides (NO_x = 0.7) were transformed with the documented factors to acid depositions in SO_2-equivalents.

(3) Carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4), nitrogen oxides (NO_x) cause ozone formation.

Sources: Federal Statistical Office of Germany (Destatis) and Eurostat.

7.3. Gross fixed capital formation and capital stock

The first two satellite systems include information on investment and the use of capital and labor in the industries. The matrix on gross fixed capital formation identifies how much the industries have invested in buildings and machinery in this year. The second matrix on capital stock shows how much capital is used in the activities.

7.4. Employment

The third matrix reflects the actual employment in industries. So far, only wage and salary earners and self-employed are covered. Other categories such as men, women, skilled, and unskilled can be integrated into the framework.

7.5. Energy

The International Energy Agency (IEA) published energy balances for 185 nations covering the period 1971–2025 (International Energy Agency, 2025). The matrix on energy use has been derived from energy balances, which are available for most nations. This reflects the total energy use of the economy in petajoule, which is equivalent to total supply of energy from domestic production and imports. Comprised are all primary and secondary energy sources.

7.6. Air emissions

In the next matrix of the satellite system, air emissions of pollutants are presented, which were derived from the energy use in Table 1. Included are 11 gases, among them the most important gases that contribute to global warming, acid deposition, and tropospheric ozone formation. The International Energy Agency (IEA) also provides information on CO_2 emissions from fuel combustion.

7.7. Global warming, acid deposition, and tropospheric ozone formation

Air emissions are harmful for the global climate. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are transformed to greenhouse gases in CO_2-equivalents. Sulphfur dioxide (SO_2) and nitrogen oxides (NO_x) are transformed into acid depositions as Sulphur dioxide (SO_2) and SO_2-equivalents. Substances causing tropospheric ozone formation are carbon monoxide (CO), non-methane volatile organic compounds, methane (CH_4), and nitrogen oxides (NO_x).

7.8. Waste, sewage, and water

The matrix of waste includes information on waste and sewage generation. The Eurostat database includes information on 38 hazardous and non-hazardous wastes and 46 different sources of waste water generation. So far, I distinguish only water from waterworks and water from nature. The information was extracted from the Genesis databank of the Federal Statistical Office of Germany.

8. Extended input-output table 2019 for Germany

For this article, I compiled a second extended input-output table for Germany for the year 2019. During the period 2009–2019, difficult events affected the German economy.

International financial crisis (2009–2013), Euro crisis (2009–2014), Fukushima (2011), US budget crisis (2011), Recession in the Eurozone (2012), Annexation of Crimea (2014), ISIS in the Middle East, Ebola in West Africa (2014), Paris Climate Conference (2015), Refugee crisis in Europe (2015–2016), Brexit of United Kingdom (2016), Terrorist attacks in Europe and crises in Afghanistan, Somalia, Nigeria, Congo, South Sudan, Yemen (2017), Trade conflict with USA (2018), Kashmir war between Pakistan and India, and the outbreak of the COVID-19 pandemic (2019).

These events had a strong impact on the economic development of Germany during 2009–2019.

In Table 2, the extended input-output table for Germany is shown for 2019. Again, all data were extracted from the Genesis-Databank of the Federal Statistical Office of Germany (Destatis).

Despite modest real growth, energy consumption was reduced from 12.134 Petajoule in 2009 to 11.292 Petajoule. This is a striking observation indicating a modest decoupling of GDP growth and energy consumption in Germany. Consequently, the emission of greenhouse gases was reduced from 1.053 million tons in 2009 to 970 million tons in 2019 despite modest economic growth. However, the data reveal also that Germany is a large net importer of energy. In 2019, Germany exported 4.267 Petajoule energy and imported 14.089 Petajoule energy at the same time.

It should be noted that Germany increased the import of energy in this time form 11.909 in 2009 to 14.089 Petajoule in 2019, while the domestic production of energy was reduced from 12.134 Petajoule in 2009 to 11.292 Petajoule in 2029. This had a strong impact on the reduction of domestic emissions but increased the emissions abroad.

Table 2. Extended input-output table 2019 with satellite systems.

		Input of homogeneous branches						Final uses					Less imports	Output at basic prices
	Products (CPC)	Agricul-ture, forestry and fishing	Mining, manufacturing, electricity and water	Construc-tion	Trade, transport and com-muni-cation	Finance and busi-ness services	Public and other services	Private consumption	Govern-ment con-sump-tion	Gross fixed capital forma-tion	Chan-ges in inven-tories	Exports		
No.	Products (CPC)	1	2	3	4	5	6	7	8	9	10	11	12	13
	Input-output table (billions of Euro)													
1	Products of agricul., forestry, fishing	4	46		1	0	3	25		0	6	10	- 35	59
2	Mining, manufactured products, electricity and water	11	859	92	98	23	72	435	29	242	25	1 222	- 1 081	2 027
3	Construction work	1	18	32	14	52	21	6		227	4	2	- 2	375
4	Trade, transport and communication	6	228	31	399	90	89	411	23	57	- 9	217	- 131	1 410
5	Finance and business services	9	156	46	143	320	81	430	10	140	- 1	131	- 100	1 365
6	Public and other services	1	57	11	46	51	96	214	684	12	0	16	- 15	1 172
7	Products at basic prices	32	1 363	212	702	536	363	1 520	746	677	26	1 597	- 1 364	6 408
8	Taxes less subsidies on products	1	10	2	13	16	29	198	9	65				344
9	Products at purchasers' prices	33	1 373	214	715	552	392	1 718	755	742	26	1 597	- 1 364	6 752
10	Compensation of employees	8	407	91	443	319	585							1 853
11	Other net taxes on production	- 5	- 2	0	2	10	- 5							0
12	Consumption of fixed capital	11	131	7	92	282	118							640
13	Net operating surplus	13	118	63	159	202	82							637
14	Value added at basic prices	26	654	161	695	813	780							3 130
15	Input at basic prices	59	2 027	375	1 410	1 365	1 172							6 408
	Imports (billions of Euro)													
1	Products of agricul., forestry, fishing	1	15		1	0	1	12		0	2	3		35
2	Mining, manufactured products, electricity and water	4	378	27	32	5	22	135	16	106	53	304		1 081
3	Construction work	0	0	0	0	0	0	0		1				2
4	Trade, transport and communication	0	16	1	58	23	10	16	0	4	4	1		131
5	Finance and business services	1	21	2	12	30	6	5	0	25	0	0		100
6	Public and other services	0	4	1	3	2	2	3	0			0		15
7	Products at basic prices	5	434	31	105	60	40	171	16	136	58	308		1 364
	Gross capital formation (billions of Euro)													
1	Machinery and equipment	7	1	119	13	9	87	101	68					405
2	Buildings	2		10	16	3	32	238	62					363
3	Total	9	1	129	29	12	119	339	130					768
	Capital stock (billions of Euro)													
1	Machinery and equipment	115	22	1 421	154	65	706	770	642					3 894
2	Buildings	247	1 228	57	1 169	10 966	3 176							16 843
3	Total	362	1 250	1 478	1 323	11 030	3 882	770	642					20 736
	Employment (1.000 persons)													
1	Wage and salary earners	340	6 986	2 119	11 222	5 434	15 016							41 117
2	Self-employed	240	248	472	1 015	868	1 317							4 160
3	Total	580	7 234	2 591	12 237	6 302	16 333							45 277
	Energy (Petajoule)													
1	Coal and coal products	0	1 393		0		0	2			1	35	- 1 179	253
2	Brown coals, lignite products		1 280					12			- 3	28	- 1	1 316
3	Crude oil		3 710								22	5	- 3 655	82
4	Gasolines	2	224	5	11	12	10	768			- 92	245	- 174	1 011
5	Diesel fuels	61	105	103	461	28	79	609			- 174	599	- 749	1 122
6	Jet fuels		2		397		3				265	141	- 591	218
7	Heating oil, light	12	143	10	156	14	47	428			34	77	- 265	657
8	Fuel oil, heavy		203		329						26	136	- 394	301
9	Other petroleum products	2	1 251	56	27	1	3	49			- 43	218	- 451	1 112
10	Natural gas and other gases	7	1 991	15	189	51	178	927			249	2 394	- 5 571	431
11	Renewable Energy	54	1 600	5	26	2	15	417			- 12	126	- 96	2 138
12	Electric power, other energy	17	2 034	15	250	97	157	643			139	262	- 963	2 651
13	Total	155	13 938	209	1 846	206	493	3 856			412	4 267	- 14 089	11 292
	Air emissions (1.000 tons)													
1	Carbon dioxide (CO_2)	13 357	487 254	10 536	116 760	7 356	22 472	221 472						879 206
2	Methane (CH_4)	1 243	536	1	127	1	5	61						1 973
3	Nitrous oxide (N_2O)	95	16	0	5	0	1	4						120
4	Nitrogen oxides (NOx)	148	427	35	918	10	35	350						1 923
5	Sulfur dioxide (SO_2)	2	249	0	30	0	0	10						292
6	Organic compounds (NMVOC)	315	500	6	62	1	10	263						1 157
7	Ammonia (NH_3)	558	16	0	3	0	0	12						589
8	Particulate matter (PM_{10})	35	49	14	128	0	2	43						271
9	Hydroflurocarbons (HFC)	11	3 398	90	2 654	312	522	2 625						9 612
10	Perflurorocarbons (PFC)		229		3									232
11	Sulfur hexafluoride (SF_6)		3 587			333								3 919
12	Total	15 763	496 259	10 683	120 689	8 013	23 047	224 840						899 294
	Global warming, acid deposition and tropospheric ozone formation (1.000 tons)													
1	Greenhouse gases 1)	76 384	506 909	10 662	121 695	7 442	22 818	224 316						970 226
2	Acid deposition 2)	106	548	25	672	7	25	255						1 638
3	Tropospheric ozone formation 3)	1 706	1 463	42	1 107	12	50	674						5 053
	Waste, sewage and water													
1	Waste (1.000 tons)	993	119 594	225 648	7 722	6 202	5 288	37 891						403 340
2	Sewage (Mio. cbm)	29	16 042	46	174	168	144	3 825						20 428
3	Water from waterworks (Mio. cbm)	198	- 4 189	20	184	178	153	3 600						145
4	Water from nature (Mio. cbm)	444	25 068	27	74	72	62	20						25 767

Note: Germany 2019   [white box] = Values   [blue box] = Quantities

(1) Carbon dioxide (CO_2 = 1), methane (CH_4 = 28) and nitrous oxide (N_2O = 298) transformed with the factors to greenhouse gases in CO_2-equivalents.

(2) Sulfur dioxide (SO_2 = 1) and nitrogen oxides (NO_x = 0.7) were transformed with the factors to acid depositions in SO_2-equivalents.

(3) Carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4), nitrogen oxides (NO_x) cause ozone formation.

Sources: Federal Statistical Office of Germany (Destatis) and Eurostat

9. Economic development 2009–2019

Three approaches are commonly used for compiling Gross Domestic Product (GDP) from a system of supply and use tables or input-output tables.

The expenditure approach calculates GDP by summing the total spending for Private consumption, Government consumption, and Investment and Net exports (Exports minus imports). The income approach is used for compiling GDP by summing up Gross value added of industries and Taxes less subsidies on products. The production approach starts with compiling total output of industries. Then intermediate consumption of industries is deducted from output and taxes less subsidies on products added to arrive at GDP. All three methods should theoretically produce the same result, though small discrepancies can occur due to data collection methods. Small deviations are balanced out in a mechanical procedure. However, large disseminations must be solved by going back to the major sources.

Table 3. Gross domestic product of Germany and global warming.

	bn Euro		Share in %	
	2009	2019	2009	2019
	Expenditure approach of GDP			
Private consumption	1,319	1,718	55.6	49.5
+ Government consumption	513	755	21.6	21.7
+ Gross fixed capital formation	409	742	17.2	21.4
+ Changes in inventories	-18	26	-0.8	0.7
+ Exports	984	1,597	41.5	46.0
- Imports	-833	-1,364	-35.1	-39.3
= Gross domestic product	2,375	3,473	100.0	100.0
	Income approach of GDP			
Value added at basic prices	2,117	3,130	89.2	90.1
+ Taxes less subsidies on products	257	344	10.8	9.9
= Gross domestic product	2,375	3,473	100.0	100.0
	Production approach of GDP			
Output of industries at basic prices	4,365	6,408	183.8	184.5
- Intermediate consumption at purchasers' prices	-2,247	-3,278	-94.7	-94.4
+ Taxes less subsidies on products	257	344	10.8	9.9
= Gross domestic product	2,375	3,473	100.0	100.0
Global warming, acid deposition and tropospheric ozone formation				
	1.000 tons		Growth rate %	
	2009	2019	2009 - 2019	
Greenhouse gases	1,053,480	970,226	-7.9	
Acid deposition	2,034	1,638	-19.5	
Troposheric ozone formation	5,662	5,053	-10.7	

Note: Source: Extended input-output tables of Germany 2009 and 2019

In Table 3, the major trends of gross domestic product at current prices are shown for 2009 and 2019. All data were extracted from the two extended input-output tables. The share of private consumption in GDP dropped from 55.6% to 49.5% while the share of gross fixed capital formation rose from 17.2% to 21.4%. The share of exports in GDP rose from 41.5 to 46.0% and of imports from 35.1% to 39.3%. This is a significant increase toward higher interdependencies in production and trade.

During the ten years, the structure of the German industry did not change very much. Induced by more investment, the construction industry increased its share in gross value added from 4.7% to 5.2%, and for public and other services, its share from 23.5% to 24.5%.

The major objectives of macroeconomics are to achieve steady and appropriate economic growth, a stable price level, a high level of employment, and external balance. These four goals are also known as the “magic square” and are contained in the German Stability Act.

Another important goal for the future is environmental protection. Despite a modest real annual growth rate of GDP by 2.0%, the emission of greenhouse gases declined during the period 2009–2019 by 7.8%, of acid deposition by 10.5%, and of tropospheric ozone depletion by 10.7%. This is a real achievement for the nation but a problem for the rest of the world.

The major macroeconomic results for 2009–2019 are:

- The annual growth rate of GDP at the time was 3.6%. For several years now, real GDP has been calculated at previous year prices. The advantage is that real growth rates always reflect the economic structure of the most recent year. In contrast to the traditional method of constant prices of a base year, chain-linking enables a more accurate representation of actual growth, which has adjusted to the changing structure of the economy. The average annual real growth rate of GDP during 2009–2019 was 2.0%.
- Furthermore, inflation was low. The annual growth rate of the consumer price index was 1.3%. The unemployment rate of 7.8% was high in 2009 and dropped in 10 years to 5.0% in 2019. This is a major achievement for the labor market, which was induced by major reforms in the labor market in earlier years. The external balance of foreign trade was reached in both years. A modest surplus of net exports of 1.817 bn Euro was reported for 2009 and of 2.961 bn Euro for 2019. As in the past, Germany is a large net importer of energy. In 2019, the export of energy was 4.267 Petajoule and the import of energy was 14.089 Petajoule.
- Despite modest real economic growth and higher imports of energy, the emission of greenhouse gases was reduced from 1,053,480 million tons in 2009 to 970,226 million tons in 2019. This is a positive result and is improving environmental protection in Germany. A modest trend for the decoupling of economic growth and energy consumption is thus underway.
- Moreover, a major achievement was reported for the labor market. Induced by a substantial labor market reform in earlier years (Hartz Reform), the number of wage and salary earners increased from 40.4 Mio persons in 2009 to 45.3 Mio persons in 2019. As a result, the unemployment rate dropped from 7.8% in 2009 to 5.0% in 2019. This decline of unemployment is a major achievement in the decade before the coronavirus pandemic.

10. Emission model

Input-output analysis has often been used to study the impact of final demand on output (quantity model) and the impact of value-added changes on prices (price model). Appropriate extensions of the input-output system also enable evaluating the direct and indirect impact of economic policies on other economic variables such as labor, capital, energy, and emissions (joint product). Most of these policy issues (labor policy, structural policy, fiscal policy, environmental policy) can be analysed with macroeconomic models with a minimum of sectoral disaggregation. Ideally, input-output tables constitute the data base for such models.

The central model of input-output analysis is used to assess the emission content of final demand. I attempted to give a first assessment to the following question: How many emissions are generated world-wide for the production for final uses of goods and services for consumption, capital formation, exports, and imports? In this analysis, I assumed that all imports were also produced with the German technology. This is an optimistic assumption, as many countries do not meet the environmental standards of Germany in production.

The following extension of the input-output system offers multiple approaches for analysis, central equation of input-output analysis:

$$\mathrm{Z} = \mathrm{B}(\mathrm{I} - \mathrm{A})^{-1}\mathrm{diag}(\mathrm{Y}) \tag{1}$$

where Z = Matrix with results for direct and indirect requirements (intermediates, labor, capital, energy, emissions); B = Matrix of input coefficients for specific variables in economic analysis (intermediates, labor, capital, energy, emissions) I = Unit matrix; A = Matrix of input coefficients for intermediates; and diag(Y) = Diagonal matrix for final uses.

Matrix B includes the input coefficients of the variable under investigation (intermediates, labor, capital, energy, emissions, etc.). Diagonal matrix Y denotes exogenous final demand for goods and services. Matrix Z incorporates the results for the direct and indirect requirements (intermediates, labor, capital energy, emission) to produce goods and services. Direct contributions of final use (for example direct emissions of carbon dioxide by private households) must be added as a column vector to the results of matrix Z.

The emission models for Germany were published in the Eurostat Manual of Supply, Use and Input-Output Tables (Eurostat, 2008, pp. 493) and in the Handbook on Supply and Use Tables and Input-Output-Tables with Extensions and Applications (United Nations, 2018, pp. 623–628).

Emission models for Germany for 2009 and 2019.

Model 1: Input-output model for domestic emissions:

$$\mathrm{Z} = \mathrm{B}(\mathrm{I} - \mathrm{A})^{-1}\mathrm{diag}(\mathrm{Y} - \mathrm{M}) + \mathrm{Eh} \tag{2}$$

Model 2: Input-output model for imported emissions:

$$\mathrm{Z} = \mathrm{B}(\mathrm{I} - \mathrm{A})^{-1}\mathrm{diag}(\mathrm{M}) \tag{3}$$

Model 3: Input-output model for world-wide emissions:

$$\mathrm{Z} = \mathrm{B}(\mathrm{I} - \mathrm{A})^{-1}\mathrm{diag}(\mathrm{Y}) + \mathrm{Eh} \tag{4}$$

where Z = Direct and indirect emissions; B = Matrix of input coefficients for emissions; A = Matrix of input coefficients for intermediate use of domestic and imported products; Y = Vector of final demand of products; M = Vector of imports; diag(Y-M) = Diagonal matrix of final uses less imports; and Eh = Vector of direct emissions of private households.

I decided to base my analysis on Matrix A, the matrix of input coefficients for intermediates (domestic and imported intermediates combined). An alternative would be basing the analysis on domestic intermediates (Ad). However, the input coefficients A are more stable in time than the input coefficients Ad. The substitution of domestic intermediates and imported intermediates is always an option. Input coefficients A reflect cost shares of intermediates in output and do not change so easily as input coefficients Ad.

In Table 4, a calculation is presented for the emission of 11 different gases. My objective was to compile the emission content of final uses. The direct and indirect emissions per unit of output are quite different from the direct air emissions.

The actual direct emissions (rows 1–12) and total output of production (row 13) are reported for 2019. In the next matrix, the corresponding emission coefficients were calculated. The lowest carbon dioxide emission coefficient (5.388) is reported in row 14 for "Finance and business services". However, the inclusion of indirect emissions result in a much higher value of carbon dioxide emission (45.511) for the same activity in row 31. This time, all direct and indirect emissions of carbon dioxide for one unit of output are reported, which are required for all stages of production.

As shown in row 42, "Agriculture, forestry and fishing" is delivering goods and services in the magnitude of 5.679 billion euros for final use. The calculation reveals that during the production, 2.093 million tons of carbon dioxide have been emitted in Germany across all stages of production for the provision of these agricultural products for final users.

"Mining, manufacturing, electricity, and water" has the largest emissions at this level of aggregation. As shown in row 1, this industry is directly responsible for the emission of 487.254 million tons of carbon dioxide. This industry provides 871.621 bn Euros for final uses (row 43). To produce these products in Germany, this industry requires direct and indirect emissions of 416.714 million tons of carbon dioxide (Row 48).

Table 4. Emission model for Germany 2019.

		Input of homogeneous branches						Final uses					Less imports	Output at basic prices
	Products(CPC)	Agricul-ture, forestry and fishing	Mining, manufacturing, electri-city and water	Con-struc-tion	Trade, transport and com-muni-cation	Finance and busi-ness services	Public and other services	Private con-sump-tion	Govern-ment con-sump-tion	Gross fixed capital forma-tion	Chan-ges in inven-tories	Ex-ports		
No.	PRODUCTS (CPC)	1	2	3	4	5	6	7	8	9	10	11	12	13
		Direct air emissions E (1.000 tons)												
1	Carbon dioxide (CO_2)	13 357	487 254	10 536	116 760	7 356	22 472	221 472						879 206
2	Methane (CH_4)	1 243	536	1	127	1	5	61						1 973
3	Nitrous oxide (N_2O)	95	16	0	5	0	1	4						120
4	Nitrogen oxides (NO_x)	148	427	35	918	10	35	350						1 923
5	Sulfur dioxide (SO_2)	2	249	0	30	0	0	10						292
6	Organic compounds (NMVOC)	315	500	6	62	1	10	263						1 157
7	Ammonia (NH_3)	558	16	0	3	0	0	12						589
8	Particulate matter (PM_{10})	35	49	14	128	0	2	43						271
9	Hydroflurocarbons (HFC)	11	3 398	90	2 654	312	522	2 625						9 612
10	Perflurorocarbons (PFC)	0	229	0	3	0	0	0						232
11	Sulfur hexafluoride (SF_6)	0	3 587	0	0	333	0	0						3 919
12	Total	15 763	496 259	10 683	120 689	8 013	23 047	224 840						899 294
		Output X (billion euros)												
13	Output at basic prices	59	2 027	375	1 410	1 365	1 172	0	0	0	0	0	0	917 408
		Emission coefficients B (1.000 tons per billion euros)												
14	Carbon dioxide (CO_2)	226.907	240.382	28.072	82.821	5.388	19.180							
15	Methane (CH_4)	21.108	0.264	0.001	0.090	0.001	0.004							
16	Nitrous oxide (N_2O)	1.610	0.008	0.001	0.003	0.000	0.001							
17	Nitrogen oxides (NO_x)	2.514	0.211	0.094	0.651	0.007	0.030							
18	Sulfur dioxide (SO_2)	0.034	0.123	0.000	0.021	0.000	0.000							
19	Organic compounds (NMVOC)	5.355	0.247	0.016	0.044	0.001	0.008							
20	Ammonia (NH_3)	9.478	0.008	0.000	0.002	0.000	0.000							
21	Particulate matter (PM_{10})	0.586	0.024	0.037	0.091	0.000	0.002							
22	Hydroflurocarbons (HFC)	0.194	1.676	0.241	1.883	0.228	0.445							
23	Perflurorocarbons (PFC)	0.000	0.113	0.000	0.002	0.000	0.000							
24	Sulfur hexafluoride (SF_6)	0.000	1.770	0.000	0.000	0.244	0.000							
		Leontief inverse for products $(I\text{-}A)^{-1}$												
25	Agriculture, forestry and fishing	1.0790	0.0443	0.0130	0.0062	0.0025	0.0066							
26	Mining, manufacturing, electricity and water	0.4097	1.8188	0.5243	0.2052	0.0919	0.1569							
27	Construction work	0.0404	0.0340	1.1140	0.0291	0.0603	0.0315							
28	Trade, transport and comm.	0.2605	0.3265	0.2434	1.4598	0.1526	0.1601							
29	Finance and business services	0.3007	0.2476	0.2736	0.2260	1.3515	0.1438							
30	Public and other services	0.0517	0.0785	0.0705	0.0680	0.0646	1.1065							
		Direct and indirekt air emissions per unit of output $B(I\text{-}A)^{-1}$												
31	Carbon dioxide (CO_2)	368.622	478.091	183.244	174.970	45.511	75.362							
32	Methane (CH_4)	22.907	1.445	0.437	0.318	0.093	0.200							
33	Nitrous oxide (N_2O)	1.741	0.086	0.027	0.017	0.006	0.013							
34	Nitrogen oxides (NO_x)	2.976	0.715	0.411	1.016	0.142	0.191							
35	Sulfur dioxide (SO_2)	0.092	0.232	0.070	0.057	0.015	0.023							
36	Organic compounds (NMVOC)	5.891	0.701	0.228	0.150	0.045	0.091							
37	Ammonia (NH_3)	10.230	0.435	0.128	0.063	0.025	0.065							
38	Particulate matter (PM_{10})	0.668	0.101	0.084	0.142	0.020	0.025							
39	Hydroflurocarbons (HFC)	1.488	3.772	1.702	3.182	0.794	1.099							
40	Perflurorocarbons (PFC)	0.047	0.206	0.060	0.026	0.011	0.018							
41	Sulfur hexafluoride (SF_6)	0.798	3.279	0.994	0.418	0.492	0.313							
		Diagonal matrix of final uses of products from domestic production (billion euros) diag(Y-M)												
42	Agriculture, forestry and fishing	5.679	0.000	0.000	0.000	0.000	0.000							5.679
43	Mining, manufacturing, electricity and water	0.000	871.621	0.000	0.000	0.000	0.000							871.621
44	Construction work	0.000	0.000	236.592	0.000	0.000	0.000							236.592
45	Trade, transport and comm.	0.000	0.000	0.000	566.708	0.000	0.000							566.708
46	Finance and business services	0.000	0.000	0.000	0.000	609.610	0.000							609.610
47	Public and other services	0.000	0.000	0.000	0.000	0.000	911.239							911.239
		Emission content of final uses of products from domestic production (1.000 tons) $Z = B(I\text{-}A)^{-1}diag(Y\text{-}M) + Eh$												
48	Carbon dioxide (CO_2)	2 093	416 714	43 354	99 157	27 744	68 673	221 472						879 206
49	Methane (CH_4)	130	1 259	103	180	57	183	61						1 973
50	Nitrous oxide (N_2O)	10	75	6	9	3	12	4						120
51	Nitrogen oxides (NOx)	17	623	97	576	87	174	350						1 923
52	Sulfur dioxide (SO_2)	1	202	17	32	9	21	10						292
53	Organic compounds (NMVOC)	33	611	54	85	28	83	263						1 157
54	Ammonia (NH_3)	58	379	30	36	15	59	12						589
55	Particulate matter (PM_{10})	4	88	20	81	12	23	43						271
56	Hydroflurocarbons (HFC)	8	3 288	403	1 804	484	1 001	2 625						9 612
57	Perflurorocarbons (PFC)	0	180	14	15	7	16	0						232
58	Sulfur hexafluoride (SF_6)	5	2 858	235	237	300	285	0						3 919
59	Total	2 359	426 276	44 334	102 210	28 745	70 530	224 840						899 294

Note: Sources: Federal Statistical Office of Germany (Destatis) and Eurostat.

In row 1 of the system, it is shown that private households are responsible for direct emission of 224.840 million tons of carbon dioxide. The direct emissions of private consumption must be added as a separate column vector to the matrix of direct emissions by industries to attain the national emission total of 879.208 million tons of carbon dioxide, as shown in column 15. In column 15, the total air emissions of the economy in 2019 are reported with 899.294 million tons.

The largest emission content of final uses is observed for products of mining, manufacturing, electricity, and water (426,276 million tons). The second largest emission content of final uses is reported for private consumption (224,840 million tons).

A corresponding interpretation of the results is valid for all industries of the economy. This approach enabled me to allocate the emissions to products that are purchased by final users. However, it should be noted that this approach applies only to emissions on domestic territory and not to emissions created abroad for imports.

This approach was also used to estimate separate results for the emission content of private consumption, government consumption, gross capital formation, export, and imports. In the case of imports, I assumed that all imported goods and services were produced with the technology of Germany.

11. Results for 2009 and 2019

The major results of the emission model are summarized in Table 5.

During the period 2009–2019, the domestic emissions declined by 63,446 million tons. However, the emissions abroad for German imports stagnated. This estimate assumes that German technology is used abroad to produce German imports. Another key point is whether Germany is a net-exporter of emissions. My estimates indicate that Germany was a modest net-exporter of emissions during this period. The emissions in Germany for German exports were slightly larger in both years than the emissions abroad for German imports. The stagnation of emissions abroad for German imports is a matter of concern for the national environmental policy. Thus, I ask the following question: Could it be that dirty technologies are reduced at home and reimported to a certain extent via imports?

Table 5. Emissions of Germany 2009 and 2019.

	1.000 tons	Domestic emissions	Emissions of imports abroad	Total emissions	Emissions of exports	Emissions of imports abroad	Emissions of net exports
		2009			2009		
1	Carbon dioxide (CO_2)	942 012	560 752	1 502 763	645 180	560 752	84 428
2	Methane (CH_4)	2 348	2 568	4 915	2 326	2 568	- 242
3	Nitrous oxide (N_2O)	153	178	331	155	178	- 22
4	Nitrogen oxides (NO_x)	2 034	988	3 022	1 107	988	119
5	Sulfur dioxide (SO2)	610	385	995	455	385	70
6	Organic compounds (NMVOC)	1 280	962	2 242	948	962	- 14
7	Ammonia (NH_3)	620	801	1 421	633	801	- 168
8	Particulate matter (PM_{10})	303	144	447	156	144	12
9	Hydroflurocarbons (HFC)	10 031	3 875	13 906	4 706	3 875	831
10	Perflurorocarbons (PFC)	406	357	763	412	357	54
11	Sulfur hexafluoride (SF_6)	2 943	2 349	5 291	2 700	2 349	351
12	Total	962 740	573 358	1 536 098	658 778	573 358	85 420
		2019			2019		
1	Carbon dioxide (CO_2)	879 206	558 875	1 438 081	633 154	558 875	74 279
2	Methane (CH_4)	1 973	2 417	4 391	2 072	2 417	- 346
3	Nitrous oxide (N_2O)	120	157	277	127	157	- 30
4	Nitrogen oxides (NO_x)	1 923	1 028	2 951	1 145	1 028	117
5	Sulfur dioxide (SO_2)	292	263	555	299	263	36
6	Organic compounds (NMVOC)	1 157	990	2 147	954	990	- 36
7	Ammonia (NH_3)	589	840	1 429	649	840	- 191
8	Particulate matter (PM_{10})	271	153	424	164	153	10
9	Hydroflurocarbons (HFC)	9 612	4 647	14 259	5 438	4 647	790
10	Perflurorocarbons (PFC)	232	229	461	260	229	30
11	Sulfur hexafluoride (SF_6)	3 919	3 684	7 604	4 175	3 684	491
12	Total	899 294	573 285	1 472 579	648 435	573 285	75 150
		Change			Change		
1	Carbon dioxide (CO_2)	- 62 805	- 1 877	- 64 682	- 12 026	- 1 877	- 10 149
2	Methane (CH_4)	- 374	- 150	- 524	- 255	- 150	- 104
3	Nitrous oxide (N_2O)	- 33	- 20	- 54	- 28	- 20	- 8
4	Nitrogen oxides (NO_x)	- 111	40	- 70	38	40	- 2
5	Sulfur dioxide (SO_2)	- 319	- 122	- 441	- 157	- 122	- 35
6	Organic compounds (NMVOC)	- 124	28	- 95	6	28	- 23
7	Ammonia (NH_3)	- 31	39	8	16	39	- 23
8	Particulate matter (PM_{10})	- 32	9	- 23	7	9	- 2
9	Hydroflurocarbons (HFC)	- 420	773	353	732	773	- 41
10	Perflurorocarbons (PFC)	- 174	- 128	- 302	- 152	- 128	- 24
11	Sulfur hexafluoride (SF_6)	977	1 335	2 312	1 475	1 335	140
12	Total	- 63 446	- 73	- 63 519	- 10 343	- 73	- 10 271

Note: Source: Extended input-output tables of Germany for 2009 and 2019

12. Energy transition in Germany

In this paper, I analysed if energy transition is well underway in Germany. The decoupling of energy consumption and air emissions from economic growth was studied for the period 2009–2019. Decoupling energy consumption from economic growth is the ability of an economy to grow without a corresponding increase in energy use. This is often achieved through technical progress, higher energy efficiency, structural change, or changing demand. With a world-wide perspective, DIW Econ conducted a major study on decoupling greenhouse gas emission from economic growth (Handrich et al, 2015). The assessment covered data for the period 1990–2014 for 34 countries, including China, the USA, and Germany.

In my analysis for Germany, I distinguished weak decoupling and strong decoupling of economic growth. Weak decoupling of energy consumption and economic growth is defined as a reduction of energy intensity. In this case, the energy use per GDP is declining. However, energy consumption and

GDP are growing. Moreover, strong decoupling of energy consumption and economic growth is observed if energy consumption is reduced while GDP is growing.

For the period 2009–2019, a strong decoupling of energy and greenhouse gas emission from economic growth is observed for Germany. The major results on decoupling are shown in Table 6. For this period, real GDP was growing at the annual growth of +1.97%. Furthermore, negative annual growth rates were reported for energy consumption (−0.72%), for air emissions (−0.68%), and for greenhouse gases (−0.82%).

Moreover, renewable energy increased its share in total energy consumption by +6.1% from 12.8% in 2009 to 18.9% in 2019. The opposite happened with the consumption primary fuels. The combined share of coal, crude oil, and natural gas in total energy consumption dropped from 24.7% in 2009 to 17.7% in 2019. The share of primary fuels in total energy consumption decreased by −7.0%.

Table 6. Decoupling energy consumption and emissions from economic growth.

		2009	2019	Average annual growth rate in %
Gross Domestic Product				
Nominal GDP - At current prices	bn EUR	2,494	3,537	3.56
Real GDP - Price adjusted, chain-linked volume data	bn EUR	2,963	3,599	1.97
Energy and emissions				
Energy	Petajoule	12,134	11,292	-0.72
Air emissions	1.000 tons	962,740	899,294	-0.68
Greenhouse gas emissions	1.000 tons	1,053,480	970,226	-0.82
Intensities for nominal GDP				
Energy/Nominal GDP	Petajoule per bn EUR	4.865	3.192	-4.13
Air emissions/Nominal GDP	1.000 tons per bn EUR	386.027	254.233	-4.09
Greenhouse gas emissions/Nominal GDP	1.000 tons per bn EUR	422.411	274.286	-4.23
Intensities for real GDP				
Energy/Real GDP	Petajoule per bn EUR	4.095	3.137	-2.63
Air emissions/Real GDP	1.000 tons per bn EUR	324.944	249.842	-2.59
Greenhouse gas emissions/Real GDP	1.000 tons per bn EUR	355.571	269.549	-2.73

Note: Source: Extended input-output tables of Germany 2009 and 2019 and Destatis (National Accounts)

A key question is if a decoupling of air emissions abroad is also observed for imports of Germany. The results in Table 7 indicate that despite strong real growth of imports (+4.52%), air emissions abroad for producing German imports stagnated (0.00%). For imports, a stronger decoupling of air emissions from producing German imports (−4.32%) is observed for the reference period. Striking is the substantial increase of natural gas imports from 3,083 Petajoule in 2009 to 5,571 Petajoule in 2019.

Table 7. Decoupling emission abroad to produce German imports

		2009	2019	Average annual growth rate in %
Imports of goods and services - At current prices	bn EUR	765	1,299	5.44
Real imports - Price adjusted, chain-linked volume d	bn EUR	816	1,270	4.52
Air emissions	1.000 tons	573,358	573,285	0.00
Air emissions/Nominal GDP	1.000 tons per bn EUR	749.228	441.209	-5.16
Air emissions/Real GDP	1.000 tons per bn EUR	702.281	451.336	-4.32

Note: Source: Extended input-output tables of Germany 2009 and 2019 and Destatis (National Accounts).

Following the Fukushima disaster in March 2011, the German parliament passed in June 2011 the legislation to shut down all nuclear power plants by the end of 2022. With the shutdown of the last three nuclear power plants in April 2023, the era of nuclear power use in Germany officially ended. So far, Italy, Germany, and Taiwan have phased out nuclear power generation. Other countries, such as Spain, have announced a nuclear phase-out. However, several countries, including Japan and Sweden, have abandoned their plans to phase out nuclear power.

A total of 15 years after the Fukushima nuclear disaster, Germany learned to live without nuclear power and uses renewable energies instead. They make the country safer and more independent. For the future, providing speed limits on highways, electrification of industrial plants, acceleration of energy transition for heating of buildings and more home offices are important initiatives.

13. Outlook

After 2019, several conflicts had strong impacts on the economy of Germany. Major events were the Covid-19 pandemic (2020–2023), Russia invaded Ukraine (2022–2026), Nord Stream Pipeline Sabotage (2022), Civil War in Sudan (2023–2026), Occupation of Palestine (2024–2026), and the Iran and Lebanon Crisis (2026).

After a prolonged downturn during the last 10 years, the German economy is experiencing a slow recovery with moderate growth of GDP. For the following years, slightly higher growth rates of GDP are expected due to expansionary fiscal policies with more expenditure for defence and infrastructure. High energy prices are expected to prevail due to geopolitical tension in the Middle East, which will create structural problems for energy intensive industries in Germany.

14. Conclusions

In this paper, I demonstrate how extended input-output tables can be used to evaluate environmental policies. My aim is to develop a new database that helps identify if national emissions reduction targets are met and how they comply with the Paris Agreement of the UN Climate Change Conference (COP21) in Paris (2015) and the targets of the Intergovernmental Panel on Climate Change (IPCC) of the United Nations (2023). Furthermore, the same database can be used for other important fields of economic analysis, such as the impact of employment policies, substitution of labor and capital, productivity analysis, energy issues, environmental protection, and problems of structural policies.

The compilation of extended input-output tables is a valuable complement for the system of national accounts. The extended input-output tables of Germany show the structure of the economy on one page. Larger tables are available on request.

The results reveal that Germany achieved a significant decoupling of economic growth from greenhouse gas emissions and other pollutants in the reported years. This success was driven by a transition toward more regenerative energy sources, changing technologies, and a cleaner economy with more recycling. However, the positive trend was counteracted by more energy imports from abroad.

However, I ask the following question: Do the results really indicate a more sustainable development of Germany in the foreseeable future? I am not so sure. However, my conclusion is that the economic development of the economy is moving in the right direction. If we want to tackle the major environmental problems in the future, the new data base will help identify the significance of problems at hand and possibly encourage stricter measures to reduce environmental problems. It is never too late for such actions, but it may become very costly if we wait much longer.

Use of AI tools declaration

The author declares that he has not used Artificial Intelligence (AI) tools in the creation of this article.

Data

germany_iot_2009_final_table 1_26may26.xlsx;
germany_iot_2019_final_table2_26may26.xlsx;
germany_iot_ext_tables_revised_table3_26may26.xlsx;
germany_iot_ext_2009_emission_model_6x6_26may26.xlsx;
germany_iot_ext_2019_emission_model_6x6_table4_26may26.xlsx;
germany_iot_ext_emissions_2009_2019_table5_26may26.xlsx;
germany_iot_ext_tables_revised_table6_table7_26may26.xlsx;
extended_iot_germany_joerg_beutel_26may26.docx (Article).

Conflict of interest

The author declares no conflicts of interest in this paper.

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