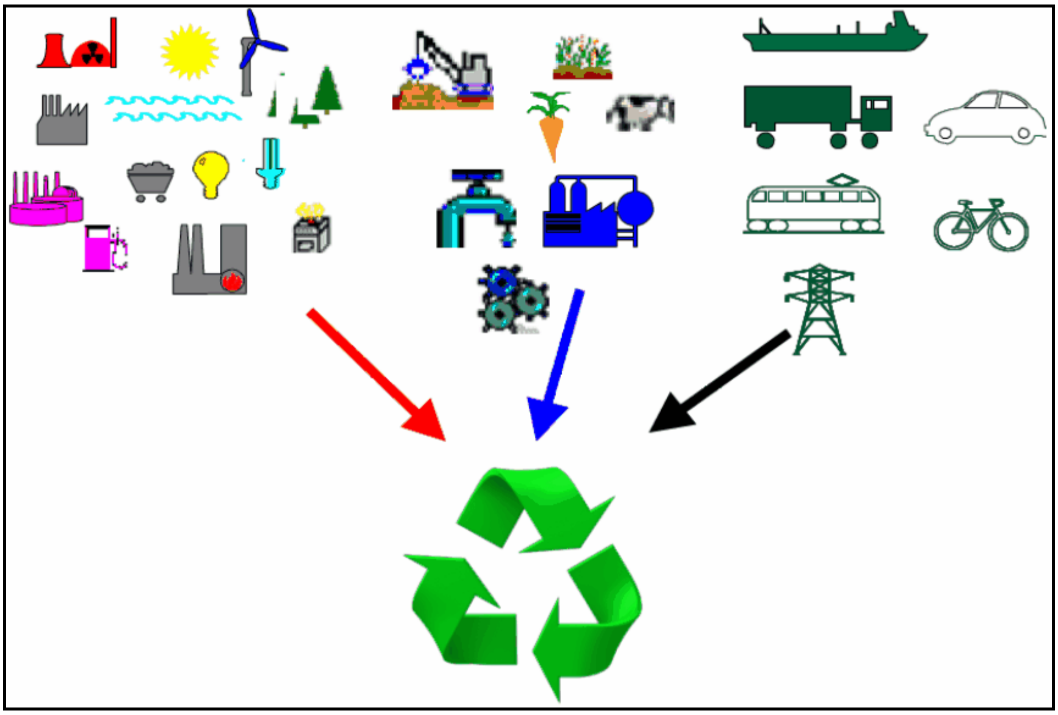
Life Cycle Analysis of GHG and Air Pollutant Emissions from Renewable and Conventional Electricity, Heating, and Transport Fuel Options in the EU until 2030



ETC/ACC Technical Paper 2009/18
June 2009

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European Topic Centre
on Air and Climate Change

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Updated Report for the
European Environment Agency (EEA)

Darmstadt, June 2009

prepared by

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Note on this Report

In 2006, the European Environment Agency (EEA) commissioned a study from the Oeko-Institut (Institute for applied ecology) to give an overview on **life cycle emissions** of renewable and conventional electricity generating options in the EU-25 (EU-15 plus the 10 new Member States), and EU-28 (EU-25 + Bulgariaä Romania, and Turkey), as well as heating and transport fuel provision in those countries.

In addition, the life cycle emissions from the average electricity mix for each country was given for the year 2000, and for electricity generation in 2010, 2020, and 2030 based on the PRIMES reference scenario.

The LCA was extended to cover also heating systems, and transport fuels (from biomass, natural gas, and oil). The data for these systems is indicative, as only some European country figures are included (with some detail on biomass).

This study gave input to parallel work carried out for the EEA to determine the environmentally-compatible bioenergy potential in the EU (EEA 2006+2007), and its use for electricity, heat and transport fuel provision (EEA 2008). Also, results were presented to the DG-TREN, and to the JRC in 2006.

The LCA work was based on the Global Emissions Model for integrated Systems (GEMIS)[1] developed by Oeko-Institut.

This report updates results of the 2006 study using GEMIS version 4.5, adds data for the year 2005, and for the EU-27, and uses the new EU methodology for GHG emission calculation from bioenergy, and also energy allocation for electricity from combined heat and power generation (CHP, or cogeneration).

Key data on energy technologies and their direct emissions of greenhouse gases and air emissions are given in the Annex.

We would like to thank the EEA for sponsoring this study, and for giving helpful tips and feedback during the preparation of this report.

All responsibility for its contents remains with the authors.

Darmstadt, June 2009 The Authors

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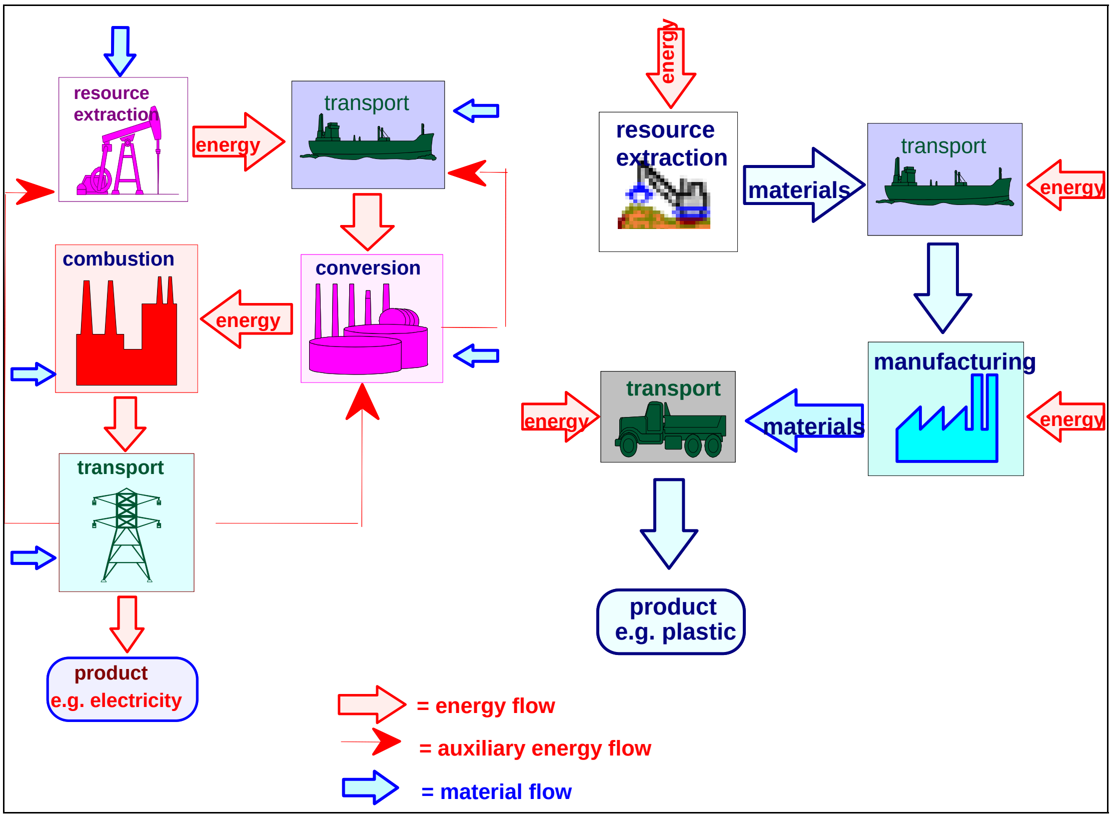
[1] see www.gemis.de

1 Introduction

The role of renewable energies in a sustainable energy system is emphasized more and more, both EU-wide, and globally. The environmental impacts of renewable energies are – in general – lower than those of conventional (fossil and nuclear) energy systems, as non-biomass renewables require no direct fuel input or combustion, and biomass is CO_2-neutral when burnt.

Still, material acquisition and manufacturing of energy systems, as well as upstream fuel-cycles (for biomass, fossil, and nuclear) also cause environmental impacts. A comprehensive comparison of conventional and renewable energies must factor in all these impacts. For that, the concept of **life cycle assessment** (LCA) was developed in the 1980ies: LCA identifies environmental impacts of whole **networks of activities**, from resource extraction to end-use, including the manufacturing stage for processes involved ("cradle-to-grave"). The LCA approach is data-intensive – it covers not just direct emissions, but also indirect ones from "upstream" activities such as mining, processing, and transport as well as materials (and energy) needed to manufacture all processes.

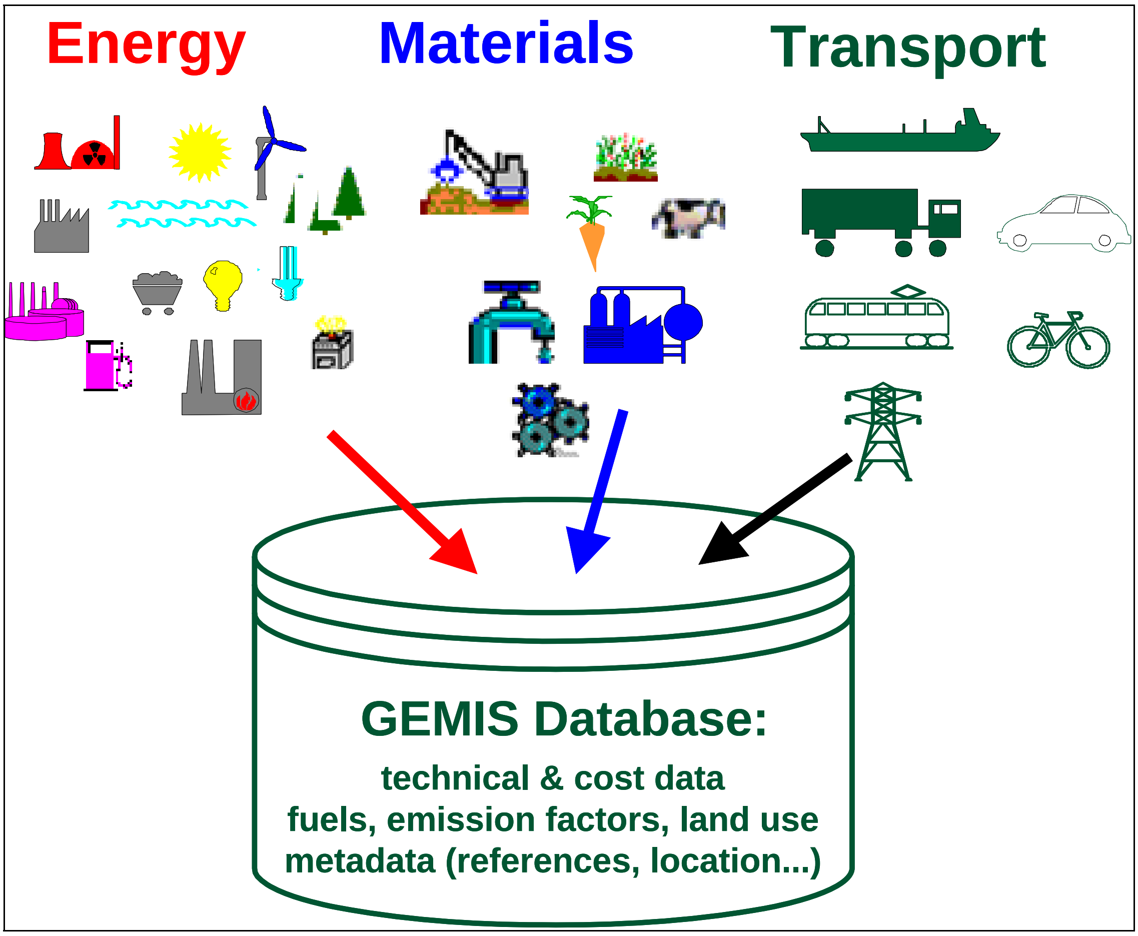
Figure 1 Principle Scheme of the LCA Approach



Source: OEKO (2006a)

Along all nodes of the network, environmental impacts can arise, so that a variety of data for each process in the network - as well as their interlinkages – must be collected, compiled, and stored. For this, electronic databases have been developed in the 1980ies and 1990ies – one of which is GEMIS[2].

Figure 2 GEMIS Database for LCA, and Material-Flow Analysis



Source: OEKO (2006a)

GEMIS includes all key energy, material, and transport processes for more than 50 countries, and was extended to cover the EU-25 and EU-28, for the year 2000, 2010, 2020, and 2030, respectively (OEKO 2005). An update was prepared in 2006 which reflects some new studies for natural gas fuel-cycles, and updated statistical material for coal, oil, and gas (OEKO 2006b). Meanwhile, GEMIS was extended to 2005 base year, and updated for several (renewable) energy and transport processes (OEKO 2008).

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[2] GEMIS = Global Emissions Model for integrated Systems, a public-domain software available at no cost (see www.gemis.de).

2 Life Cycle Data for Fossil and Nuclear Energies

As a basis for the comparison with renewables, this section briefly discusses conventional (fossil and nuclear) upstream life cycles, i.e., primary extraction, fuel conversion, and transport of fossil and nuclear energy carriers to the “point of use”, e.g., a thermal powerplant, a heating plant, or a transport system.

The upstream fuel-cycles for the various coal options are described in OEKO (2003), while the data for the oil and natural gas fuel-cycles are detailed and discussed in OEKO (2006b). The data background for nuclear systems is given in OEKO (2006a)[3].

2.1 Upstream Life Cycles for Hard Coal and Lignite

The life cycle of coal-fired powerplants mainly consists of

- fuel extraction, either in underground (deep) or surface (open-pit) mining,
- fuel benefication (screening, drying, milling), and transport,
- and the material acquisition and manufacturing of all processes involved in those activities (mainly steel, and concrete).

The following table gives the GHG emissions of the lignite and (hard) coal delivery to powerplants or other large-scale customers in the respective countries. Note that in this data, the combustion of the coal itself is *not included*.

The data is shown for lignite and hard coal delivery in EU countries, but also for imports from Russia (RU), the United States of America (US), and the Republic of South Africa (ZA) as those are key exporters of hard coal to Europe, and several EU countries do not have domestic coal extraction industries.

Lignite is mined in surface (open-cast) operations throughout Europe, while hard coal is mainly extracted from “deep” mining with the exception of the UK where also surface mining is used.

For coal exported from RU and US, only surface mining is considered, while for ZA, deep mining for hard coal is assumed.

The import life cycles include ocean-going ships to move the coal to Europe.

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[3] Note that the GEMIS database offers a description of all processes in English, and all data is given explicitly (including references) in the data records.

Table 1 GHG emissions of lignite/hard coal upstream life cycles, 2005

emissions [g/GJ$_{end}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
lignite AT	1,052	530	22.37	0.025
lignite BG	4,730	2,197	109.28	0.065
lignite DE	4,203	4,130	1.49	0.130
lignite GR	3,908	1,513	103.47	0.052
lignite HU	2,749	2,031	28.64	0.202
lignite PL	2,137	2,084	1.46	0.065
lignite RO	4,730	2,197	109.28	0.065
lignite SI	2,258	2,197	1.82	0.065
lignite SK	24,185	2,084	960.04	0.065
lignite TR	2,446	1,700	31.67	0.058
coal deep CZ	18,001	3,864	613.19	0.114
coal deep DE	11,866	2,750	395.07	0.099
coal deep ES	5,477	1,811	158.07	0.105
coal deep PL	8,287	3,011	227.73	0.129
coal surface UK	849	501	14.83	0.024
import coal RU	20,705	12,693	342.33	0.470
import coal US	7,580	4,821	115.02	0.373
import coal ZA	16,002	7,031	388.62	0.109

Note: data for upstream life cycles *only* (source: GEMIS 4.5)

As can be seen, lignite has (due to the surface mining) rather low upstream GHG emissions, while deep mining of hard coal leads to higher results.

Imported hard coal from the US has lower emissions than coal from EU countries (except ES), while imports from RU and ZA have higher emissions, mainly due to international transports and more carbon-intense “background” systems.

As regards air pollutant emissions from lignite and coal life cycles, the following table gives the results.

Table 2 Air pollutants from lignite/hard coal upstream life cycles, 2005

emissions in [g/GJ_{end}]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates***	**CO**	**NMVOC**
lignite AT	1.36	0.28	1.51	0.05	0.64	0.05
lignite BG	29.38	25.25	5.75	5.12	1.51	0.04
lignite DE	3.64	1.56	2.76	0.10	2.30	0.05
lignite GR	7.65	3.68	5.65	0.57	1.92	0.16
lignite HU	24.90	22.45	3.35	6.83	1.45	0.03
lignite PL	3.51	2.42	1.55	0.50	1.56	0.04
lignite RO	29.38	25.25	5.75	5.12	1.51	0.04
lignite SI	29.38	25.25	5.75	5.12	1.51	0.04
lignite SK	3.51	2.42	1.55	0.50	1.56	0.04
lignite TR	87.71	81.04	8.50	6.70	2.10	0.18
coal deep CZ	8.92	4.75	5.90	0.31	1.76	0.07
coal deep DE	3.89	1.65	2.73	0.20	1.68	0.11
coal deep ES	6.70	1.41	7.54	0.06	1.45	0.04
coal deep PL	7.15	3.57	4.99	0.45	1.98	0.09
coal surface UK	2.53	0.63	2.72	0.25	0.81	0.09
import coal RU	77.72	47.60	36.82	9.98	18.63	1.32
import coal US	64.77	34.02	44.12	6.23	12.20	3.67
import coal ZA	124.54	72.46	74.27	11.20	16.06	4.26

Note: data for upstream life cycles *only* (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

High emissions of SO_2 (and, hence, SO_2 equivalents) occur for lignite mining (especially in TR), but also for coal imports, especially from ZA. Air emissions from lignite and coal are rather low for AT, DE, SK, and UK surface mining.

Besides data for mining of lignite and coal, it is of interest which upstream emissions are associated with the average hard coal in EU countries, as there is a mix of domestic and imported coals. The data for the modeling of the national coal mixes are based on IEA (2007).

The results for the upstream emissions with respect to the national coal mixes are given below.

Table 3 GHG emissions of coal upstream life cycles in the EU, 2005

emissions [g/GJ$_{end}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
AT	13,565	4,570	388.79	0.179
BE	14,812	8,336	277.78	0.289
CZ	18,001	3,864	613.19	0.114
DE	13,309	6,271	303.00	0.232
DK	15,378	7,749	328.76	0.225
ES	13,534	7,532	257.30	0.279
FI	11,320	6,226	218.50	0.234
FR	11,217	6,256	211.55	0.314
IE	10,076	5,430	200.29	0.131
IT	14,102	7,960	265.00	0.158
NL	12,360	6,709	242.59	0.240
PL	8,287	3,011	227.73	0.129
PT	14,527	8,143	273.56	0.307
SE	14,835	8,684	263.03	0.340
UK	15,401	7,103	355.81	0.382

Note: data for upstream life cycles *only* (source: GEMIS 4.5)

The GHG emissions are quite close to each other with the exception of PL on the lower end, and CZ and the UK on the upper end of the range.

As regards air pollutants, the range is far larger – more than a factor of 10 lies between the lowest and the highest emissions, as the following table shows.

Table 4 Air pollutants from coal upstream life cycles in the EU, 2005

emissions in [g/GJ$_{end}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates***	**CO**	**NMVOC**
AT	11.83	5.52	8.89	0.61	2.99	0.26
BE	108.47	62.80	64.06	9.85	16.64	3.68
CZ	8.92	4.75	5.90	0.31	1.76	0.07
DE	60.24	38.12	29.89	6.43	10.26	1.60
DK	90.05	52.92	51.49	8.01	13.48	2.28
ES	78.46	45.58	45.32	7.61	13.07	2.44
FI	40.77	24.66	20.25	4.71	8.31	0.60
FR	81.83	48.44	46.72	7.84	12.73	2.94
IE	84.62	48.98	50.76	7.06	11.10	2.71
IT	121.89	71.92	70.21	10.37	15.74	3.38
NL	52.44	29.98	31.08	4.79	9.51	1.52
PL	7.15	3.57	4.99	0.45	1.98	0.09
PT	84.81	49.11	49.15	8.28	14.61	2.69
SE	73.74	42.43	43.12	6.99	13.07	2.27
UK	67.92	38.34	41.40	3.81	9.84	1.95

Note: data for upstream life cycles *only* (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

2.2 Upstream Life cycles for Natural Gas

The life cycle of natural-gas-fired powerplants mainly consists of

- fuel extraction, either in onshore or offshore sites,
- fuel processing (drying, removal of heavy hydrocarbons, desulfurization),
- transport (by pipeline, or LNG via ships),
- and the material acquisition and manufacturing of all processes involved in those activities (mainly steel, and concrete).

The following table gives the GHG emissions of natural gas delivered to powerplants or other large-scale customers in the respective countries. Note that in this data, the combustion of the gas itself is **not included**.

The data is shown for natural gas delivered in EU countries (based on data from IEA 2007b), but also for imports from RU, and Norway (NO) as those are key exporters of natural gas to the EU, and several EU countries do not have domestic gas extraction industries.

Table 5 GHG emissions of natural gas upstream life cycles, 2005

emissions in [g/GJ$_{end}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
AT	13,745	7,382	272.71	0.308
BE	4,568	3,060	63.97	0.122
CZ	7,152	4,474	114.06	0.183
DE	8,823	5,034	162.11	0.204
DK	2,212	973	53.42	0.033
ES	11,371	8,735	109.68	0.382
FI	19,030	10,138	381.17	0.424
FR	9,068	5,554	149.81	0.231
GR	17,558	9,643	338.95	0.404
HU	12,061	6,989	216.74	0.297
IE	2,548	1,341	51.82	0.050
IT	10,078	6,088	170.20	0.256
NL	2,629	1,483	49.09	0.059
PL	19,931	15,382	189.32	0.656
PT	9,480	6,929	107.06	0.300
TR	17,206	10,320	293.36	0.467
UK	2,507	1,241	54.49	0.045
EU	11,131	6,173	212.25	0.255
NO	3,852	2,522	56.57	0.098
RU	17,777	9,847	339.49	0.412

Note: data for upstream life cycles *only* (source: GEMIS 4.5)

The range of GHG emissions covers about one order of magnitude, with DK, IE and the UK at the lower and, and GR, PL and TR at the higher end.

The air pollutant emissions from natural gas life cycles are shown below.

Table 6 Air pollutants of natural-gas upstream life cycles, 2005

emissions in [g/GJ$_{end}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates***	**CO**	**NMVOC**
AT	29.72	1.67	40.16	1.62	25.51	4.77
BE	11.51	2.12	13.46	0.55	6.31	0.60
CZ	16.77	0.86	22.81	0.88	13.49	1.85
DE	19.06	1.52	25.07	1.09	15.99	2.64
DK	2.68	0.48	3.15	0.30	3.52	0.16
ES	37.05	1.43	51.16	1.00	27.48	1.97
FI	41.14	2.31	55.58	2.23	35.37	6.79
FR	20.23	1.41	26.97	0.97	14.95	2.36
GR	38.17	2.36	51.27	1.98	31.26	5.85
HU	28.51	1.98	37.96	1.60	23.23	3.61
IE	4.20	0.51	5.29	0.33	4.20	0.32
IT	22.17	1.94	28.99	1.00	15.39	2.39
NL	4.66	0.45	6.01	0.31	4.07	0.23
PL	45.80	12.79	46.83	2.61	24.59	3.16
PT	21.92	2.68	27.63	0.58	8.72	0.65
TR	41.77	3.35	55.02	2.10	33.91	5.04
UK	3.77	0.55	4.61	0.34	4.09	0.26
EU	24.14	1.41	32.55	1.32	20.53	3.59
NO	8.45	0.46	11.48	0.49	7.09	0.78
RU	40.11	2.23	54.21	2.16	34.23	6.00

Note: data for upstream life cycles *only* (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

Here, the range is similar – there is a factor of 10 between the lowest and the highest emissions of SO_2 equivalents from national gas life cycles.

2.3 Upstream Life Cycles for Oil

The life cycle of oil-fired powerplants mainly consists of

- fuel extraction, either in onshore or offshore sites,
- fuel processing (drying, removal of water, desulfurization),
- transport (by pipeline, train, truck),
- refinery and regional distribution,
- and the material acquisition and manufacturing of all processes involved in those activities (mainly steel, and concrete).

The following table gives the GHG emissions of heavy-fuel oil (HFO) delivered to powerplants or other large-scale customers in the respective countries (based on data from IEA 2007a). Note that in this data, the combustion of the oil itself is **not included**.

The data is shown for HFO delivery in EU countries, but also for imports from RU (for EE, LT, LV), and for “generic” which reflect typical situations in countries of the Middle East (assumed for imports to BG, CY, MT).

Table 7 GHG emissions of heavy fuel oil upstream life cycles, 2005

emissions in [g/GJ_{end}]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
AT	12,770	12,016	29.24	0.273
BE	12,648	11,915	28.36	0.275
DE	10,355	9,789	21.31	0.257
DK	8,978	8,656	10.65	0.261
ES	11,934	11,399	19.92	0.261
FI	14,511	13,491	40.17	0.325
FR	11,139	10,608	20.00	0.239
GR	13,470	12,790	25.92	0.284
IE	8,634	8,353	9.03	0.245
IT	12,427	11,808	23.39	0.274
NL	12,266	11,640	23.54	0.284
NO	7,712	7,471	7.91	0.200
PL	20,633	19,276	51.55	0.576
PT	11,962	11,475	17.73	0.267
RO	16,993	15,555	57.55	0.387
SE	10,803	10,211	22.54	0.251
UK	8,613	8,310	10.06	0.245
EU	**8,436**	**8,157**	**9.17**	**0.231**
RU	22,978	21,521	56.76	0.514

Note: data for upstream life cycles *only* (source: GEMIS 4.5)

GHG emissions from heavy fuel oil life cycles differ by a factor of about 2, with most countries close to the EU average, but PL, RO about twice as high which is a result of the high import shares from RU.

As regards air pollutants, the life cycle emissions from national heavy fuel oil are between 60 and 230 g of SO_2 equivalents per GJ_{end}, with an EU average of 80 g/GJ_{end}, as shown in the following table.

Table 8 Air pollutants from heavy fuel oil upstream life cycles, 2005

emissions in [g/GJ_{end}]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates***	**CO**	**NMVOC**
AT	121.36	95.44	36.63	4.71	15.75	24.47
BE	118.18	92.74	35.94	4.58	15.72	24.14
DE	58.86	40.05	26.41	3.60	11.66	18.84
DK	79.93	63.29	23.74	1.80	10.44	13.61
ES	131.07	100.26	44.03	4.60	14.09	21.20
FI	114.75	91.59	32.11	5.10	18.70	28.60
FR	116.57	91.63	35.51	4.04	13.58	20.74
GR	133.56	104.17	41.77	5.10	15.72	23.58
IE	80.59	64.20	23.52	1.75	9.58	13.58
IT	129.68	100.17	42.04	4.70	14.73	22.20
NL	117.55	91.00	37.67	4.20	14.61	21.78
NO	76.25	62.22	20.14	1.65	9.33	13.51
PL	193.94	160.21	47.35	12.96	33.42	41.98
PT	138.41	105.36	47.05	4.98	13.77	20.34
RO	167.51	136.81	42.83	10.39	19.93	28.97
SE	95.72	77.08	26.26	3.34	13.80	20.63
UK	77.86	63.08	21.18	1.79	9.84	13.65
EU	79.70	64.44	21.81	1.78	9.73	13.58
RU	213.21	177.64	48.84	12.43	28.07	46.05

Note: data for upstream life cycles *only* (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

2.4 Upstream Life Cycles for Nuclear Generation

The life cycle of nuclear powerplants mainly consists of

- uranium ore extraction in underground (deep) or surface (open-pit) mining,
- processing (milling) and enrichment (centrifuges, gas diffusion),
- fuel-rod production,
- and the material acquisition and manufacturing of all processes involved in those activities, including the construction of the nuclear powerplants (mainly steel, and concrete)[4].

The re-processing of spent fuel rods was not considered here, as this seems to be too costly in the future. Therefore, only *once-through cycles* with are included.

As there are only few countries in Europe with systems for uranium enrichment and fuelrod fabrication, the results of the upstream nuclear life cycle is included in the country-specific comparison of nuclear energy (see Section 3.3).

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[4] The final repository has not been included in this analysis, as no final configuration of such a process is available, nor its possible lifetime and storage capacity.

2.5 Upstream Life Cycles for Bioenergy

The upstream life cycles of bioenergy systems can be separated into two categories: bioenergy from residues and wastes (e.g. biogas from manure, straw from agriculture, wood chips from forest thinnings), and from dedicated energy crops (e.g. rape seeds, miscanthus, short-rotation forestry).

For residues and wastes, no upstream life cycles other than transport processes are to be considered, as they are by-products of agriculture or forestry operations, or other activities (e.g. food and wood industry, households). Still, as this biomass is not directly available for energy purposes, it usually needs processing – e.g., baling, chipping, fermentation, gasification, pelletization. Therefore, bioenergy from theses sources also has upstream life cycles.

For bioenergy crops, though, the full upstream activities must be factored in, as these activities occur to deliver bioenergy. Therefore, the farming operations for bioenergy crops (planting, harvesting, transport etc.) and the inputs needed for those (e.g. fertilizer, pesticides, transport fuels) must be accounted for.

Furthermore, also by-products from bioenergy feedstock conversion in upstream life cycles must be factored in, e.g., oil cake and glycerine from FAME, or DDGS from EtOH fermentation. In contrast to earlier versions of this report where the substitution approach was used, the results **presented here** were derived using the **new EU methodology for GHG emission calculation for biomass**, as specified in the EU Directive on the Promotion of the Use of Energy from Renewable Sources (RES-D)[5]. This “energy allocation” methodology was also used to determine GHG emissions from cogeneration systems[6].

The variety of bioenergy crops is large, and the farming operations and yields differ with respect to soil, climate conditions, and crops characteristics. Furthermore, the inputs into these systems (electricity, fuels, and agrochemicals) have also different life cycles depending on the national systems.

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[5] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC; Official Journal of the EU, June 5, 2009 L 140 pages 16-62 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

[6] In energy allocation, the overall environmental “burden” of a process with several outputs is allocated to each output based on the respective lower heating value (LHV). If electricity is one of the outputs, it is assumed that its LHV is 2.5 times the one of heat, which reflects the methodology of the EU Cogeneration Directive (Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:052:0050:0060:EN:PDF) and the subsequent decision on efficiency data (2007/75/EC: Commission Decision of 21 December 2006 establishing harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:032:0183:0188:EN:PDF .

To deal with this huge variety, a *selection* of bioenergy crops was made in this study with respect to sustainability considerations, and an aggregation of EU-25 countries into environmental zones (see EEA 2006; EEA 2007).

The regional aggregation using environmental zones groups EU countries into five zones[7]:

- Atlantic Central (ATC): BE, DE, FR, UK
- Atlantic North (ATN): FI, SE, as well as EE, LT, LV
- Continental (CON): AT, PL
- Mediterranean (MED): ES, GR, IT, PT
- Pannonic-Pontic (PAN): CZ, HU, SI, SK

It should be noted that this aggregation is not perfect, as the land area of some countries has considerable shares in other environmental zones (e.g. MED for FR).

Still, the concept is workable to reduce the variety of countries, and allows to group bioenergy crops with respect to zone-specific yields.

As relevant bioenergy crops, the following plants were selected:

- rape seed and sunflower seed for liquid biofuels (FAME)
- maize, sorghum and wheat for biogas and bioethanol (both first generation, and lignocellulosic EtOH)
- short-rotation coppice (SRC) from poplar, and willow as a solid fuel, and as feedstock for gasification, and BtL
- giant reed, miscanthus, and switchgrass also as solid fuels, and as feedstock for gasification, and BtL
- double-cropping systems (both with optimal yields, and with reduced yields due to less favorable site conditions) for biogas.

Furthermore, residues and wastes from agriculture (manure, straw), forestry (logging and thinning residues), paper and wood industry (black liquor, pellets), and the waste sector (organic household wastes, waste wood) were included in the analysis.

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[7] The environmental zones consist of nine groups with several subgroups. Not included here were the Alpine, Boreal, Lusitanean, and Nemoral groups. Also, the Alpine (North, South) and the Mediterranean (Mountains, North, South) subgroups were not considered.

As upstream conversion technologies for these biomass sources, the following systems were considered:

- biodiesel from plant oils (1st generation), and from BtL (2nd generation)
- biogas from anaerobic fermentation, both as direct biogas, and as processed (cleaned and upgraded) biomethane for gas pipeline feed-in
- ethanol from fermentation (1st generation, and 2nd generation lignocellulosic process)
- bales, chips and pellets from solid biomass
- synthesis gas from biomass gasification (fluidized-bed, entrained flow).

The upstream life cycles of bioenergy also change over time, as technology learning occurs for both the bioenergy cropping systems (especially yields), and the conversion systems (e.g. efficiency of biogas fermenters).

Furthermore, “background” systems for electricity, fuels etc. also evolve over time. Therefore, the bioenergy upstream life cycles were analyzed with respect to the years 2010, 2020, and 2030.

For simplicity, only 2010 and 2030 data is presented here[8].

The following tables give the upstream life cycle emissions of bioenergy systems with respect to feedstock, conversion routes, and environmental zones.

As said before, the data reflect the **new EU methodology for GHG emission calculation for biomass**, as specified in the EU Directive on the Promotion of the Use of Energy from Renewable Sources (RES-D)[9]

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[8] Note that for most bioenergy life cycles also 2005 data were compiled. The full disaggregation of all data is given in the GEMIS database which is freely available (www.gemis.de).

[9] For details, see footnotes 5 and 6.

Table 9 GHG emissions of bioenergy upstream life cycles in EU countries grouped into Environmental Zones, 2010

	CON	**ATC**	**MED**	**ATN**	**PAN**
CO_2eq [kg/GJ_{output}]	**AT, PL**	**DE, FR, UK**	**ES, GR, IT, PT**	**FI, SE, EE, LT, LV**	**CZ, HU, SI, SK**
FAME	56.1	56.5	78.3	🟦	82.2
biogas maize	32.0	34.2	36.5	34.9	27.4
biogas cereals	32.5	34.8	23.1	35.7	28.5
biogas grass cuttings	10.9	9.2	7.6	6.0	8.9
biogas double cropping opt	21.7	18.2	🟦	15.1	19.2
biogas double cropping red.	26.2	23.8	🟦	22.1	24.7
biogas manure large	10.9	9.2	7.6	6.0	8.9
biogas manure small	13.3	10.9	8.8	6.5	10.5
biogas other wastes	10.9	9.2	7.6	6.0	8.9
EtOH maize grain	40.9	40.8	41.1	37.2	38.2
EtOH cereals grain	41.2	41.2	31.9	37.8	38.9
EtOH sorghum	🟦	🟦	25.7	🟦	🟦
wood pellets	4.7	3.5	2.5	1.4	3.4
SRC chips	6.4	5.9	🟦	6.2	7.0
waste wood + forest residue chips	2.0	2.0	2.0	2.0	2.0
miscanthus, reed bales	🟦	5.0	4.8	🟦	5.4
switchgrass bales	5.7	5.2	🟦	5.1	5.5
straw bales	0.9	0.8	0.8	0.8	0.9
gas from gasifier - black liquor	10.6	8.8	7.2	5.4	8.5
gas from gasifier - SRC	16.0	13.6	🟦	10.7	14.7
gas from gasifier - forest chips	10.6	8.8	7.2	5.4	8.5
gas from gasifier - miscanthus/reed	🟦	12.5	10.8	🟦	12.8
gas from gasifier - switchgrass	15.6	13.3	🟦	9.8	13.3
gas from gasifier - straw	9.3	7.3	5.7	4.0	12.9
biogas-processed-feed-in from:					
biogas maize	44.4	42.7	41.5	36.1	35.3
biogas cereals	44.8	43.3	28.1	37.0	36.4
biogas grass cuttings	23.3	17.6	12.7	7.2	16.8
biogas double cropping opt	34.0	26.7	🟦	16.4	27.0
biogas double cropping red.	38.5	32.2	🟦	23.4	32.6
biogas manure large	23.3	17.6	12.7	7.2	16.8
biogas other wastes	25.6	19.3	13.8	7.7	18.4

Note: data for upstream life cycles *only* (source: GEMIS 4.5), by-product allocation using LHV; **blue cells** indicate unsuitable options

As can be seen from this table, GHG emissions vary from approx. 1 kg/GJ_{out} for straw bales to 67 kg/GJ_{out} for 1st generation EtOH from grains, with significant differences between the environmental zones (and hence, countries). Differences are higher for air pollutants from bioenergy life cycles, as shown below.

Table 10 Air Emissions of bioenergy upstream life cycles in EU countries grouped into Environmental Zones, 2010

	CON	**ATC**	**MED**	**ATN**	**PAN**
SO_2eq [g/GJ_{output}]	**AT, PL**	**DE, FR, UK**	**ES, GR, IT, PT**	**FI, SE, EE, LT, LV**	**CZ, HU, SI, SK**
FAME	300	278	419	🟦	454
biogas maize	190	181	205	200	158
biogas cereals	194	186	135	207	167
biogas grass cuttings	67	40	42	36	42
biogas double cropping opt	159	109	🟦	109	152
biogas double cropping red.	197	152	🟦	165	186
biogas manure large	67	40	42	36	42
biogas manure small	80	42	45	38	45
biogas other wastes	67	40	42	36	42
EtOH maize grain	187	141	163	148	130
EtOH cereals grain	189	144	115	153	136
EtOH sorghum	🟦	🟦	69	🟦	🟦
wood pellets	26	7	8	5	8
SRC chips	35	29	🟦	33	39
waste wood + forest residue chips	8	7	8	8	8
miscanthus, reed bales	🟦	23	23	🟦	30
switchgrass bales	31	24	🟦	27	30
straw bales	8	6	6	6	9
gas from gasifier - black liquor	50	21	23	18	24
gas from gasifier - SRC	84	48	🟦	49	62
gas from gasifier - forest chips	50	21	23	18	24
gas from gasifier - miscanthus/reed	🟦	40	43	🟦	52
gas from gasifier - switchgrass	80	43	🟦	43	52
gas from gasifier - straw	50	19	21	16	52
biogas-processed-feed-in from:					
biogas maize	206	185	221	272	158
biogas cereals	209	190	151	279	167
biogas grass cuttings	82	44	57	109	42
biogas double cropping opt	175	113	🟦	182	152
biogas double cropping red.	213	156	🟦	238	186
biogas manure large	82	44	57	109	42
biogas other wastes	95	46	60	110	45

Note: data for upstream life cycles *only* (source: GEMIS 4.5), by-product allocation using LHV; **blue cells** indicate unsuitable options

Between environmental zones, SO_2-eq emissions vary by a factor of roughly 3, while between bioenergy life cycles, the range is larger (factor of 30).

Life cycle emissions of future bioenergy are subject to technology learning, so that results for 2030 are lower (see next table).

Table 11 *GHG emissions of bioenergy upstream life cycles in EU countries grouped into Environmental Zones, 2030*

	CON	**ATC**	**MED**	**ATN**	**PAN**
CO_2eq [kg/GJ_{output}]	**AT, PL**	**DE, FR, UK**	**ES, GR, IT, PT**	**FI, SE, EE, LT, LV**	**CZ, HU, SI, SK**
FAME	51.3	54.1	79.6	🟦	77.6
biogas maize	14.0	15.3	13.9	14.1	12.2
biogas cereals	14.3	15.7	11.5	14.5	23.4
biogas grass cuttings	8.8	9.4	6.8	7.0	8.1
biogas double cropping opt	15.3	14.8	🟦	12.4	14.5
biogas double cropping red.	18.4	18.9	🟦	17.4	17.8
biogas manure large	8.8	9.4	6.8	7.0	8.1
biogas manure small	10.6	11.4	7.9	8.1	9.6
biogas other wastes	8.8	9.4	6.8	7.0	8.1
ligno-EtOH - maize whole plant	22.0	22.2	21.6	21.0	22.2
ligno-EtOH - cereals whole plant	20.1	20.4	17.2	17.4	19.7
ligno-EtOH - sorghum whole plant	🟦	🟦	12.3	🟦	🟦
ligno-EtOH from straw	12.2	12.2	12.3	12.2	12.3
wood pellets	3.6	4.0	2.3	2.4	3.2
SRC chips	4.3	3.9	🟦	4.2	4.3
waste wood + forest residue chips	2.0	2.0	2.0	1.9	2.0
miscanthus, reed bales	🟦	3.2	2.8	🟦	9.4
switchgrass bales	3.2	3.4	🟦	3.1	3.5
straw bales	0.9	0.8	0.8	0.8	0.9
gas from gasifier - black liquor	8.5	9.0	6.4	6.6	7.8
gas from gasifier - SRC	11.0	11.2	🟦	9.2	10.5
gas from gasifier - forest chips	8.5	9.0	6.4	6.6	7.8
gas from gasifier - miscanthus/reed	🟦	10.6	7.5	🟦	15.9
gas from gasifier - switchgrass	10.3	11.1	🟦	8.4	9.9
gas from gasifier - straw	7.4	7.9	5.2	5.4	15.9
BtL from gasifier - SRC	8.9	7.1	🟦	8.8	8.9
BtL from gasifier - forest chips	6.0	6.0	5.9	6.0	6.0
BtL from gasifier - miscanthus/reed	🟦	7.8	7.0	🟦	15.4
BtL from gasifier - switchgrass	9.3	9.5	🟦	9.1	9.6
BtL from gasifier - straw	4.6	4.5	4.4	4.4	4.6
biogas-processed-feed-in from:					
biogas maize	22.9	25.4	18.3	18.9	19.5
biogas cereals	23.1	25.8	15.9	19.3	30.6
biogas grass cuttings	17.7	19.5	11.2	11.8	15.3
biogas double cropping opt	24.0	24.8	🟦	17.2	21.7
biogas double cropping red.	27.3	29.0	🟦	22.2	25.0
biogas manure large	17.7	19.5	11.2	11.8	15.3
biogas other wastes	19.4	21.4	12.2	12.9	16.8

Note: data for upstream life cycles *only* (source: GEMIS 4.5), by-product allocation using LHV; **blue cells** indicate unsuitable options

Table 12 Air Emissions of bioenergy upstream life cycles in EU countries grouped into Environmental Zones, 2030

	CON	**ATC**	**MED**	**ATN**	**PAN**
SO_2eq [g/GJ$_{output}$]	**AT, PL**	**DE, FR, UK**	**ES, GR, IT, PT**	**FI, SE, EE, LT, LV**	**CZ, HU, SI, SK**
FAME	250	255	403	🟦	413
biogas maize	87	94	91	91	72
biogas cereals	83	85	67	93	128
biogas grass cuttings	35	35	33	33	34
biogas double cropping opt	84	72	🟦	69	89
biogas double cropping red.	105	101	🟦	105	121
biogas manure large	35	35	33	33	34
biogas manure small	38	37	34	34	36
biogas other wastes	35	35	33	33	34
ligno-EtOH - maize whole plant	103	112	121	118	103
ligno-EtOH - cereals whole plant	110	84	66	74	71
ligno-EtOH - sorghum whole plant	🟦	🟦	103	🟦	🟦
ligno-EtOH - straw	103	103	103	103	103
wood pellets	7	7	5	6	6
SRC chips	21	20	🟦	19	28
waste wood + forest residue chips	8	7	7	7	8
miscanthus, reed bales	🟦	14	12	🟦	72
switchgrass bales	17	14	🟦	16	16
straw bales	6	5	4	4	8
gas from gasifier - black liquor	20	19	16	17	19
gas from gasifier - SRC	33	32	🟦	32	40
gas from gasifier - forest chips	20	19	16	17	19
gas from gasifier - miscanthus/reed	🟦	26	22	🟦	89
gas from gasifier - switchgrass	31	28	🟦	28	29
gas from gasifier - straw	18	16	14	14	89
BtL from gasifier - SRC	120	117	🟦	118	130
BtL from gasifier - forest chips	104	103	103	103	104
BtL from gasifier - miscanthus/reed	🟦	113	109	🟦	185
BtL from gasifier - switchgrass	122	119	🟦	121	121
BtL from gasifier - straw	102	100	100	100	104
biogas-processed-feed-in from:					
biogas maize	98	104	96	97	81
biogas cereals	94	95	73	99	137
biogas grass cuttings	47	45	38	39	43
biogas double cropping opt	95	82	🟦	75	98
biogas double cropping red.	117	111	🟦	111	130
biogas manure large	47	45	38	39	43
biogas other wastes	49	47	40	40	45

Note: data for upstream life cycles *only* (source: GEMIS 4.5), by-product allocation using LHV; **blue cells** indicate unsuitable options

3 Country-specific Comparisons of Selected Non-Renewable Electricity Generation Technologies

In this section, a brief comparison is made for non-renewable electricity generation technologies in selected EU countries, taking into account their full life cycles. The technical and emission data for the electricity generation systems were taken from the GEMIS database which offers a broad choice of steam turbines, gas turbines, and combined-cycle conversion systems for various fuels, and sizes.

For future coal and gas technologies, learning curves were included based on the prospective development of these technologies until 2030[10].

For oil-based power generation, no significant improvement is envisioned, as the share of this fuel in the overall generation mix in Europe will be reduced in the next decades.

For nuclear generation technologies, the potential improvements are still speculative, and the reference scenarios assume a drastic reduction of nuclear generation in Europe until 2030, so that **no** learning is assumed.

3.1 Country-specific Comparison of Coal Electricity Generation

The coal-to-electricity fuel-cycles in EU countries vary according to coal extraction, transport distances, powerplant efficiencies, and emission control technologies, as shown in Section 2.1. Also, fuel quality of domestic coals varies[11].

In the following table, lignite-fired steam-turbine powerplants in Bulgaria (BG), Estonia (EE), Germany (DE), Greece (GR), Hungary (HU), Romania (RO), and Turkey (TR) are compared for the emissions in 2005, and 2030, respectively.

In addition, hard coal-fired steam-turbine powerplants are shown for DE, Spain (ES), United Kingdom (UK), and an “average” EU import-coal plant.

For 2030, convergence of powerplant efficiencies, and air pollutant emission limits is assumed for all EU countries.

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[10] The background for the learning curves assumed here is given in DLR/IFEU/WI (2004) for fossil and non-biomass renewable systems, and for biomass systems in OEKO (2004).

[11] This is especially true for lignite (brown coal), while for hard coal, the ultimate analysis is quite similar.

Table 13 GHG emissions from lignite and coal electricity, 2005 and 2030

emissions in [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
lignite-BG-2005	1,115	1,081	1.09	0.032
lignite-BG-2030	876	849	0.85	0.024
lignite-DE-2005	1,248	1,236	0.04	0.039
lignite-DE-2030	921	913	0.03	0.025
lignite-EE-2005	1,043	999	1.30	0.046
lignite-EE-2030	957	917	1.20	0.041
lignite-GR-2005	1,063	1,030	1.04	0.031
lignite-GR-2030	959	929	0.94	0.028
lignite-HU-2005	1,035	999	0.28	0.100
lignite-HU-2030	899	891	0.26	0.007
lignite-RO-2005	1,115	1,081	1.09	0.032
lignite-RO-2030	874	847	0.85	0.024
lignite-TR-2005	935	918	0.34	0.030
lignite-TR-2030	809	794	0.30	0.026
coal-DE-2005	1,038	937	3.84	0.043
coal-DE-2030	784	742	1.66	0.014
coal-ES-2005	969	918	1.53	0.054
coal-UK-2005	994	906	3.17	0.050
coal-EU-import 2005	894	843	1.71	0.042
coal-EU-import 2030	780	741	1.51	0.014

Note: data incl. upstream life cycles (source: GEMIS 4.5)

GHG emissions from lignite-fired steam-turbine powerplants are quite close between countries in 2005, and also in 2030.

For air pollutant emissions, the results are quite different, as shown in the next table. Most countries can reduce air pollutants from lignite until 2030 by more than 90 %, and from coal by a factor of 3.

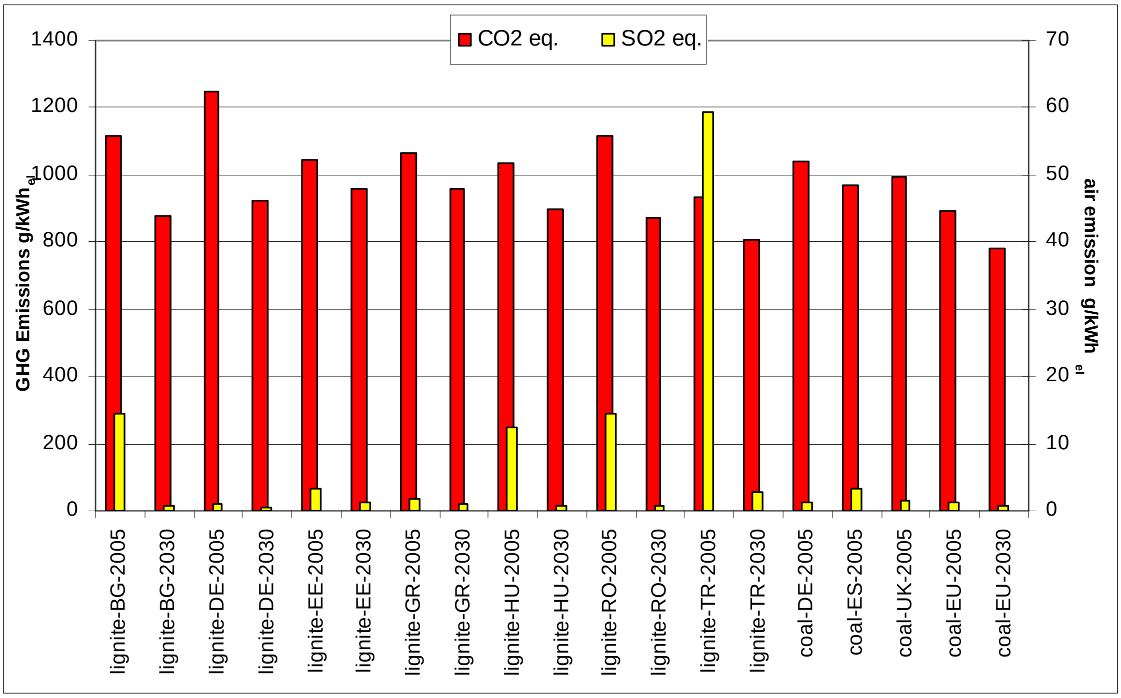
As a result, the huge differences between EU countries in 2005 become small in 2030.

Table 14 Air pollutants from lignite and coal electricity, 2005 and 2030

emissions [g/kWh$_{el}$]	**SO$_2$ eq.**	**SO$_2$**	**NO$_x$**	**partic. ***	**CO**	**NMVOC**
lignite-BG-2005	14.52	12.49	2.83	2.53	0.62	0.02
lignite-BG-2030	0.84	0.62	0.32	0.00	0.17	0.01
lignite-DE-2005	1.08	0.46	0.82	0.03	0.63	0.01
lignite-DE-2030	0.42	0.17	0.33	0.04	0.18	0.01
lignite-EE-2005	3.41	2.31	1.47	0.11	1.42	0.03
lignite-EE-2030	1.23	0.85	0.52	0.04	0.89	0.03
lignite-GR-2005	1.86	1.51	0.46	0.10	0.61	0.02
lignite-GR-2030	0.99	0.69	0.42	0.09	0.55	0.02
lignite-HU-2005	12.30	11.10	1.64	3.37	0.59	0.02
lignite-HU-2030	0.74	0.50	0.33	0.06	0.37	0.01
lignite-RO-2005	14.52	12.49	2.83	2.53	0.62	0.02
lignite-RO-2030	0.84	0.61	0.32	0.12	0.17	0.01
lignite-TR-2005	59.40	57.01	2.67	4.51	0.59	0.02
lignite-TR-2030	2.76	2.47	0.40	0.03	0.51	0.02
coal-DE-2005	1.17	0.67	0.67	0.04	0.15	0.03
coal-DE-2030	0.73	0.37	0.51	0.05	0.17	0.03
coal-ES-2005	3.41	0.71	3.85	0.02	0.59	0.02
coal-UK-2005	1.64	1.02	0.85	0.20	0.44	0.17
coal-EU-import 2005	1.27	0.70	0.79	0.08	0.29	0.04
coal-EU-import 2030	0.81	0.42	0.55	0.06	0.17	0.03

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM$_{10}$ (> 90%)

Figure 3 GHG and air pollutant emissions from lignite and coal electricity in EU countries, 2005 and 2030



Note: data incl. upstream life cycles (source: GEMIS 4.5)

This comparison shows that in 2005 (and some years later), quite high air pollutant emissions occur for lignite-based electricity especially in TR, but also for BG, EE, GR, HU, and RO. Until 2030, this will be reduced due to flue-gas cleaning in all countries. Compared to this, hard coal is more favorable in all countries, and will reduce its impacts even further until 2030.

3.2 Country-specific Comparison of Gas Electricity Generation

The natural gas-to-electricity life cycles in EU countries vary according to differences in gas extraction, import mixes, transport distances, powerplant efficiencies, and NO_X emission control technologies. Also, fuel quality of domestic natural gas varies[12]. The following table compares the emissions of gas-fired combined-cycle powerplants in EU countries in 2005, and 2030, respectively.

Table 15 GHG emissions from natural gas electricity, 2005-2030

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
DE 2005	427.6	398.3	1.05	0.018
DE 2030	397.0	376.1	0.79	0.009
ES 2005	414.7	400.4	0.40	0.017
ES 2030	374.4	360.4	0.50	0.009
NL 2005	411.0	397.2	0.37	0.018
NL 2030	351.5	346.0	0.14	0.008
UK 2005	463.5	439.6	0.78	0.020
UK 2030	408.4	385.9	0.85	0.010

Note: data incl. upstream life cycles (source: GEMIS 4.5)

The GHG emissions are rather close, while air pollutants show a large variation.

Table 16 Air pollutants from natural gas electricity, 2005-2030

emissions in [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic. ***	**CO**	**NMVOC**
DE 2005	0.51	0.01	0.71	0.01	0.38	0.04
DE 2030	0.22	0.01	0.30	0.01	0.25	0.04
ES 2005	1.02	0.01	1.46	0.01	0.32	0.03
ES 2030	0.19	0.01	0.25	0.01	0.21	0.04
NL 2005	1.05	0.01	1.50	0.01	0.33	0.03
NL 2030	0.12	0.01	0.16	0.01	0.16	0.03
UK 2005	1.26	0.01	1.79	0.01	0.49	0.04
UK 2030	0.29	0.01	0.40	0.01	0.29	0.04

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

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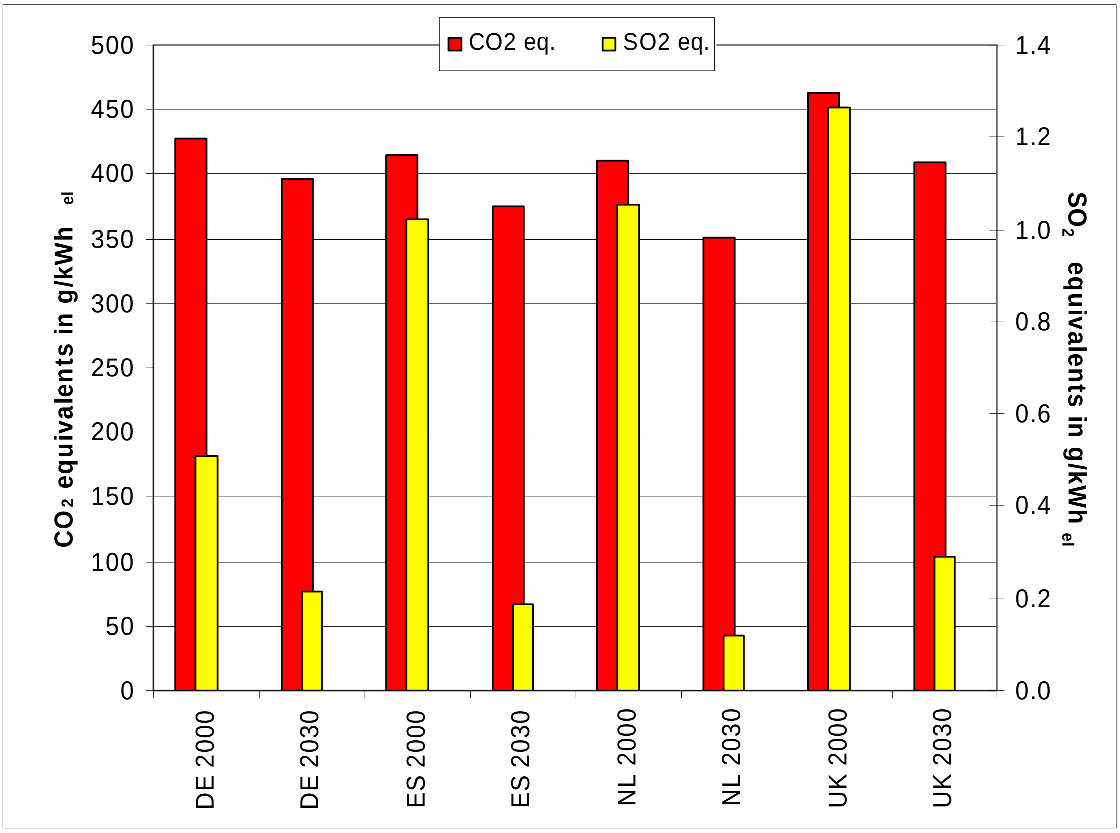
[12] Especially for sour and sweet gas, and high-LHV gas from North Sea/Russian compared to Dutch gas.

Figure 4 *GHG and air pollutant emissions from natural gas electricity, 2005-2030*



Note: data incl. upstream life cycles (source: GEMIS 4.5)

This comparison shows that in 2005 (and some years later), quite high air pollutant emissions occur for gas-CC-based electricity in ES, but also for NL and UK.

Until 2030, the emission pattern for air pollutants (given in SO_2 equivalents) narrows to a range of 0.1-0.3 g/kWh_{el}.

The GHG emissions are quite close, and will be reduced as the efficiencies of the gas-CC plants will increase until 2030.

3.3 Country-specific Comparison of Nuclear Electricity Generation

As mentioned before, life cycle emissions from uranium-based nuclear generation differs between countries, as both enrichment technologies, and powerplant mixes for delivering electricity to enrichment plants vary. This is shown in the following table.

Table 17 GHG emissions from nuclear electricity, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
CZ	71.0	68.3	0.08	0.003
DE	31.9	30.4	0.05	0.001
FR	7.5	7.1	0.01	0.000
UK	31.7	30.2	0.05	0.001
RO	69.1	65.5	0.13	0.002
RU	64.8	61.4	0.12	0.002
JP	47.9	46.0	0.06	0.002
CA	8.0	7.7	0.01	0.000
US	61.0	58.7	0.06	0.003
ZA	125.2	113.6	0.43	0.006

Note: data incl. upstream life cycles (source: GEMIS 4.5)

Similarly, the life cycle air pollutants emissions were calculated for the nuclear electricity generation in selected countries.

Table 18 Air pollutants from nuclear electricity, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic. ***	**CO**	**NMVOC**
CZ	0.26	0.07	0.26	0.01	0.07	0.02
DE	0.19	0.10	0.13	0.02	0.05	0.00
FR	0.02	0.01	0.02	0.00	0.02	0.00
UK	0.18	0.10	0.12	0.02	0.05	0.00
RO	0.57	0.38	0.24	0.07	0.10	0.01
RU	0.52	0.35	0.23	0.06	0.10	0.01
JP	0.21	0.08	0.18	0.02	0.06	0.01
CA	0.03	0.01	0.03	0.00	0.02	0.00
US	0.23	0.06	0.24	0.01	0.07	0.02
ZA	1.04	0.63	0.51	0.30	0.09	0.00

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

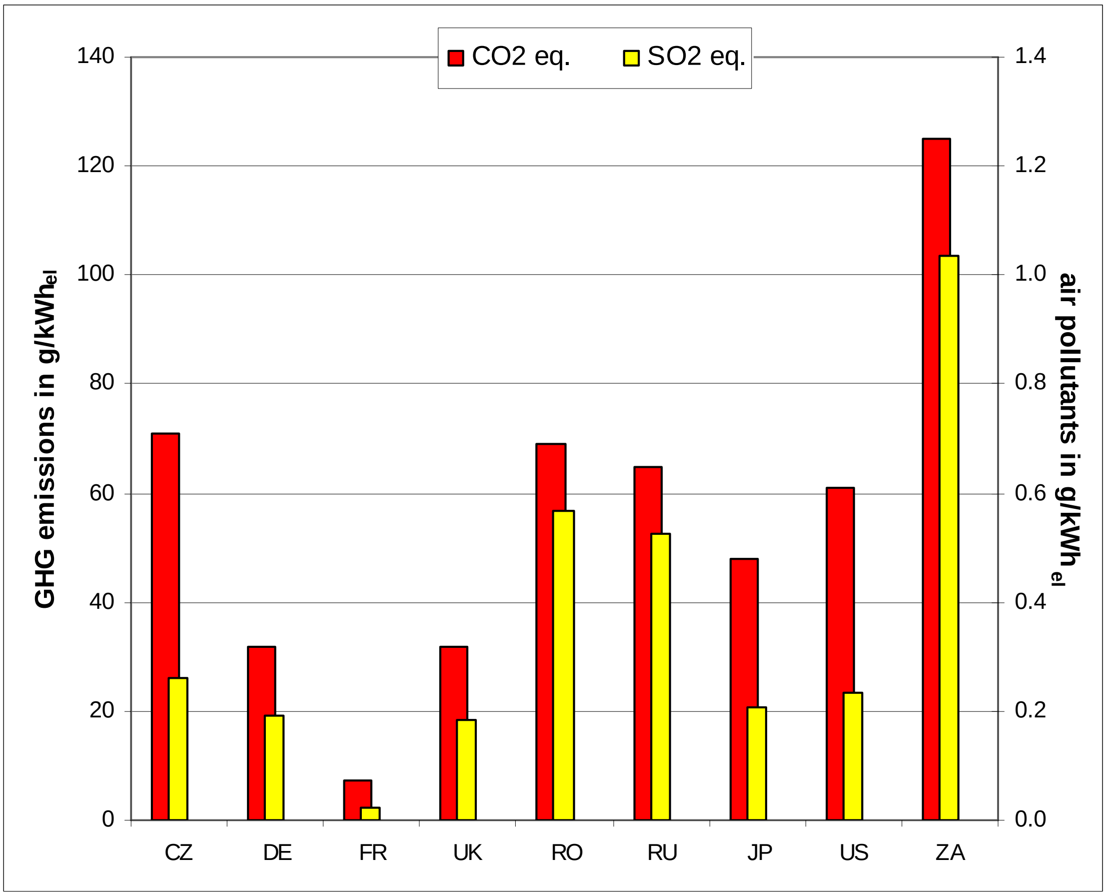
As for GHG emissions, air pollutants also depend on the electricity mix used to enrich uranium to the level used in nuclear plants, so that e.g. France with a high nuclear share has rather low emissions, while for South Africa with its coal-dominated generation mix and no SO_2 emission control, the nuclear life cycle emissions are high.

Similarly, nuclear generation in Russia (RU), the US and South Africa (ZA) use gas diffusion, and have high coal shares in the electricity feed.

Interestingly, the Canadian nuclear system also shows low emissions, as it uses nature-grade uranium as a fuel.

The following figure shows these results in graphical form.

Figure 5 GHG emissions and air pollutants from nuclear electricity, 2005



Note: data incl. upstream life cycles (source: GEMIS 4.5)

It should be noted that the life cycle emissions determined here **exclude** the so-called "back end" of the nuclear life cycle, as no valid data is available on the conditions of future final repositories for spent nuclear fuel.

Also, "recycling" of ^{239}Pu from spent fuel through reprocessing and MOX fuel fabrication is **not** included, as no adequate data is available on reprocessing. All nuclear systems are assumed to be operated in once-through mode, i.e. without reprocessing.

Furthermore, future nuclear systems might differ in their technical characteristics (e.g. larger sizes), use of different materials (e.g. ceramic "core catcher" for the European Pressurized Reactor), and higher enrichment.

The impacts of these future designs might well differ from the systems considered here.

4 Life Cycles for Renewable Energies

The life cycle of non-biomass renewable energies consists just of the material acquisition and manufacturing of the primary conversion systems (e.g. wind turbines, photovoltaic modules, solar-thermal collectors). Only for biomass, processes like extraction, fuel processing, and fuel combustion are of additional relevance (see OEKO 2004 for details).

As there is no country-specific information on the materials manufacturing of renewables, all upstream data come from the GEMIS database for Germany and were taken as representative for all EU countries[13].

Other renewables not considered here are wave power, and ocean thermal-electric (OTEC) systems which do not play a major role in the near future[14].

4.1 Non-Biomass Renewables

For hydropower, large run-of-river (ROR) plants are considered here, as well as small-scale hydro ROR plants without reservoir, and an existing small-scale hydro plant which is retrofitted with new turbines and generators to generate more electricity. No direct GHG emissions are assumed for all hydro plants due to European climate conditions, and the removal of biomass from inundated area before flooding.

For wind power, *on-shore* wind parks with 1.5-MW-sized turbines and future *offshore* wind parks with 5 MW turbines are considered.

For geothermal electricity, a closed-loop ORC system with 1,000 m depth for the wells is included which uses auxiliary electricity from the grid.

For solar electricity, a concentrating *solar-thermal* power generation system with parabolic troughs is assumed (Southern Spain/Mediterranean site), and three variants of photovoltaics (PV) – monocrystal, multicrystal, and amorphous modules on reference site with 1,000 h/a of sunlight.

The results from the LCA of these renewable options are shown below.

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[13] Processes such as cement plants and electric steel mills differ among EU countries, as well as the e.g. electricity input into these plants vary according to national generation mixes. Furthermore, these processes develop over time (e.g. more recycling, less energy intensity, lower emissions), in parallel to the evolution of national energy systems which deliver auxiliary inputs for the material conversion systems. Due to restricted time, no analysis of these effects was possible. It should be noted, though, that renewable energy technologies are traded between countries (e.g. wind mills from DK to ES, or from DE to UK), as well as materials like aluminium and steel are traded between countries. Therefore, the use of the German data instead of “true” EU country-specific data seems a valid approximation.

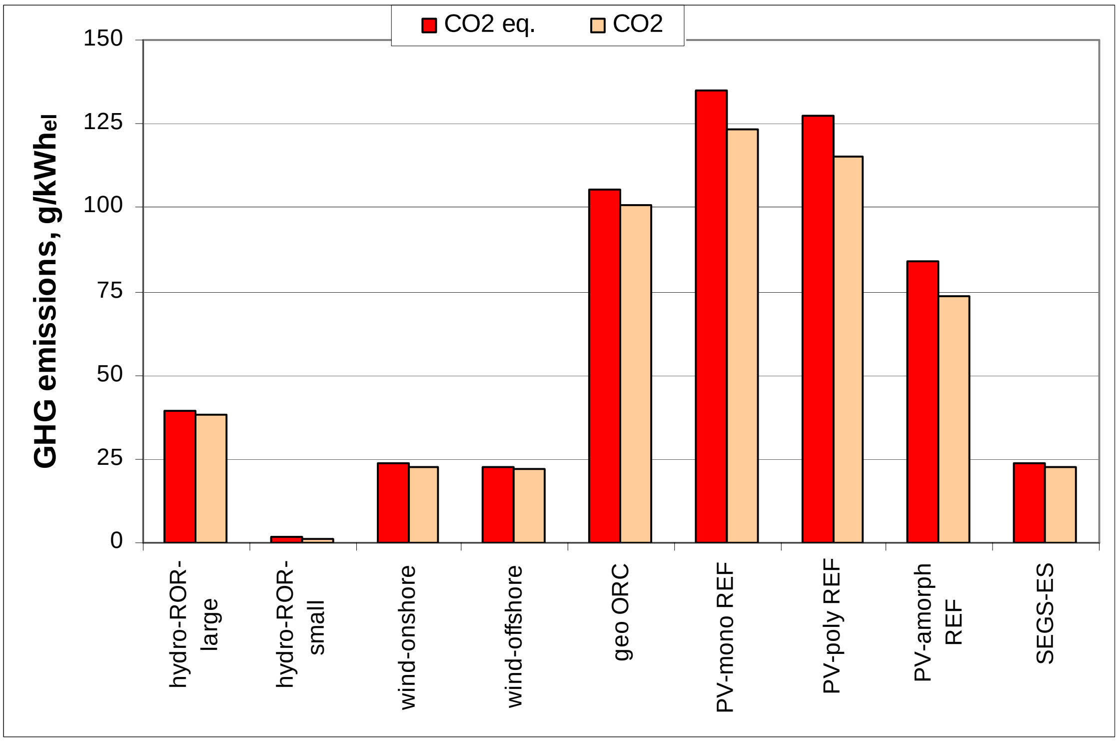
[14] Geothermal from “deep” well (hot dry rock) could become an important electricity and heat source, though. Still, the environmental impacts are very site-specific, and no LCA data is available (yet).

Table 19 GHG emissions from renewable (non-biomass) electricity, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
hydro-ROR-large	39.6	38.4	0.04	0.001
hydro-ROR-small	1.5	1.4	0.00	0.000
wind-onshore	23.6	22.5	0.04	0.000
wind-offshore	22.6	21.9	0.03	0.000
geo ORC	105.2	101.0	0.14	0.004
PV-mono REF	135.1	123.2	0.29	0.004
PV-poly REF	127.2	115.3	0.29	0.003
PV-amorph REF	83.8	73.6	0.17	0.002
SEGS-ES	23.5	22.5	0.04	0.000

Note: data incl. upstream life cycles (source: GEMIS 4.5); geothermal incl. auxiliary electricity

Figure 6 GHG emissions from renewable (non-biomass) electricity, 2005



Note: data incl. upstream life cycles (source: GEMIS 4.5)

As can bee seen, small-scale hydro has nearly no emission impacts, while large hydro, wind, and solar-thermal are in the medium-range of 20-40 g/kWh$_{el}$, i.e. they have similar emission factors as nuclear.

Geothermal ORC and solar PV options show 3-4 times higher GHG emissions due to auxiliaries (electricity for ORC, material and manufacturing of PV). Still, their emissions are far lower than those of e.g. gas-fired CC powerplants.

Besides GHG emissions, the life cycle of renewable electricity systems also cause air pollutants from manufacturing. The results are shown below.

Table 20 Air pollutants from renewable (non-biomass) electricity, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic. ***	**CO**	**NMVOC**
hydro-ROR-large	0.07	0.01	0.08	0.02	0.05	0.00
hydro-ROR-small	0.00	0.00	0.00	0.00	0.01	0.00
wind-onshore	0.05	0.01	0.05	0.01	0.09	0.00
wind-offshore	0.04	0.01	0.05	0.01	0.04	0.00
geo ORC	0.15	0.06	0.11	0.01	0.11	0.00
PV-mono REF	0.29	0.15	0.18	0.07	1.85	0.01
PV-poly REF	0.28	0.15	0.17	0.07	2.32	0.01
PV-amorph REF	0.25	0.14	0.13	0.07	0.35	0.01
SEGS-ES	0.05	0.01	0.05	0.01	0.07	0.00

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

4.2 Site- and Technology-Specific Variation for Solar and Geothermal Electricity

As can be seen from the tables and figures before, electricity from solar photovoltaics (PV) has a comparatively high emission pattern for sites in Germany.

Still, the same PV device could generate more electricity in a more “sunny” setting than the under the reference (German) conditions. Therefore, the average data for Germany (1,000 h/a) were extended to sites with 1,500 h/a (e.g., Italy), and 2,500 h/a (e.g., Spain) of direct sunlight.

Furthermore, solar-*thermal* electricity generation schemes are included for a Southern European site (Almeria in Spain) – a SEGS with parabolic trough, a solar tower plant with a concentrating mirror field, and a parabolic solar-“dish” mirror with a stirling engine.

Finally, two geothermal electricity plants are added to the comparison: a large open-loop geothermal steam-turbine (ST) plant in Italy (IT) with a small fossil CO_2 release, and a smaller-scale “binary” ORC system in Germany which uses a closed loop, but needs auxiliary electricity for pumping (1,000 m depth).

Table 21 GHG emissions from solar and geothermal electricity, 2005

emissios [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
PV-mono REF	135.1	123.2	0.29	0.004
PV-mono 1500 (IT)	90.1	82.2	0.20	0.002
PV-mono 2500 (ES)	54.0	49.3	0.12	0.001
PV-poly REF	127.2	115.3	0.29	0.003
PV-poly 1500 (IT)	84.8	76.9	0.19	0.002
PV-poly 2500 (ES)	84.8	76.9	0.19	0.002
PV-amorph REF	83.8	73.6	0.17	0.002
PV-amorph 1500 (IT)	55.9	49.1	0.11	0.002
PV-amorph 2500 (ES)	33.5	29.4	0.07	0.001
solar-thermal SEGS (ES)	23.5	22.5	0.04	0.000
solar-thermal tower (ES)	18.8	18.0	0.03	0.000
solar-thermal dish (ES)	72.0	63.1	0.38	0.001
geothermal conv (IT)	131.2	130.6	0.02	0.000
geothermal-ORC (DE)	105.2	101.0	0.14	0.004

Note: data incl. upstream life cycles (source: GEMIS 4.5)

As can be seen, the higher yields from more “sunny” sites reduce the life cycle emission impacts of solar PV systems significantly. All solar-*thermal* options compare favorably with PV, and ORC-based geothermal is also extremely low-emitting, while “conventional” geothermal with venting (small quantities) of fossil CO_2 is in the order of monocrystaline PV in the reference case.

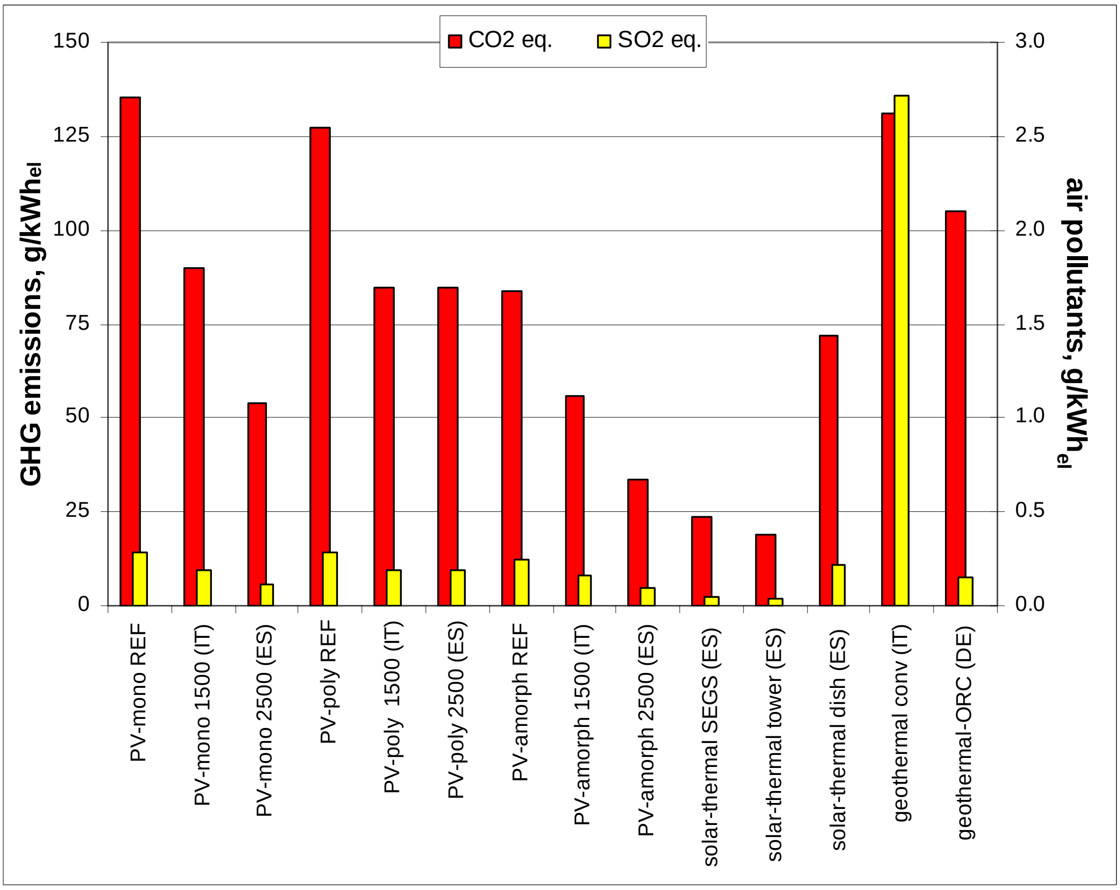
Table 22 Air pollutants from solar and geothermal electricity, 2005

emissios [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic. ***	**CO**	**NMVOC**
PV-mono REF	0.29	0.15	0.18	0.07	1.85	0.01
PV-mono 1500 (IT)	0.19	0.10	0.12	0.05	1.23	0.01
PV-mono 2500 (ES)	0.11	0.06	0.07	0.03	0.74	0.00
PV-poly REF	0.28	0.15	0.17	0.07	2.32	0.01
PV-poly 1500 (IT)	0.19	0.10	0.12	0.05	1.55	0.01
PV-poly 2500 (ES)	0.19	0.10	0.12	0.05	1.55	0.01
PV-amorph REF	0.25	0.14	0.13	0.07	0.35	0.01
PV-amorph 1500 (IT)	0.16	0.09	0.09	0.05	0.23	0.00
PV-amorph 2500 (ES)	0.10	0.06	0.05	0.03	0.14	0.00
solar-thermal SEGS (ES)	0.05	0.01	0.05	0.01	0.07	0.00
solar-thermal tower (ES)	0.04	0.01	0.04	0.01	0.06	0.00
solar-thermal dish (ES)	0.22	0.12	0.14	0.08	1.18	0.01
geothermal conv (IT)	2.72	2.71	0.02	0.01	0.07	0.00
geothermal-ORC (DE)	0.15	0.06	0.11	0.01	0.11	0.00

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

GHG emissions and air pollutants are shown jointly in the following figure.

Figure 7 GHG emissions and air pollutants from solar and geothermal electricity, 2005



Note: data incl. upstream life cycles (source: GEMIS 4.5)

4.3 Electricity from Biomass Residues

Due to the large variety of biomass fuels, and biomass electricity generation technologies, as well as country-specific conditions for forestry, agriculture, and energy crops, no “easy” comparison is possible.

Here, a comparison of selected biomass (cogeneration) technologies is given for biogenic residues and wastes[15].

The following table gives the GHG emissions for electricity from biogas cogeneration using the energy allocation approach to distribute the total emissions of the cogeneration systems to electricity and heat.

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[15] The data given here is for systems in Germany. This data is representative for all EU countries, as upstream life cycles for biomass residues do not differ between countries. Data on other EU countries is given for several electricity options for various bioenergy crops in Section 4.4.

As said before, the data reflect the **new EU methodology for GHG emission calculation for biomass**, as specified in the EU Directive on the Promotion of the Use of Energy from Renewable Sources (RES-D), and the EU Cogeneration Directive [16]

Note that for biogas systems, the theoretical amount of cogenerated heat is reduced by 50% to reflect unfavorable siting options of the cogenerator which are caused by the need to build the cogeneration plant directly at the biogas plant which often is far away from potential heat customers[17].

The cogeneration systems assumed to convert biogas into electricity are internal combustion engines (ICE) of different electric power rating (100, 200, 500, and 1000 kW_{el}). The biogas fermentation plants are either “small” (i.e., 300 m^3 of fermentation volume), or “large” (i.e. 1,500 m^3 of fermentation volume).

Table 23 GHG emissions for biogas (from residues) electricity, 2005

emissions [g/kWh_{el}]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
biogas-manure-small-ICE-cogen-100	219.5	203.6	0.25	0.034
biogas-manure-large-ICE-cogen-500	98.3	92.1	0.08	0.014
biogas-manure-large-ICE-cogen-1000	99.0	92.8	0.09	0.014
biogas-wastes-large-ICE-cogen-500	36.5	31.8	0.05	0.012
biogas-sewage-ICE-cogen-200	3.8	0.0	0.01	0.012
landfill-gas-ICE-cogen-200	3.6	0.0	0.01	0.011

Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5)

As can be seen, larger biogas plants with larger ICE cogenerators have lower emissions than small fermenters with smaller ICE systems, while small cogen systems for landfill- and sewage gas and biogas from organic waste have the lowest emissions.

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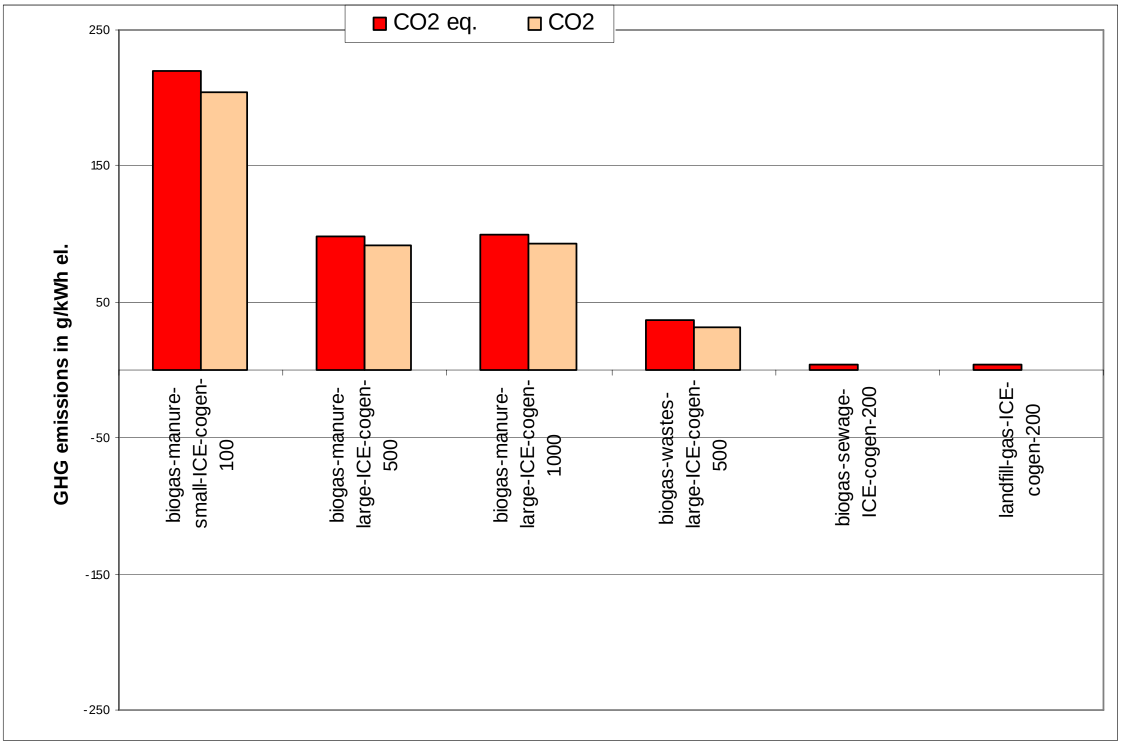
[16] For details, see footnotes 5 and 6.

[17] This problem can be overcome when biogas is processed and fed into gas distribution systems (“biomethane”) so that a biogas-driven cogenerator plant can be located close to heating demand centers. Still, a part of the cogenerated heat is needed for the fermentation process.

Figure 8 GHG emissions of biogas electricity from residues, 2005



Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5)

The corresponding air pollutant emissions are given in the following table.

Table 24 Air pollutants of biogas from residues electricity, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
biogas-manure-small-ICE-cogen-100	1.97	0.52	2.07	0.10	0.98	0.16
biogas-manure-large-ICE-cogen-500	0.95	0.25	0.99	0.05	0.49	0.08
biogas-manure-large-ICE-cogen-1000	0.99	0.26	1.05	0.05	0.24	0.08
biogas-wastes-large-ICE-cogen-500	0.55	0.19	0.52	0.02	0.38	0.03
biogas-sewage-ICE-cogen-200	0.33	0.00	0.48	0.01	0.10	0.01
landfill-gas-ICE-cogen-200	0.33	0.02	0.45	0.01	0.09	0.01

Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

The logist of emission results is the same as for the GHG emissions.

In addition to biogas from various biogenic waste streams, also woody residues from forestry and straw as an agricultural residue can be used to generate electricity.

The easiest option is *co-firing* in electricity-only (steam-turbine = ST) plants and cogeneration backpressure (BP) powerplants where 15% of the input energy could come from for woody residues (10for straw). Also, smaller-scale cogeneration technologies like steam engines (SE), organic rankine cycles (ORC), and stirling motors are included in the analysis – but as these technologies are "new", data on those is given for the year 2010.

Furthermore, solid biomass can be gasified in fixed-bed (FB) and circulating fluidized-bed (CFB), or pressurized fluidized-bed (pFB) gasifiers, and then used in internal combustion engines (ICE), and gas turbines (GT) for cogenerating electricity (and heat), or for electricity alone in combined-cycle (CC) plants. Data is given here for year 2010, as those technologies are still under development.

The life cycle emission results - here only for *net* emissions (assuming gas heating systems to be substituted) - are shown in the following table.

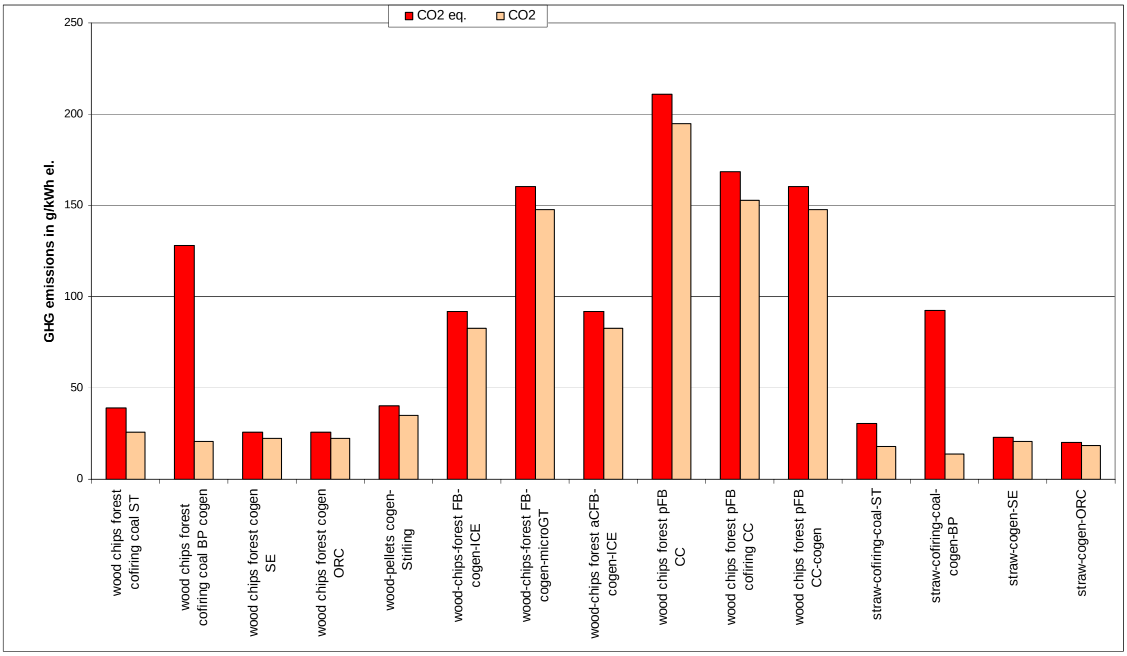
Table 25 GHG emissions from solid biomass electricity, 2010

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
wood chips forest cofiring coal ST	39.3	25.6	0.07	0.041
wood chips forest cofiring coal BP cogen	128.3	20.8	0.04	0.360
wood chips forest cogen SE	25.6	22.4	0.07	0.005
wood chips forest cogen ORC	25.8	22.5	0.07	0.005
wood-pellets cogen-Stirling	40.3	34.8	0.08	0.012
wood-chips-forest FB-cogen-ICE	91.9	82.6	0.16	0.019
wood-chips-forest FB-cogen-microGT	160.6	147.5	0.29	0.021
wood-chips forest aCFB-cogen-ICE	91.9	82.6	0.16	0.019
wood chips forest pFB CC	211.1	194.6	0.29	0.033
wood chips forest pFB cofiring CC	168.2	152.9	0.23	0.034
wood chips forest pFB CC-cogen	160.5	147.7	0.23	0.026
straw-cofiring-coal-ST	30.2	17.7	0.03	0.040
straw-cofiring-coal-cogen-BP	92.6	13.9	0.01	0.265
straw-cogen-SE	23.1	20.5	0.05	0.005
straw-cogen-ORC	20.0	18.4	0.03	0.003

Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5); ST = steam-turbine; BP = backpressure; SE = steam enginge; ORC = organic rankine cyvle; FB = fixed bed gasifier : ICE = internal combustion engine; GT = gas turbine; aCFB = atmospheric circulating fluidized-bed gasifier; pFB = pressurized fluidized-bed gasifier; CC = combined cycle

The co-firing in electricity-only coal-fired powerplants gives rather small GHG emissions, while the allocated electricity from co-firing in a coal cogeneration plant using fluidized-bed combustion has higher N_2O emissions. Note that only the emissions for the co-fired biomass are given, not the average emissions for the total generation which would include also the (major) part coming from the coal.

Figure 9 GHG emissions from solid biomass electricity, 2010



Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5); acronyms: see Table 25

Table 26 Air pollutants from solid biomass electricity, 2010

emissions [g/kWh$_{el}$]	**SO$_2$ eq.**	**SO$_2$**	**NO$_x$**	**partic.***	**CO**	**NMVOC**
wood chips forest cofiring coal ST	0.39	0.05	0.49	0.01	0.29	0.03
wood chips forest cofiring coal BP cogen	0.48	0.05	0.60	0.03	0.25	0.02
wood chips forest cogen SE	0.75	0.32	0.58	0.06	0.68	0.19
wood chips forest cogen ORC	0.76	0.33	0.59	0.06	0.70	0.20
wood-pellets cogen-Stirling	0.83	0.30	0.76	0.15	0.62	0.23
wood-chips-forest FB-cogen-ICE	0.61	0.07	0.77	0.05	0.73	0.03
wood-chips-forest FB-cogen-microGT	0.42	0.11	0.45	0.05	0.45	0.06
wood-chips forest aCFB-cogen-ICE	0.61	0.07	0.77	0.05	0.73	0.03
wood chips forest pFB CC	0.87	0.17	0.99	0.03	0.65	0.08
wood chips forest pFB cofiring CC	0.77	0.11	0.94	0.03	0.67	0.07
wood chips forest pFB CC-cogen	0.66	0.13	0.76	0.03	0.50	0.06
straw-cofiring-coal-ST	0.42	0.05	0.50	0.02	0.18	0.02
straw-cofiring-coal-cogen-BP	0.82	0.06	0.60	0.03	0.15	0.02
straw-cogen-SE	1.50	0.32	1.07	0.06	0.57	0.10
straw-cogen-ORC	0.68	0.15	0.49	0.02	0.26	0.05

Note: data incl. upstream life cycles, and allocation based on energy (source: GEMIS 4.5); * = predominantly PM$_{10}$ (> 90%); acronyms: see Table 25

4.4 Electricity from Bioenergy Crops in EU Countries

In addition to biomass residues, also dedicated bioenergy crops can be a source for electricity generation in Europe.

In the following, selected bioenergy crops grown in various EU countries for electricity generation are compared. They all use the same conversion technologies (similar to those for biogas and solid biomass residues discussed in Section 4.3), but differ in their “upstream” life cycles due to differences in soil, climate, and other factors influencing yields, and farming/harvesting practices in the EU countries (see Section 2.5). Furthermore, the emission credits for cogenerated heat differ somewhat due to differences in the national upstream fuel-cycles of the substituted gas-heating systems.

The life cycle emission results - here only for *net* emissions (assuming gas heating systems to be substituted by cogenerated heat) - are shown in the following table.

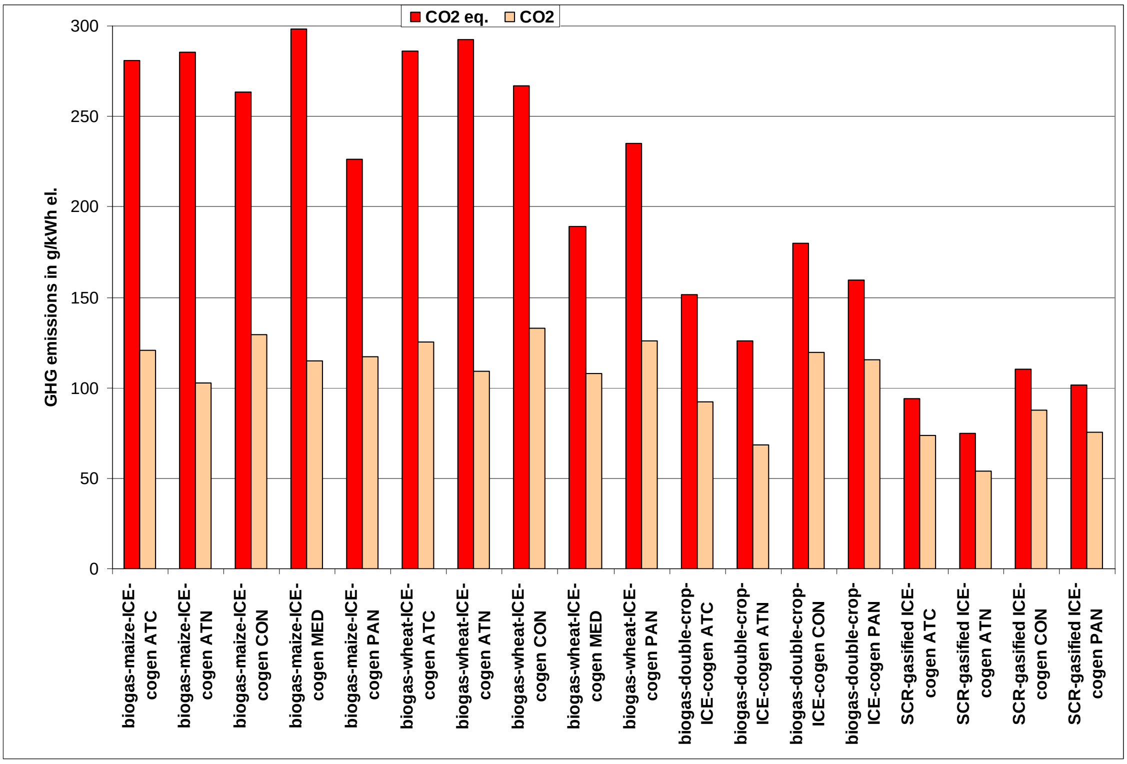
Table 27 GHG emissions for electricity from bioenergy crops, 2010

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
biogas-maize-ICE-cogen ATC	280.8	120.4	0.22	0.52
biogas-maize-ICE-cogen ATN	285.6	102.8	0.20	0.60
biogas-maize-ICE-cogen CON	263.5	129.3	0.23	0.44
biogas-maize-ICE-cogen MED	298.2	114.8	0.22	0.60
biogas-maize-ICE-cogen PAN	226.4	117.2	0.17	0.36
biogas-wheat-ICE-cogen ATC	286.0	125.5	0.23	0.52
biogas-wheat-ICE-cogen ATN	292.4	109.4	0.21	0.60
biogas-wheat-ICE-cogen CON	267.2	132.9	0.23	0.44
biogas-wheat-ICE-cogen MED	189.4	108.1	0.14	0.26
biogas-wheat-ICE-cogen PAN	235.2	125.8	0.17	0.36
biogas-double-crop-ICE-cogen ATC	151.3	92.4	0.10	0.19
biogas-double-crop-ICE-cogen ATN	125.8	68.2	0.06	0.19
biogas-double-crop-ICE-cogen CON	179.9	119.5	0.14	0.19
biogas-double-crop-ICE-cogen PAN	159.6	115.2	0.10	0.14
SRC-gasified ICE-cogen ATC	94.1	73.5	0.13	0.06
SRC-gasified ICE-cogen ATN	74.8	53.8	0.10	0.06
SRC-gasified ICE-cogen CON	110.4	87.5	0.15	0.07
SRC-gasified ICE-cogen PAN	101.4	75.5	0.11	0.08

Note: data for cogenerated electricity *only,* incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5) ; ICE = internal combustion engine; SRC = short-rotation coppice

As can be seen, electricity from biogas made from maize and wheat has higher CO_2 equivalent emissions than biogas from double cropping, and syngas from short-rotation coppice has even lower GHG emissions, as they need only minor fertilizer inputs.

Figure 10 *GHG emissions for electricity from bioenergy crops, 2010*



Note: data for cogenerated electricity *only,* incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5); acronyms see Table 27

As can be seen from the figure above, the *same* technologies give *different results* for the countries grouped into environmental zones, though:

Biogas electricity from maize has lowest emissions in the PAN zone, while for biogas electricity from wheat, the MED zone shows the lowest emissions.

For biogas electricity from double-cropping (which does not exist in MED), the ATN zone shows the lowest results, while the CON zone has the highest.

The air emissions for electricity from bioenergy crops were determined as well.

Table 28 Air pollutants for electricity from bioenergy crops, 2010

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
biogas-maize-ICE-cogen ATC	2.01	0.40	1.08	0.09	0.54	0.04
biogas-maize-ICE-cogen ATN	2.16	0.42	1.10	0.10	0.54	0.04
biogas-maize-ICE-cogen CON	2.08	0.54	1.19	0.10	0.57	0.04
biogas-maize-ICE-cogen MED	2.20	0.44	1.12	0.10	0.55	0.04
biogas-maize-ICE-cogen PAN	1.82	0.42	1.19	0.09	0.57	0.04
biogas-wheat-ICE-cogen ATC	2.04	0.42	1.11	0.10	0.55	0.04
biogas-wheat-ICE-cogen ATN	2.21	0.44	1.14	0.10	0.55	0.04
biogas-wheat-ICE-cogen CON	2.11	0.56	1.20	0.11	0.57	0.04
biogas-wheat-ICE-cogen MED	1.64	0.37	1.21	0.09	0.57	0.04
biogas-wheat-ICE-cogen PAN	1.90	0.44	1.26	0.10	0.59	0.04
biogas-double-crop-ICE-cogen ATC	1.43	0.26	1.03	0.06	0.53	0.03
biogas-double-crop-ICE-cogen ATN	1.43	0.26	1.04	0.06	0.53	0.03
biogas-double-crop-ICE-cogen CON	1.83	0.46	1.32	0.09	0.61	0.04
biogas-double-crop-ICE-cogen PAN	1.77	0.38	1.36	0.09	0.61	0.04
SCR-gasified ICE-cogen ATC	0.81	0.07	0.78	0.04	0.67	0.04
SCR-gasified ICE-cogen ATN	0.82	0.06	0.78	0.04	0.67	0.04
SCR-gasified ICE-cogen CON	1.04	0.21	0.88	0.06	0.69	0.04
SCR-gasified ICE-cogen PAN	0.90	0.09	0.82	0.05	0.68	0.04

Note: data for cogenerated electricity *only,* incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%); acronyms see Table 27

The air pollutant emissions follow the logic of the GHG emissions, although the differences between the technologies and zones are smaller.

With respect to further technology developments through learning, the GHG and air pollutant emissions were also calculated for the year 2030.

Note that the data for the 2030 systems are different from the 2010 ones – efficiencies, couple product ratios, yields etc. change over time.

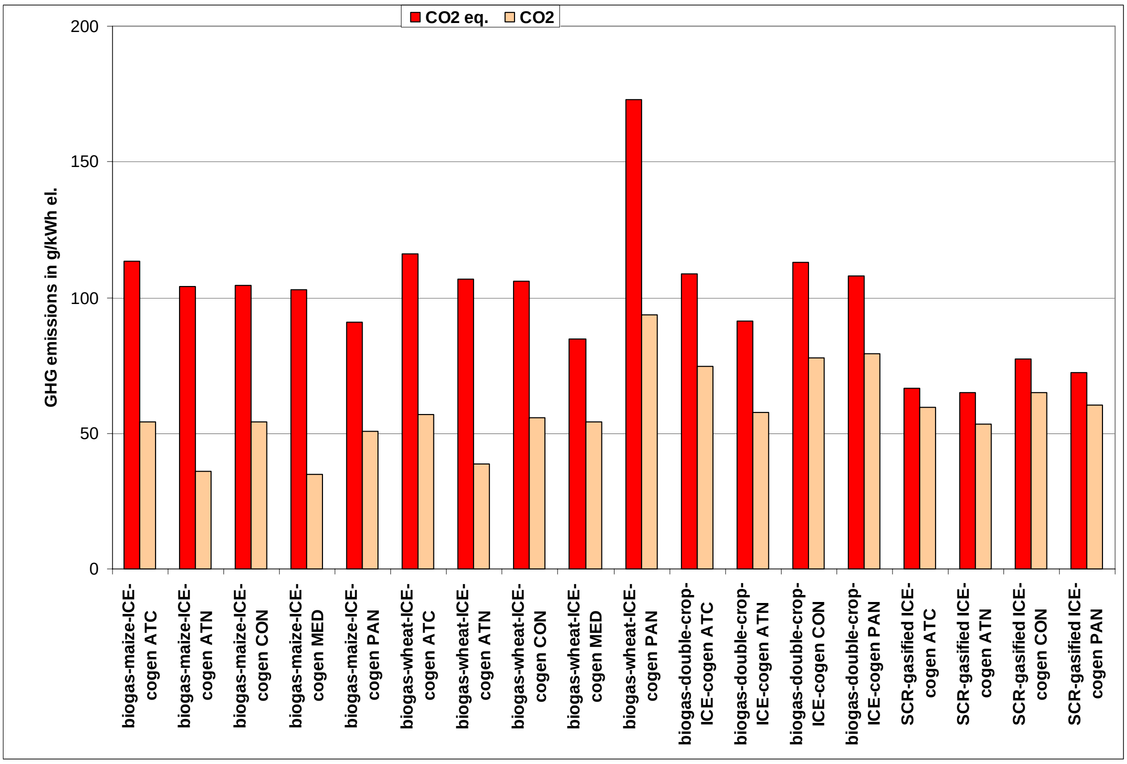
Due to these changes in bioenergy life cycles and their “background” energy infrastructures until 2030, the GHG emissions are reduced in all cases.

Table 29 GHG emissions for electricity from bioenergy crops, 2030

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
biogas-maize-ICE-cogen ATC	113.3	54.1	0.07	0.19
biogas-maize-ICE-cogen ATN	104.0	36.0	0.06	0.22
biogas-maize-ICE-cogen CON	104.4	54.2	0.09	0.16
biogas-maize-ICE-cogen MED	102.9	34.9	0.06	0.22
biogas-maize-ICE-cogen PAN	91.0	50.5	0.08	0.13
biogas-wheat-ICE-cogen ATC	116.2	57.0	0.07	0.19
biogas-wheat-ICE-cogen ATN	106.9	38.8	0.06	0.23
biogas-wheat-ICE-cogen CON	106.0	55.7	0.09	0.16
biogas-wheat-ICE-cogen MED	84.9	54.1	0.07	0.10
biogas-wheat-ICE-cogen PAN	173.1	93.5	0.15	0.26
biogas-double-crop-ICE-cogen ATC	108.9	74.7	0.07	0.11
biogas-double-crop-ICE-cogen ATN	91.4	57.6	0.06	0.11
biogas-double-crop-ICE-cogen CON	112.8	77.8	0.10	0.11
biogas-double-crop-ICE-cogen PAN	107.9	79.3	0.09	0.09
SCR-gasified ICE-cogen ATC	66.4	59.5	0.08	0.02
SCR-gasified ICE-cogen ATN	64.8	53.2	0.09	0.03
SCR-gasified ICE-cogen CON	77.2	64.9	0.12	0.03
SCR-gasified ICE-cogen PAN	72.5	60.4	0.11	0.03

Note: data for cogenerated electricity *only*, incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5); acronyms see Table 27

Figure 11 GHG emissions for electricity from bioenergy crops, 2030



Note: incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5)

Parallel to GHG emissions, also air pollutant emissions will change until 2030, as shown in the following table.

Table 30 Air pollutants for electricity from bioenergy crops, 2030

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
biogas-maize-ICE-cogen ATC	0,96	0,12	0,40	0,03	0,30	0,02
biogas-maize-ICE-cogen ATN	0,93	0,11	0,38	0,02	0,29	0,02
biogas-maize-ICE-cogen CON	0,90	0,13	0,45	0,03	0,31	0,02
biogas-maize-ICE-cogen MED	0,93	0,11	0,38	0,02	0,29	0,02
biogas-maize-ICE-cogen PAN	0,79	0,14	0,49	0,03	0,31	0,02
biogas-wheat-ICE-cogen ATC	0,89	0,13	0,41	0,03	0,30	0,02
biogas-wheat-ICE-cogen ATN	0,95	0,11	0,40	0,03	0,29	0,02
biogas-wheat-ICE-cogen CON	0,87	0,14	0,48	0,03	0,32	0,02
biogas-wheat-ICE-cogen MED	0,76	0,11	0,53	0,04	0,33	0,02
biogas-wheat-ICE-cogen PAN	1,21	0,24	0,78	0,07	0,37	0,03
biogas-double-crop-ICE-cogen ATC	0,80	0,14	0,55	0,04	0,34	0,02
biogas-double-crop-ICE-cogen ATN	0,77	0,12	0,54	0,04	0,33	0,02
biogas-double-crop-ICE-cogen CON	0,88	0,14	0,66	0,05	0,37	0,03
biogas-double-crop-ICE-cogen PAN	0,92	0,17	0,79	0,06	0,38	0,03
SCR-gasified ICE-cogen ATC	0,47	0,05	0,41	0,03	0,40	0,03
SCR-gasified ICE-cogen ATN	0,71	0,05	0,71	0,04	0,64	0,03
SCR-gasified ICE-cogen CON	0,72	0,06	0,72	0,04	0,65	0,03
SCR-gasified ICE-cogen PAN	0,76	0,06	0,73	0,04	0,64	0,03

Note: data for cogenerated electricity *only,* incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%); acronyms see Table 27

SO_2 equivalent emissions can be roughly halved for the biogas systems in all zones, while the (lower) emissions from SRC can be reduced by some 20%.

5 Electricity Generation in the EU 15

With the data for the average generation mix for electricity in the EU-15 Member States from the GEMIS database, the life cycle emissions were calculated for the year 2005, and 2030, respectively.

For the year 2005, the historic electricity generation data was used, while for the year 2030, the *Reference CAFE Scenario* from PRIMES was assumed[18].

The following tables summarize the results for greenhouse-gas emissions, and air pollutants in the year 2005.

Table 31 GHG emissions from electricity generation in the EU-15, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
AT	236.8	221.1	0.55	0.010
BE	311.1	296.3	0.45	0.015
DE	625.9	593.8	1.12	0.022
DK	675.4	640.4	1.13	0.031
ES	491.6	469.1	0.66	0.025
FI	399.3	377.7	0.70	0.019
FR	102.2	96.8	0.17	0.005
GR	880.6	850.5	0.95	0.027
IE	705.0	678.4	0.73	0.033
IT	561.8	537.7	0.75	0.024
LU	368.6	356.5	0.31	0.017
NL	619.8	594.4	0.74	0.028
PT	630.6	601.8	0.86	0.030
SE	75.8	73.3	0.07	0.003
UK	558.2	514.8	1.54	0.027
EU-15	**438.7**	**415.5**	**0.77**	**0.019**

Note: data incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5)

As the following figure indicates, there are more than half of the EU-15 Member States above the average EU-15-GHG emission factor for electricity, mainly due to their coal (hard coal and lignite) use.

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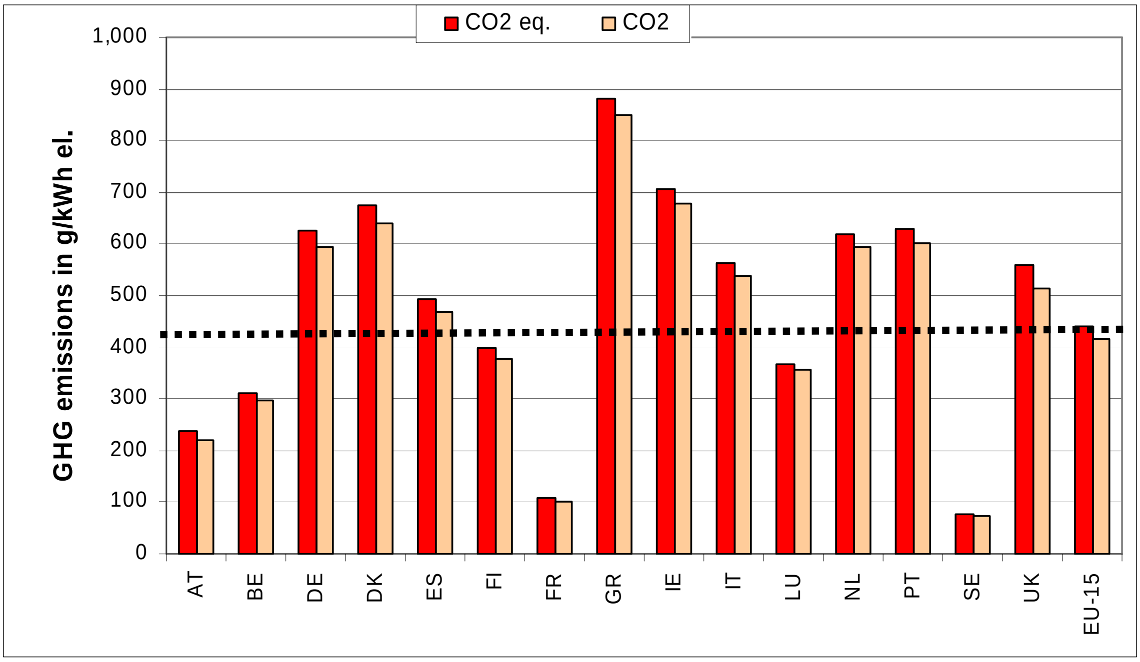
[18] The PRIMES model results are documented in EU-DG TREN (2003).

Figure 12 GHG emissions from electricity generation in the EU-15, 2005



Note: data incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5)

The following table summarizes the results for air pollutants.

Table 32 Air pollutants from electricity generation in the EU-15, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
AT	0.77	0.28	0.64	0.05	0.20	0.08
BE	1.07	0.38	0.96	0.05	0.22	0.05
DE	0.83	0.38	0.62	0.05	0.20	0.04
DK	1.27	0.59	0.95	0.06	0.35	0.13
ES	4.88	3.48	1.80	0.13	0.34	0.05
FI	1.71	0.76	1.13	0.19	0.42	0.28
FR	0.47	0.22	0.33	0.03	0.09	0.03
GR	12.96	11.01	2.27	0.70	0.53	0.07
IE	4.90	3.09	2.41	0.25	0.47	0.08
IT	4.51	3.28	1.69	0.20	0.41	0.11
LU	1.74	0.48	1.59	0.17	0.50	0.30
NL	1.59	0.54	1.42	0.12	0.41	0.13
PT	4.84	3.11	2.24	0.32	0.49	0.13
SE	0.38	0.17	0.24	0.05	0.10	0.07
UK	3.22	1.85	1.82	0.08	0.39	0.05
EU-15	**2.23**	**1.43**	**1.06**	**0.10**	**0.26**	**0.06**

*Note: data incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

In the future, the electricity generation mix in EU Member States will change – the following table gives the results for the 2030 Reference Case.

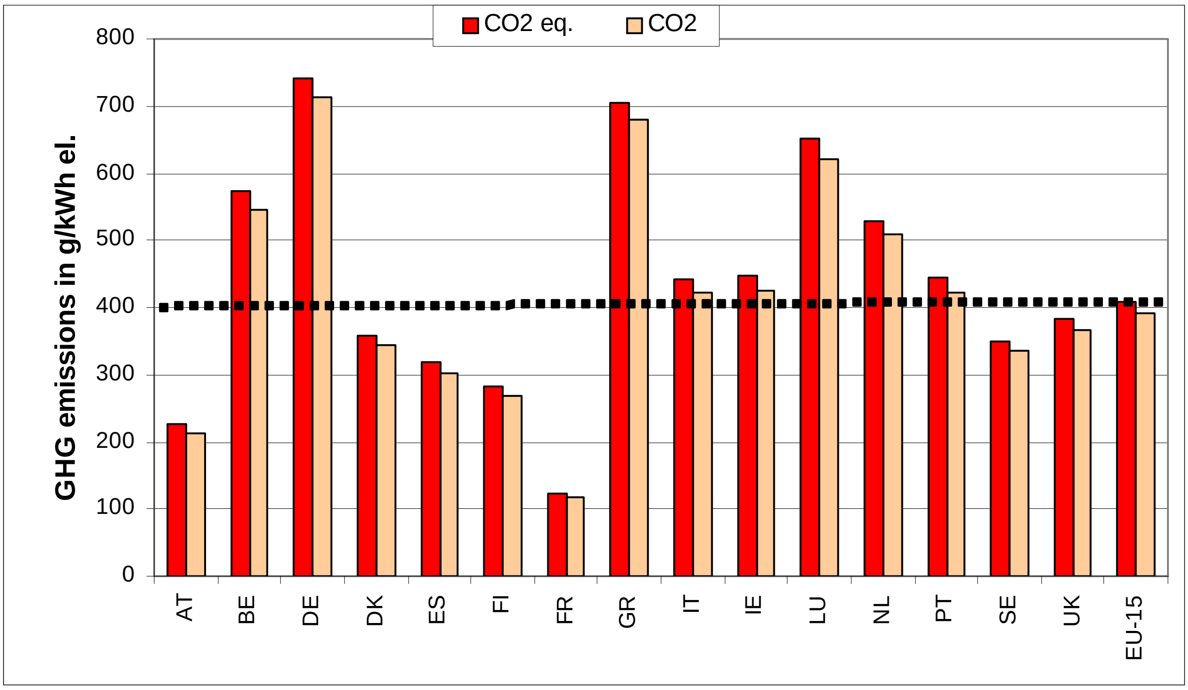
Table 33 GHG emissions from electricity generation in EU-15, 2030

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
AT	225.3	212.2	0.50	0.005
BE	574.6	546.1	1.07	0.013
DE	740.8	713.1	0.88	0.025
DK	358.9	345.1	0.46	0.011
ES	318.9	303.0	0.59	0.008
FI	283.4	269.0	0.51	0.009
FR	123.5	117.6	0.22	0.003
GR	704.2	679.4	0.81	0.021
IT	443.1	421.7	0.79	0.011
IE	447.4	426.5	0.78	0.010
LU	652.9	620.3	1.25	0.013
NL	527.7	508.5	0.58	0.020
PT	443.7	423.1	0.76	0.011
SE	350.3	335.7	0.53	0.008
UK	382.1	366.5	0.56	0.009
EU-15	**409.5**	**392.2**	**0.60**	**0.012**

Note: data incl. upstream life cycles and allocation based on energy (source: GEMIS 4.5)

Compared to the year 2005 level (Table 31 and Figure 12), GHG emissions will be **reduced** in the majority of EU-15 countries (AT, DK, ES, FI, GR, IE, IT, NL, PT, UK), but will **increase** in others (BE, DE, LU, SE), as in the reference scenario, nuclear generation is partially replaced by coal, and gas. The EU-15 average is slightly reduced, though. This is shown graphically in the following figure.

Figure 13 GHG emissions from electricity generation in EU-15, 2030



Note: data incl. upstream life cycles (source: GEMIS 4.5)

Electricity generation also emits air pollutants (see following table).

Table 34 Air pollutants from electricity generation in EU-15, 2030

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
AT	0.32	0.12	0.26	0.03	0.14	0.05
BE	0.82	0.33	0.63	0.08	0.30	0.11
DE	0.74	0.37	0.52	0.05	0.22	0.03
DK	0.48	0.12	0.49	0.03	0.33	0.21
ES	0.57	0.26	0.40	0.05	0.19	0.06
FI	0.81	0.38	0.55	0.07	0.20	0.08
FR	0.24	0.10	0.17	0.03	0.08	0.04
GR	1.46	1.07	0.53	0.10	0.45	0.07
IT	1.12	0.70	0.55	0.07	0.27	0.10
IE	0.44	0.20	0.35	0.03	0.20	0.03
LU	0.76	0.36	0.54	0.06	0.21	0.05
NL	1.11	0.42	0.89	0.10	0.33	0.14
PT	0.87	0.40	0.60	0.08	0.26	0.11
SE	0.57	0.25	0.41	0.06	0.16	0.08
UK	0.46	0.19	0.36	0.04	0.21	0.07
EU-15	**0.63**	**0.31**	**0.42**	**0.05**	**0.20**	**0.07**

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

Compared to 2005, the reference scenario will lead to a significant reduction of air pollutant emissions, mainly due to a more prominent use of natural gas, and emission control technologies in oil- and coal-fired powerplants: SO_2 equivalents are reduced by some 72%, (SO_2: - 78%; NO_x – 60%; particulates – 48%).

Only GR and IT where heavy fuel oil will still have a high generation share, SO_2 emissions from electricity will remain significantly above the EU-15 average.

6 Electricity Generation in the EU-10 Countries

With the data for the average generation mix for electricity in the *new* EU Member States (EU-10) from the GEMIS database, the life cycle emissions were calculated for 2005, and 2030, respectively.

As for the EU-15, the historic electricity generation data was used for the year 2005, while for the year 2030, the *Reference CAFE Scenario* from PRIMES was assumed.

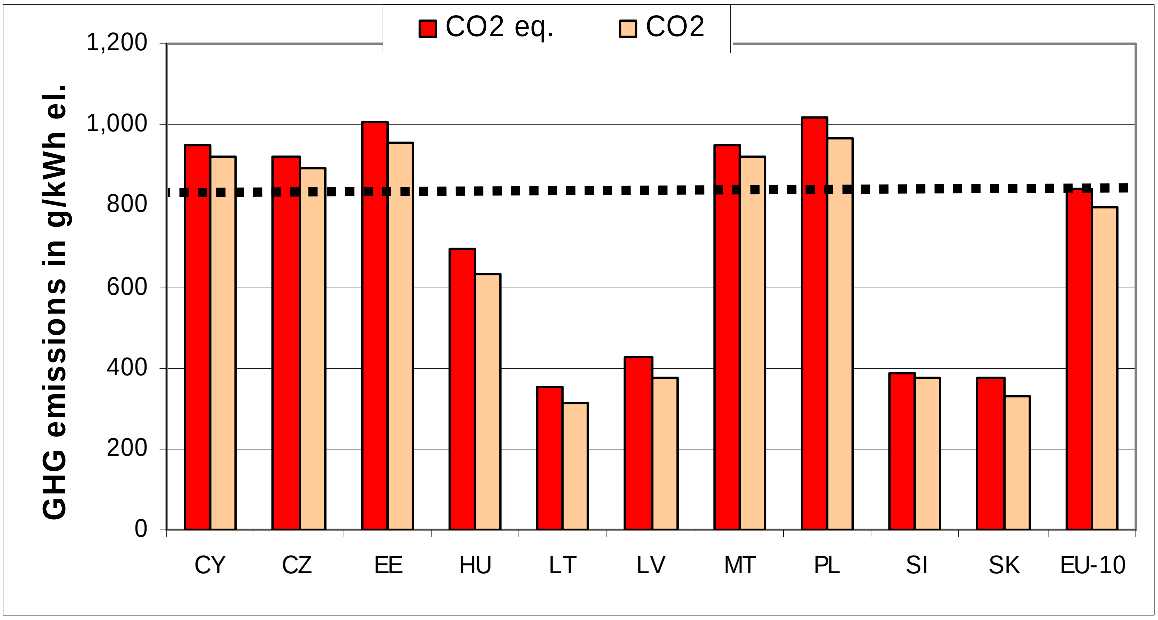
Table 35 GHG emissions from electricity generation in EU-10, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
CY	947.0	920.2	0.74	0.033
CZ	923.2	893.1	0.97	0.026
EE	1007.6	955.9	1.70	0.043
HU	657.7	630.0	0.66	0.042
LT	351.3	314.1	1.45	0.013
LV	424.1	377.9	1.79	0.016
MT	949.0	922.2	0.74	0.033
PL	1020.2	967.3	1.35	0.074
SI	389.1	377.6	0.35	0.012
SK	375.2	331.6	1.74	0.012
EU-10	**840.1**	**798.8**	**1.19**	**0.047**

Note: data incl. upstream life cycles (source: GEMIS 4.5)

Half of the new EU countries are above the EU-10 average GHG emissions, the other half is below (see following figure).

Figure 14 GHG emissions from electricity generation in EU-10, 2005



Note: data incl. upstream life cycles (source: GEMIS 4.5)

The high emissions result from the still massive shares of lignite generation, and relatively inefficient powerplants.

As for the GHG emissions, the high lignite share also influences the air pollutant emissions from electricity in the new EU Member States, especially in EE and PL, as shown below. Also high emissions occurred in CY, and MT where heavy fuel oil is the dominant fuel.

Table 36 Air pollutants from electricity generation in EU-10, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
CY	11.96	9.96	2.85	0.80	0.89	0.24
CZ	2.06	1.10	1.36	0.07	0.41	0.02
EE	14.43	12.29	2.39	1.60	1.02	0.10
HU	7.50	6.15	1.89	1.12	0.63	0.19
LT	1.74	0.33	2.00	0.09	0.59	0.19
LV	2.33	0.64	2.39	0.13	0.69	0.23
MT	12.03	9.99	2.90	0.81	0.90	0.25
PL	11.19	8.83	3.02	1.70	0.60	0.02
SI	4.62	3.77	1.16	0.74	0.28	0.03
SK	3.12	2.08	1.39	0.35	0.36	0.08
EU-10	**7.36**	**5.67**	**2.23**	**1.01**	**0.54**	**0.06**

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

The following table shows the GHG emissions from electricity generation in the EU-10 countries according to the 2030 reference scenario.

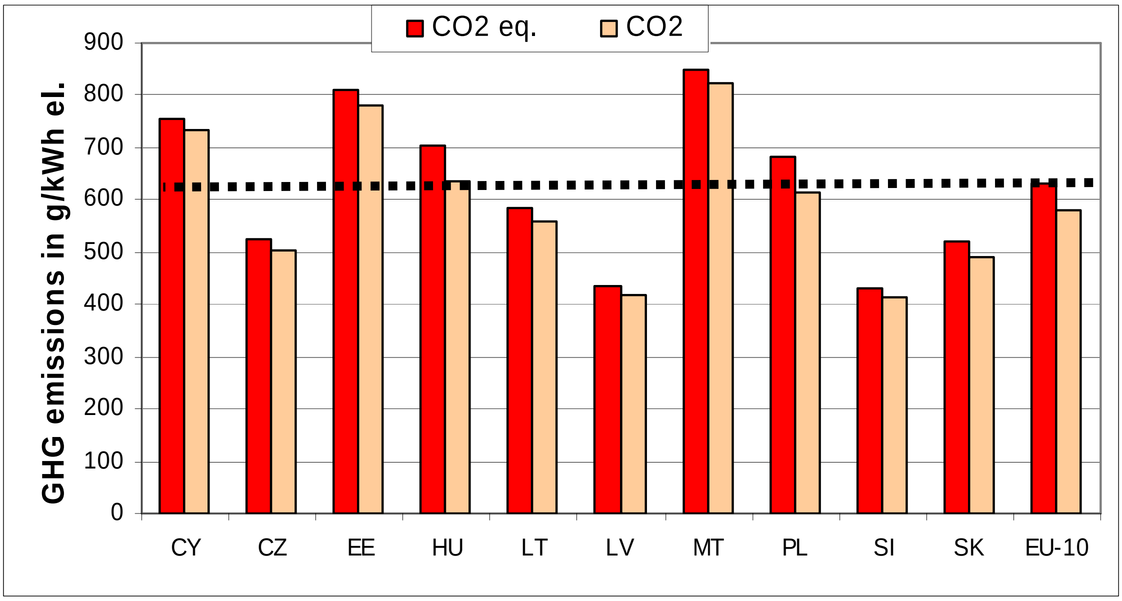
Table 37 GHG emissions from electricity generation in the EU-10, 2030

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
CY	755.3	733.6	0.58	0.028
CZ	526.0	501.4	0.92	0.012
EE	812.3	781.1	0.95	0.031
HU	664.1	632.9	1.13	0.018
LT	583.6	559.6	0.85	0.015
LV	433.9	416.9	0.58	0.012
MT	849.0	825.0	0.66	0.030
PL	646.1	613.6	1.11	0.023
SI	429.6	412.1	0.61	0.011
SK	518.3	491.4	1.00	0.013
EU-10	**609.6**	**580.4**	**1.02**	**0.019**

Note: data incl. full life cycle (source: GEMIS 4.5)

Compared to the year 2005 levels, GHG emissions will rise in LT, SI and SK, while remaining more or less constant in HU, and LV. Reductions will occur in mainly in CZ and PL, and to a lesser extend in CY, EE, and MT. The average EU-10 emissions will be reduced by 25%, though.

Figure 15 GHG emissions from electricity generation in the EU-10, 2030



Note: data incl. upstream life cycles (source: GEMIS 4.5)

According to the PRIMES REF scenario, the GHG emissions of *all* EU-10 countries will remain above the EU-15 average for 2030 – this is mainly due to the assumed increase of coal generation.

In contrast, the air pollutant emissions from electricity will be reduced drastically, with several countries getting close to the EU-15 average figures for 2030. Only CY and MT will have relatively high air emissions from electricity.

Table 38 Air pollutants from electricity generation in the EU-10, 2030

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
CY	2.90	1.69	1.71	0.22	0.83	0.20
CZ	0.65	0.28	0.53	0.04	0.21	0.03
EE	1.52	0.78	1.04	0.19	0.91	0.07
HU	1.93	1.39	0.74	0.10	0.31	0.10
LT	1.29	0.52	1.10	0.12	0.51	0.07
LV	1.59	0.92	0.92	0.16	0.45	0.05
MT	2.96	1.92	1.47	0.24	0.81	0.22
PL	0.83	0.42	0.59	0.09	0.30	0.03
SI	0.99	0.38	0.88	0.09	0.43	0.06
SK	1.01	0.43	0.83	0.09	0.39	0.05
EU-10	**1.01**	**0.54**	**0.67**	**0.09**	**0.32**	**0.04**

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

7 Electricity Generation in New Member and Candidate States

With the data for the average generation mix for electricity in the EU New Member and Candidate States from the GEMIS database, the life cycle emissions were calculated for the year 2005, and 2030, respectively.

The following table summarizes the results for greenhouse-gas emissions.

Table 39 GHG emissions from electricity generation in BG, RO, TR, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
BG	550.9	523.8	0.96	0.017
RO	633.2	600.4	1.17	0.020
TR	615.9	589.8	0.85	0.022

Note: data incl. upstream life cycles (source: GEMIS 4.5)

The GHG emissions are relatively close to each other. Somewhat larger differences exist for air pollutant emissions from electricity in these countries.

Table 40 Air pollutants from electricity generation in BG, RO, TR, 2005

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates**	**CO**	**NMVOC**
BG	6.20	4.97	1.66	0.95	0.41	0.04
RO	6.42	4.80	2.28	0.99	0.63	0.12
TR	20.54	19.11	1.80	1.46	0.53	0.08

Note: data incl. upstream life cycles (source: GEMIS 4.5)

Table 41 GHG emissions from electricity generation in BG, RO, TR, 2030

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
BG	533.1	509.6	0.86	0.012
RO	458.3	442.5	0.52	0.013
TR	452.6	431.3	0.77	0.012

Note: data incl. upstream life cycles (source: GEMIS 4.5)

Table 42 Air pollutants from electricity generation in BG, RO, TR, 2030

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**particulates**	**CO**	**NMVOC**
BG	0.72	0.34	0.55	0.07	0.28	0.04
RO	2.26	1.32	1.30	0.30	0.54	0.10
TR	1.14	0.80	0.47	0.04	0.28	0.04

Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)

Summary: Electricity Generation in the EU-15 to EU-28

With the data for the average generation mix for electricity in the EU-27 Members and Turkey as a candidate state, life cycle emissions were calculated for the year 2005, and 2030, respectively for the EU-15, EU-10, EU-27, and EU-28, respectively.

The following table summarizes the results for greenhouse-gas emissions.

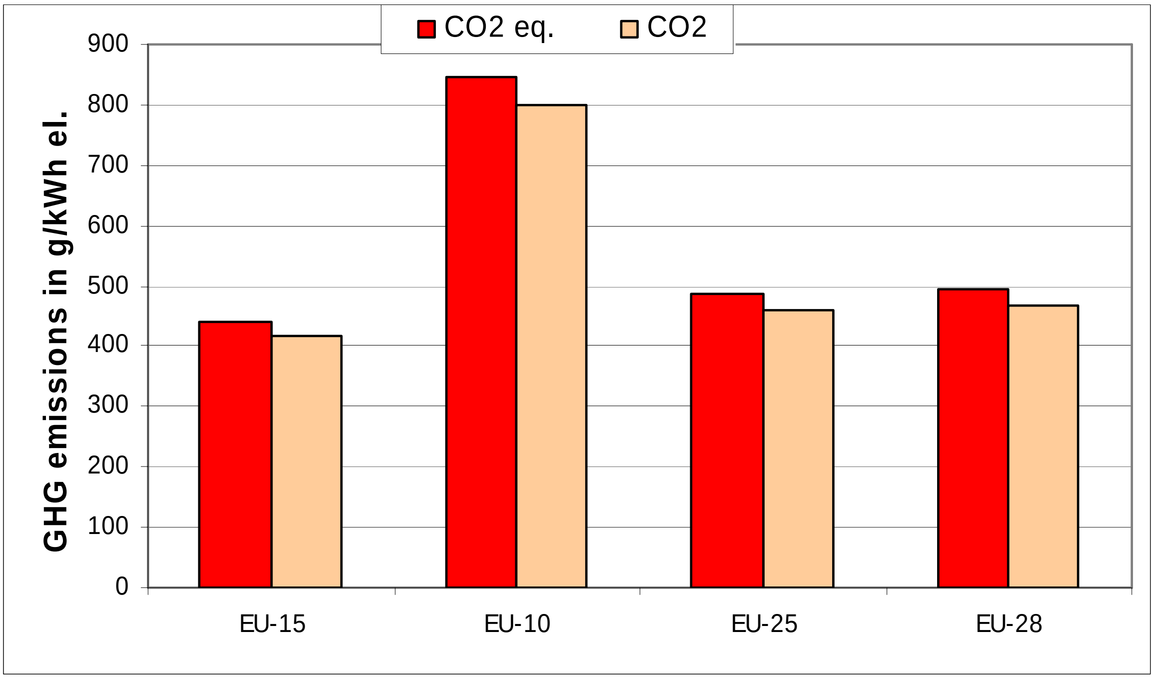
Table 43 GHG emissions from electricity generation in EU-15 to 28, 2005

emissions [g/kWh$_{el}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
EU-15	438.7	415.5	0.77	0.019
EU-10	840.1	798.8	1.19	0.047
EU-27	483.7	458.5	0.82	0.022
EU-28	492.4	466.9	0.83	0.022

Note: data incl. upstream life cycles (source: GEMIS 4.5)

The following figure shows that the new EU Member States slightly raise the average (EU-27) GHG emissions from electricity, and with BG + RO and Turkey, the average would get higher still.

Figure 16 GHG emissions from electricity generation in EU-15 to 28, 2005



Note: data incl. upstream life cycles (source: GEMIS 4.5)

As regards air pollutants, the overall emissions are as follows.

Table 44 Air pollutants from electricity generation EU-15 to 28, 2005

emissions [g/kWh$_{el}$]	SO$_2$ eq.	SO$_2$	NO$_x$	partic.*	CO	NMVOC
EU-15	2.23	1.43	1.06	0.10	0.26	0.06
EU-10	7.36	5.67	2.23	1.01	0.54	0.06
EU-25	2.81	1.90	1.19	0.20	0.29	0.06
EU-28	3.62	2.68	1.24	0.27	0.31	0.06

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM$_{10}$ (> 90%)*

In the future, the GHG emissions for the aggregated EU electricity generation would change, as the following table and figure show.

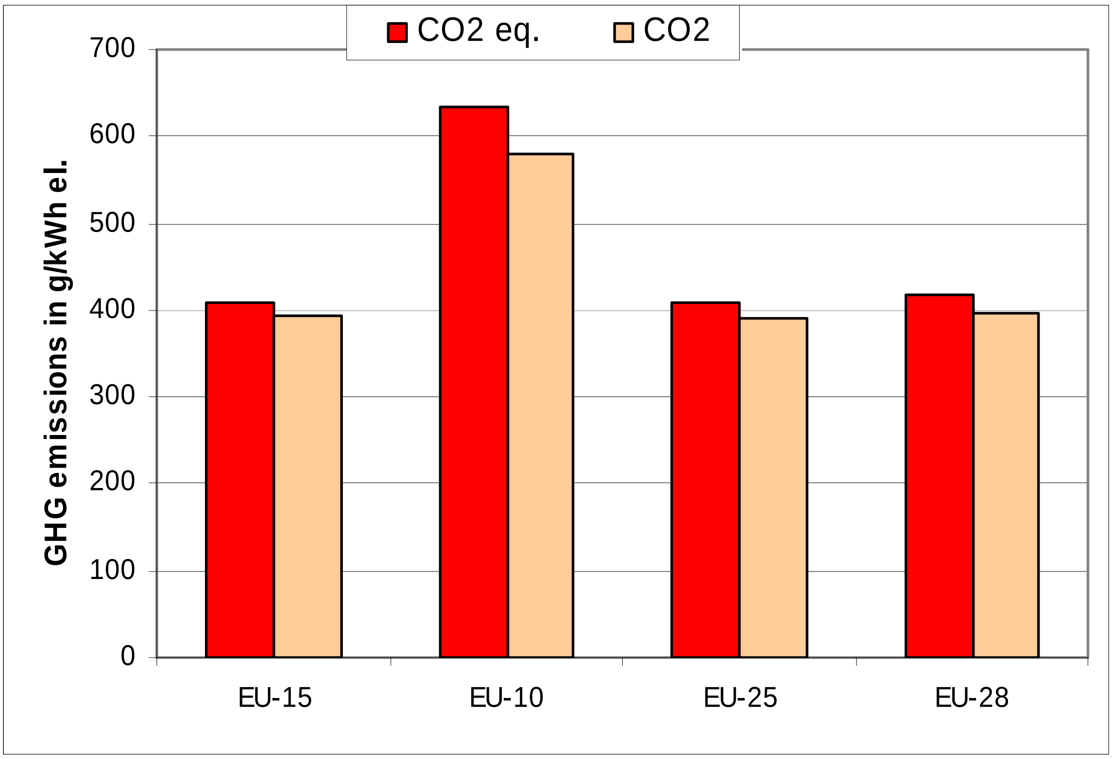
Table 45 GHG emissions from electricity generation EU-15 to 28, 2030

emissions [g/kWh$_{el}$]	CO$_2$ eq.	CO$_2$	CH$_4$	N$_2$O
EU-15	409.5	392.2	0.60	0.012
EU-10	609.6	580.4	1.02	0.019
EU-25	406.7	389.6	0.60	0.011
EU-28	413.6	396.1	0.61	0.011

Note: data incl. upstream life cycles (source: GEMIS 4.5)

Compared to 2005, the GHG emissions of the EU would be *reduced* by some 15%, with a range of -7% for the EU-15 and -27% for the EU-10 to -16% for the EU-27, and EU-28 as well, as can be seen from the following figure.

Figure 17 GHG emissions from electricity generation EU-15 to 28, 2030



Note: data incl. upstream life cycles (source: GEMIS 4.5)

The future air pollutant emissions from the aggregated EU electricity generation according to the reference 2030 scenario are given below.

Table 46 Air pollutants from electricity generation EU-15 to 28, 2030

emissions [g/kWh$_{el}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
EU-15	0.63	0.31	0.42	0.05	0.20	0.07
EU-10	1.01	0.54	0.67	0.09	0.32	0.04
EU-25	0.66	0.32	0.45	0.05	0.22	0.06
EU-28	0.73	0.39	0.47	0.06	0.23	0.06

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

As compared to 2005, the air pollutants could be reduced by 2030 by some 70%, with a range of -67% for the EU-15, - 82% for EU-10 to -72% for EU-28.

8 Life Cycle Emissions for Selected Heating Systems

In addition to electricity (co-)generation, energy is used in Europe also for heating – in residential and commercial buildings, and for process heat in industry.

In the following, a brief comparison of life cycle emissions for selected heating systems is given.

As before, the country grouping into environmental zones (see Section 2.5) is used.

First, fossil and biomass-residue heating systems are analyzed, and then heating systems for bioenergy crops.

8.1 Emissions from Fossil and Biomass Residue Heating

Heating systems are in the 10 kW_{th} range for natural gas, light oil, and wood pellets, and in the 50 kW_{th} range for wood-chips.

Wood pellets and chips are residues from wood industry (sawdust), and forest operations, respectively.

Table 47 GHG emissions from fossil and biomass residue heat, 2010

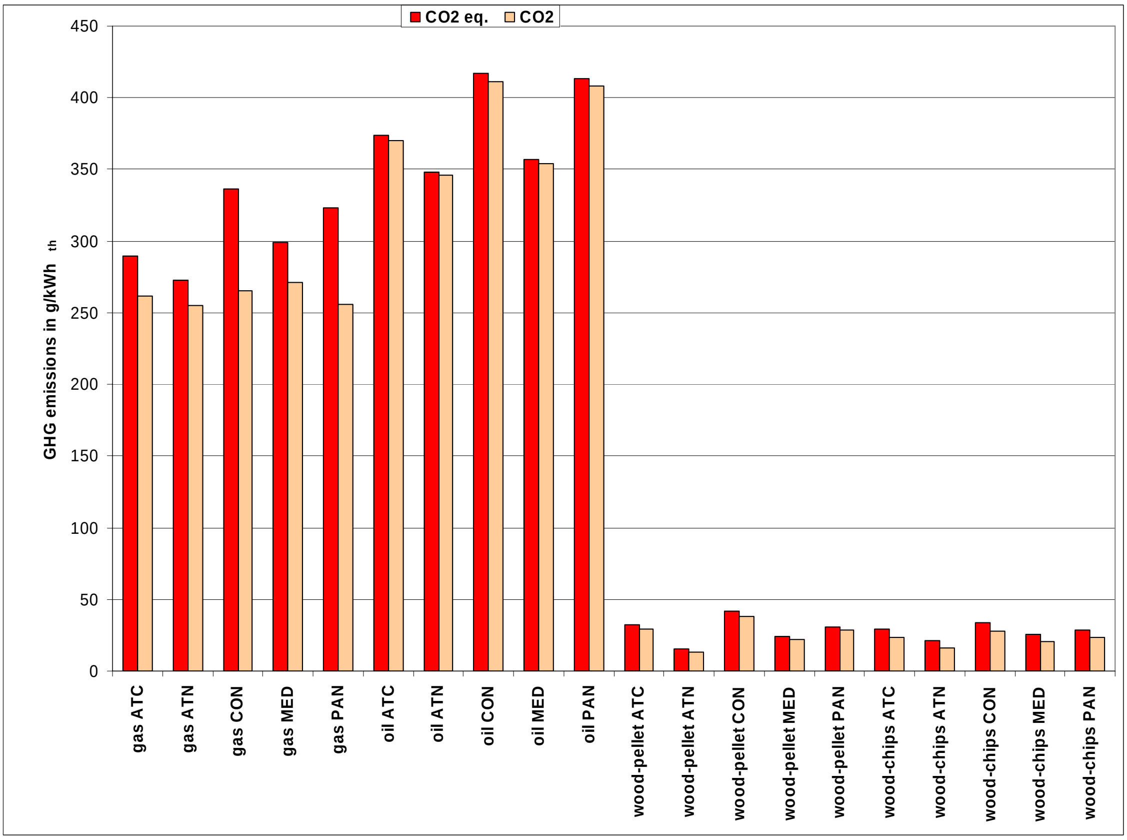
emissions [g/kWh_{th}]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
gas ATC	289.5	261.8	1.17	0.002
gas ATN	272.4	255.0	0.73	0.002
gas CON	336.4	265.0	3.07	0.003
gas MED	299.4	271.5	1.17	0.003
gas PAN	323.1	255.5	2.91	0.002
oil ATC	373.9	370.3	0.10	0.004
oil ATN	348.0	345.6	0.06	0.003
oil CON	417.3	410.9	0.21	0.005
oil MED	356.8	353.9	0.08	0.003
oil PAN	413.4	408.0	0.18	0.004
wood-pellet ATC	32.6	29.6	0.06	0.006
wood-pellet ATN	15.6	13.3	0.03	0.005
wood-pellet CON	41.9	38.3	0.07	0.007
wood-pellet MED	24.4	21.7	0.04	0.006
wood-pellet PAN	31.1	28.4	0.04	0.006
wood-chips ATC	29.4	23.8	0.17	0.006
wood-chips ATN	21.6	16.3	0.16	0.006
wood-chips CON	33.8	28.0	0.18	0.006
wood-chips MED	25.7	20.2	0.16	0.006
wood-chips PAN	28.9	23.4	0.16	0.006

Note: data incl. upstream life cycles (source: GEMIS 4.5)

The life cycles of gas and oil heating systems emit 300-400 g CO_2-eq/kWh_{th}, while heating systems for wood residues emit only 15-40 g CO_2-eq/kWh_{th}.

Thus, GHG reductions of approx. 90% could be achieved in choosing biomass heating systems instead of fossil ones (see following figure).

Figure 18 GHG emissions from fossil and biomass residue heat, 2010



Note: data incl. upstream life cycles (source: GEMIS 4.5)

The air pollutant emissions of fossil and biomass residue heating systems are given in the following table,

Table 48 Air pollutants from fossil and biomass residue heat, 2010

emissions [g/kWh$_{th}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
gas ATC	0.16	0.01	0.21	0.01	0.15	0.06
gas ATN	0.13	0.01	0.17	0.01	0.13	0.10
gas CON	0.22	0.05	0.24	0.01	0.16	0.09
gas MED	0.24	0.02	0.31	0.01	0.20	0.03
gas PAN	0.15	0.01	0.19	0.01	0.14	0.06
oil ATC	0.51	0.35	0.23	0.03	0.21	0.07
oil ATN	0.67	0.53	0.21	0.02	0.20	0.07
oil CON	0.84	0.60	0.33	0.04	0.28	0.12
oil MED	0.75	0.59	0.24	0.02	0.20	0.08
oil PAN	1.10	0.85	0.34	0.05	0.24	0.10
wood-pellet ATC	0.43	0.16	0.38	0.08	0.30	0.07
wood-pellet ATN	0.42	0.15	0.37	0.08	0.30	0.07
wood-pellet CON	0.58	0.26	0.43	0.09	0.31	0.07
wood-pellet MED	0.45	0.17	0.38	0.08	0.31	0.07
wood-pellet PAN	0.44	0.17	0.38	0.08	0.30	0.07
wood-chips ATC	0.47	0.13	0.47	0.17	0.48	0.14
wood-chips ATN	0.47	0.13	0.46	0.17	0.48	0.14
wood-chips CON	0.54	0.18	0.50	0.17	0.49	0.14
wood-chips MED	0.48	0.14	0.47	0.17	0.48	0.14
wood-chips PAN	0.48	0.14	0.47	0.17	0.48	0.14

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

SO_2 equivalent emissions from woody residues are slightly lower than those from oil, while about 3 times higher than those from natural gas.

The particulate emissions – mainly PM_{10} - from biomass residue heating are several times higher than those from the fossil systems, though.

With respect to longer-term developments, the following table gives the life cycle emissions for the year 2030.

Table 49 GHG emissions from fossil and biomass residue heat, 2030

emissions [g/kWh$_{th}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
gas ATC	277.5	252.7	1.05	0.002
gas ATN	275.5	256.6	0.79	0.002
gas CON	282.9	261.2	0.92	0.002
gas MED	283.4	256.7	1.12	0.003
gas PAN	291.4	265.8	1.08	0.003
oil ATC	373.0	370.1	0.07	0.004
oil ATN	355.1	352.6	0.06	0.003
oil CON	398.1	394.1	0.12	0.004
oil MED	358.6	356.0	0.07	0.003
oil PAN	398.7	394.9	0.12	0.004
wood-pellet ATC	32.6	30.5	0.04	0.004
wood-pellet ATN	22.8	21.0	0.04	0.003
wood-pellet CON	32.3	29.9	0.06	0.004
wood-pellet MED	21.8	20.0	0.04	0.003
wood-pellet PAN	28.5	26.3	0.05	0.003
wood-chips ATC	26.1	22.7	0.10	0.003
wood-chips ATN	22.9	19.6	0.10	0.003
wood-chips CON	27.4	23.8	0.11	0.003
wood-chips MED	22.5	19.1	0.11	0.003
wood-chips PAN	25.7	22.1	0.11	0.003

Note: data incl. upstream life cycles (source: GEMIS 4.5)

The total GHG emissions of gas heating are reduced by some 5 to 15% when compared to the 2010 emissions (exception: ATN where a minor increase occurs), while for oil heating, the results are more or less stable for ATC, ATN and MED, and some 5 % reduction occur for CON and PAN.

For biomass heating in 2030 as compared to 2010, a reduction in GHG emissions by some 10 to 25% will occur with the exception of ATN where emissions are increasing[19]. This is shown in the following figure.

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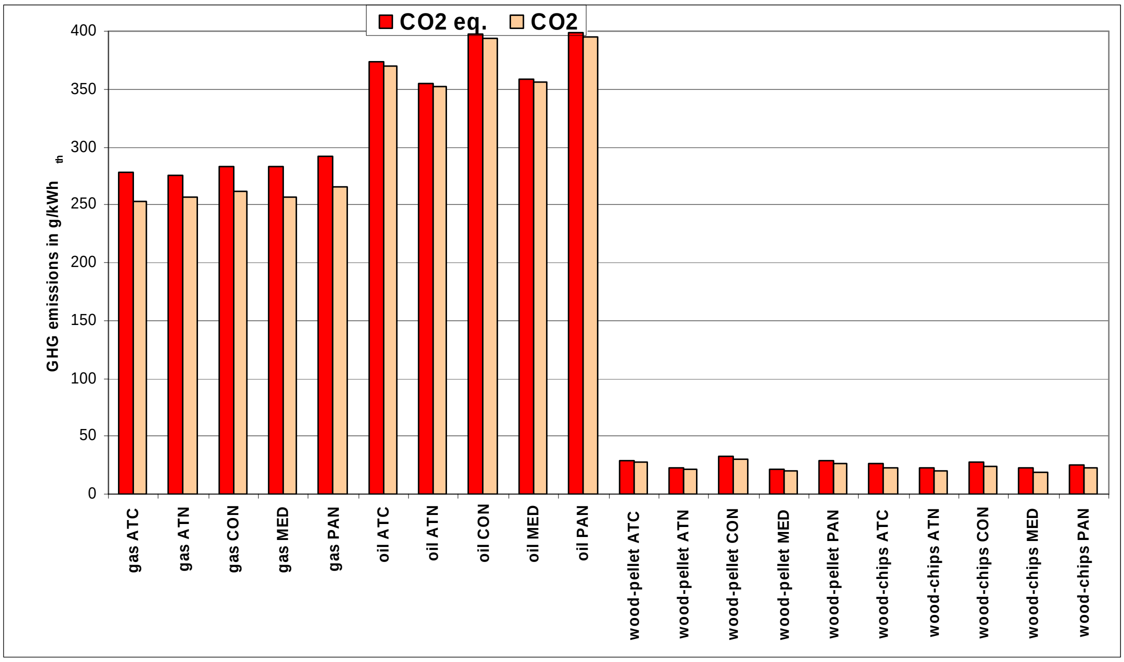
[19] This is caused by the changes in the electricity systems on ATN countries: According to the PRIMES REF scenario, the carbon intensity of their electricity systems will increase due to higher shares of fossil fuel generation.

Figure 19 GHG emissions from fossil and biomass residue heat, 2030



Note: data incl. upstream life cycles (source: GEMIS 4.5)

As can be seen, the massive reduction potential for heat from biomass residues as compared to fossil heating will remain unchanged, though.

In parallel to the GHG emissions, air pollutant emissions will also change until 2030, as shown in the following table.

Table 50 Air pollutants from fossil and biomass residue heat, 2030

emissions [g/kWh$_{th}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
gas ATC	0.15	0.01	0.21	0.01	0.15	0.06
gas ATN	0.17	0.02	0.22	0.01	0.16	0.10
gas CON	0.16	0.01	0.21	0.01	0.15	0.03
gas MED	0.20	0.01	0.27	0.01	0.18	0.03
gas PAN	0.19	0.01	0.25	0.01	0.17	0.03
oil ATC	0.33	0.17	0.22	0.02	0.21	0.05
oil ATN	0.70	0.55	0.21	0.02	0.20	0.06
oil CON	0.48	0.29	0.28	0.03	0.26	0.09
oil MED	0.75	0.58	0.23	0.02	0.21	0.06
oil PAN	0.84	0.61	0.33	0.04	0.22	0.10
wood-pellet ATC	0.38	0.15	0.31	0.08	0.23	0.04
wood-pellet ATN	0.38	0.15	0.31	0.08	0.23	0.05
wood-pellet CON	0.39	0.16	0.32	0.08	0.23	0.04
wood-pellet MED	0.38	0.15	0.31	0.08	0.23	0.05
wood-pellet PAN	0.38	0.15	0.32	0.08	0.23	0.04
wood-chips ATC	0.38	0.13	0.35	0.08	0.37	0.08
wood-chips ATN	0.38	0.13	0.35	0.08	0.36	0.08
wood-chips CON	0.39	0.13	0.35	0.09	0.37	0.08
wood-chips MED	0.38	0.13	0.35	0.08	0.36	0.08
wood-chips PAN	0.39	0.13	0.35	0.08	0.37	0.08

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

The SO2 equivalent emissions for gas heating will increase in ATN and PAN countries as compared to the year 2010, and will slightly decrease in the other regions. For oil heating, a small increase will occur also for ATN, while in the other regions, GHG emissions will be reduced.

Air emissions from heating with biomass residues will be reduced by some 10 to 25% as compared to 2010 levels, and especially particulate emissions from wood chips will be halved.

The difference of biomass particulate emissions compared to gas and oil heating will be reduced accordingly.

8.2 Emissions from Heating with Bioenergy Crops

In addition to heating with fossil and biomass residue fuels, also heating with fuels derived from bioenergy crops was analyzed with respect to their life cycle emissions[20]. As before, the country grouping into environmental zones (see Section 2.5) is used.

The heating systems are in the 10 kW_{th} range for “biogenic” oil derived from oil plants (FAME), and in the 50 kW_{th} range for chips from short-rotation coppice. Furthermore, semi-central heat plants in the range of 1 MW_{th} were assumed for heat from SRC chips, miscanthus bales, and switchgrass bales[21]. For MED, giant reed was assumed instead of switchgrass. The results for GHG emissions are given in the following table.

Table 51 GHG emissions from bioenergy crop heat, 2010

emissions [g/kWh_{th}]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
FAME-heating ATC	250.1	131.8	0.24	0.381
FAME-heating CON	250.8	145.8	0.23	0.337
FAME-heating MED	339.7	165.4	0.25	0.570
FAME-heating PAN	358.7	176.0	0.27	0.597
SRC-chips-heating ATC	45.6	32.4	0.18	0.031
SRC-chips-heating ATN	39.1	25.6	0.17	0.033
SRC-chips-heating CON	52.0	37.9	0.19	0.033
SRC-chips-heating PAN	49.6	33.6	0.17	0.040
SRC-chips-heatplant ATC	41.6	31.1	0.07	0.030
SRC-chips-heatplant ATN	32.5	21.7	0.05	0.032
SRC-chips-heatplant CON	49.5	37.9	0.08	0.033
SRC-chips-heatplant PAN	45.5	32.2	0.06	0.040
miscanthus-heatplant ATC	38.1	28.0	0.05	0.030
miscanthus-heatplant MED	38.1	28.0	0.05	0.030
miscanthus-heatplant PAN	39.4	28.8	0.04	0.033
switchgrass-heatplant ATC	41.4	31.2	0.05	0.030
switchgrass-heatplant ATN	30.2	19.7	0.04	0.033
switchgrass-heatplant CON	49.1	37.6	0.07	0.033
giant-reed-heatplant MED	32.2	22.3	0.04	0.030
switchgrass-heatplant PAN	41.9	31.1	0.04	0.033

Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

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[20] It should be noted that the bioenergy *cogeneration* systems analyzed in Sections 4.3 and 4.4 with respect to electricity *also deliver heat* – this is not included here for simplicity. Furthermore, biogas and “green” syngas can also be used for heating when they are processed and compressed to be fed into natural-gas distribution grids. This is not included here, but the use of such fuels is analyzed with respect to their use in transport systems in Section 9

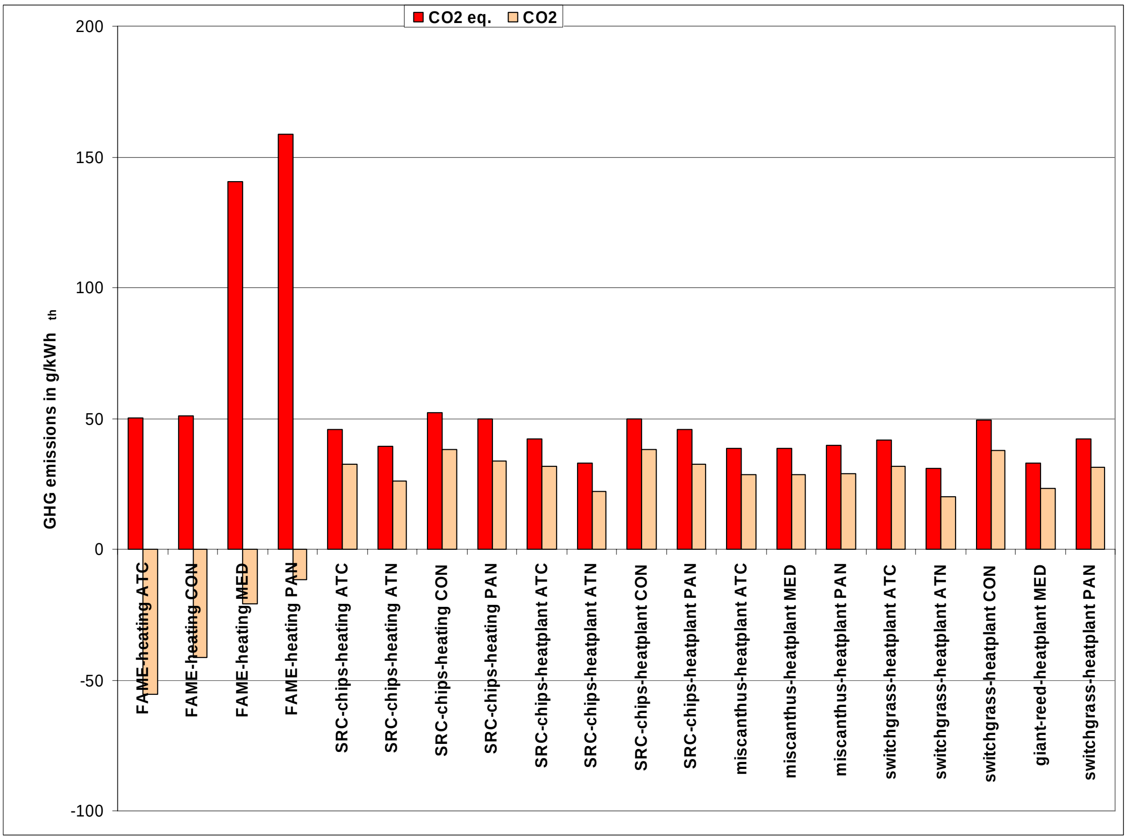
[21] Note that the heat plants are modeled here *without* heat distribution grids. Typically, their inclusion would add some 15% more emissions due to losses, and electricity for pumping.

All bioenergy crop heating systems are within a rather narrow range of 30 to 50 g CO_2-eq per kWh of heat delivered with the exception of FAME for which N_2O emissions from farming are quite high, which drives up the CO_2-eq. results.

Compared to fossil gas and oil heating (see Table 47), heat from bioenergy crops can reduce GHG emissions by some 85% - and even for FAME in CON and MED, the GHG reduction compared to fossil oil heating is still lower.

The following figure shows these results in graphical form.

Figure 20 GHG emissions from bioenergy crop heat, 2010



Note: data incl. upstream life cycles (source: GEMIS 4.5)

Heating with bioenergy crops also causes air pollutants, both from the combustion of the biomass, and the upstream life cycles to deliver the biomass fuel to the heating systems (and from the materials used for all activities as well).

The results are shown in the following table.

Table 52 Air pollutants from bioenergy crop heat, 2010

emissions [g/kWh$_{th}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
FAME-heating ATC	1.28	0.22	0.62	0.07	0.28	0.03
FAME-heating CON	1.42	0.34	0.75	0.08	0.30	0.04
FAME-heating MED	1.89	0.31	0.91	0.10	0.35	0.04
FAME-heating PAN	2.03	0.39	0.94	0.12	0.35	0.05
SRC-chips-heating ATC	0.57	0.16	0.52	0.13	0.50	0.14
SRC-chips-heating ATN	0.58	0.16	0.53	0.47	0.49	0.14
SRC-chips-heating CON	0.67	0.21	0.57	0.48	0.50	0.14
SRC-chips-heating PAN	0.62	0.17	0.54	0.48	0.50	0.14
SRC-chips-heatplant ATC	0.49	0.19	0.35	0.10	0.39	0.06
SRC-chips-heatplant ATN	0.49	0.19	0.35	0.10	0.39	0.06
SRC-chips-heatplant CON	0.60	0.26	0.40	0.11	0.40	0.06
SRC-chips-heatplant PAN	0.53	0.21	0.37	0.11	0.40	0.06
miscanthus-heatplant ATC	1.28	0.75	0.33	0.05	0.34	0.05
miscanthus-heatplant MED	1.28	0.75	0.33	0.05	0.34	0.05
miscanthus-heatplant PAN	1.32	0.77	0.35	0.05	0.34	0.05
switchgrass-heatplant ATC	0.99	0.56	0.37	0.11	0.37	0.06
switchgrass-heatplant ATN	0.99	0.55	0.38	0.11	0.37	0.06
switchgrass-heatplant CON	1.11	0.63	0.43	0.11	0.38	0.06
giant-reed-heatplant MED	1.15	0.63	0.34	0.05	0.35	0.06
switchgrass-heatplant PAN	1.02	0.57	0.39	0.11	0.38	0.06

*Note: data incl. upstream life cycles (source: GEMIS 4.5); * = predominantly PM$_{10}$ (> 90%)*

The SO_2-eq. emissions of FAME heating are in the order of those for fossil oil (see

Table 48), and heat from SRC chips is slightly lower. Heat from perennial grasses emits somewhat more SO_2-eq., but is lower than fossil oil heating in PAN.

Compared to natural gas heating, the SO_2-eq. emissions from bioenergy crops are about 3 to 5 times higher.

As for heat from biomass residues, particulate emissions from bioenergy crop heating are several times higher than those from the fossil systems, though.

The longer-term perspective of bioenergy crop heating is shown in the next table with respect to GHG emissions.

Table 53 GHG emissions from bioenergy crop heat, 2030

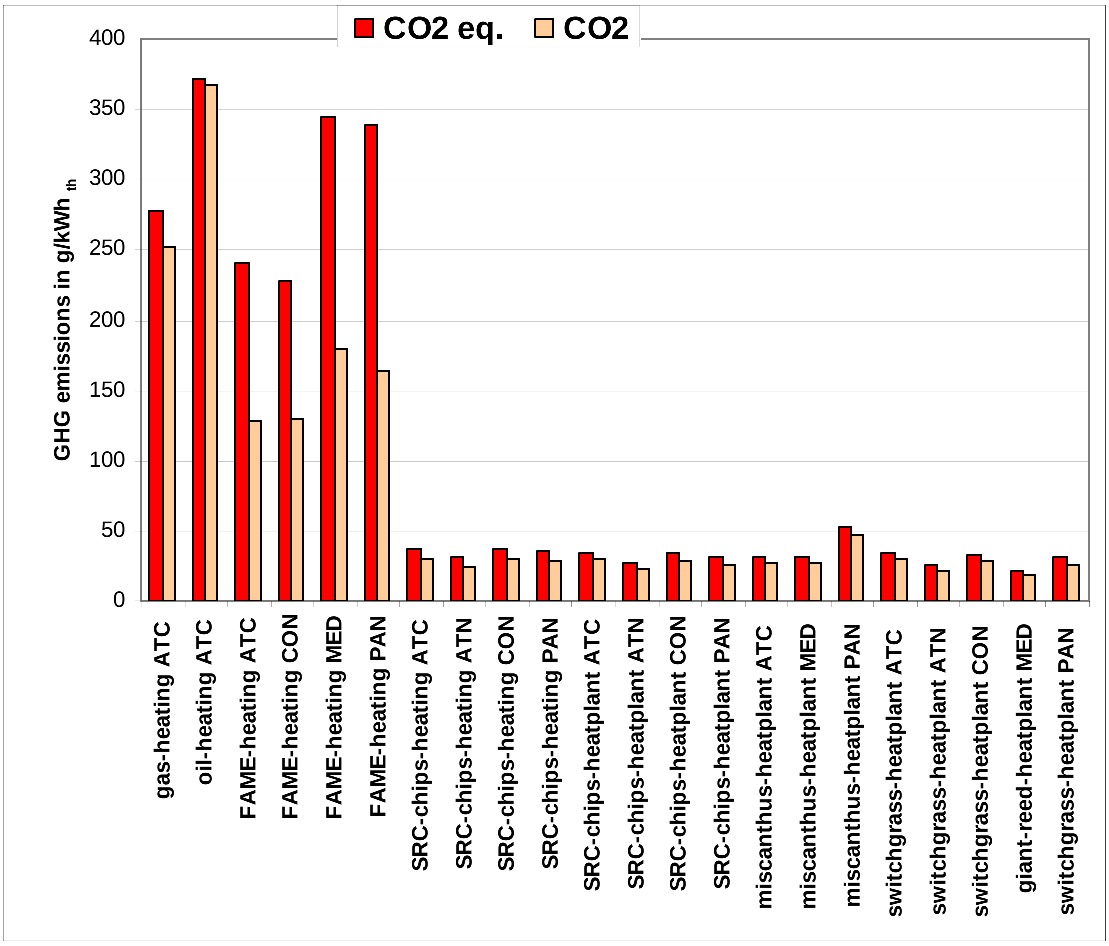
emissions [g/kWh$_{th}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
FAME-heating ATC	241.1	128.3	0.22	0.364
FAME-heating CON	228.0	130.2	0.20	0.315
FAME-heating MED	344.9	179.0	0.24	0.542
FAME-heating PAN	338.8	164.3	0.26	0.569
SRC-chips-heating ATC	36.5	30.5	0.11	0.012
SRC-chips-heating ATN	31.8	24.7	0.11	0.016
SRC-chips-heating CON	36.8	29.5	0.12	0.016
SRC-chips-heating PAN	35.1	27.9	0.11	0.016
SRC-chips-heatplant ATC	34.2	29.7	0.05	0.011
SRC-chips-heatplant ATN	27.6	22.1	0.04	0.015
SRC-chips-heatplant CON	34.2	28.3	0.05	0.016
SRC-chips-heatplant PAN	31.9	26.2	0.05	0.015
miscanthus-heatplant ATC	31.5	27.3	0.03	0.011
miscanthus-heatplant MED	31.5	27.3	0.03	0.011
miscanthus-heatplant PAN	53.0	47.1	0.05	0.016
switchgrass-heatplant ATC	34.3	30.0	0.04	0.012
switchgrass-heatplant ATN	25.2	21.2	0.03	0.011
switchgrass-heatplant CON	32.2	27.8	0.04	0.012
giant-reed-heatplant MED	22.0	18.1	0.03	0.011
switchgrass-heatplant PAN	30.9	25.5	0.04	0.015

Note: incl. upstream life cycles, by-product allocation based on energy (source: GEMIS 4.5)

Emissions from FAME heating are slightly reduced compared to the 2010 results (exception: FAME in PAN where a slight increase occurs), and the other bioenergy crop heating system show a reduction by some 15 to 30%.

The overall results are shown in the following figure.

Figure 21 GHG emissions from bioenergy crop heat, 2030



Note: incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

The CO_2-eq. emissions of the bioenergy crop heating systems are about 10% of those from fossil oil heating in 2030 (exception: FAME heating in MED and PAN), and about 15% of those from fossil gas (exception: FAME heating in MED and PAN). Therefore, significant reductions of GHG could be achieved if bioenergy crops would be used for heating instead of fossil oil or natural gas.

As regards SO_2-eq. emissions, the 2030 systems achieve reductions by 5 to 35% as compared to the 2010 results (exception: miscanthus heatplant in PAN where a 6% increase occurs). The particulate emissions can be reduced by 50 to 70% (exception: FAME in MED, where a 23% increase occurs), so that they will be about the same as those from fossil oil heating in 2030.

Table 54 Air pollutants from bioenergy crop heat, 2030

emissions [g/kWh$_{th}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
FAME-heating ATC	1.18	0.20	0.54	0.07	0.27	0.03
FAME-heating CON	1.16	0.23	0.60	0.07	0.28	0.03
FAME-heating MED	1.82	0.25	0.94	0.12	0.36	0.04
FAME-heating PAN	1.85	0.32	0.85	0.11	0.33	0.05
SRC-chips-heating ATC	0.45	0.15	0.38	0.06	0.37	0.08
SRC-chips-heating ATN	0.44	0.15	0.38	0.23	0.37	0.08
SRC-chips-heating CON	0.45	0.15	0.39	0.23	0.38	0.08
SRC-chips-heating PAN	0.48	0.15	0.39	0.23	0.38	0.08
SRC-chips-heatplant ATC	0.39	0.18	0.26	0.05	0.29	0.02
SRC-chips-heatplant ATN	0.38	0.18	0.25	0.05	0.29	0.02
SRC-chips-heatplant CON	0.40	0.18	0.27	0.05	0.30	0.02
SRC-chips-heatplant PAN	0.42	0.18	0.27	0.05	0.30	0.02
miscanthus-heatplant ATC	1.16	0.72	0.24	0.02	0.24	0.02
miscanthus-heatplant MED	1.16	0.72	0.24	0.02	0.24	0.02
miscanthus-heatplant PAN	1.40	0.77	0.51	0.04	0.30	0.02
switchgrass-heatplant ATC	0.87	0.53	0.27	0.03	0.26	0.02
switchgrass-heatplant ATN	0.87	0.53	0.28	0.03	0.26	0.02
switchgrass-heatplant CON	0.88	0.54	0.29	0.03	0.27	0.02
giant-reed-heatplant MED	1.01	0.59	0.24	0.02	0.24	0.02
switchgrass-heatplant PAN	0.87	0.54	0.28	0.03	0.26	0.02

Note: incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5);
** = predominantly PM$_{10}$ (> 90%)*

9 Life Cycle Emissions for Selected Transport Fuels

Similar to electricity and heat, life cycle emissions can also be determined for transport fuels used in buses, cars, ships, trucks, etc. In the following, a brief comparison of life cycle emissions for selected transport fuels is given with special emphasis on biofuels. To avoid mixing of the efficiencies of the transport fuel with the respective upstream life cycles of fuels used, all fuels are assumed to be burnt in a reference diesel or otto motor (for gasoline), and the emissions are expressed then in terms of g/kWh of fuel **consumed** (input).

For upstream life cycles of fuels, country-specific data (grouped for environmental zones) were used, and all results given here are using **energy allocation for by-products in the upstream life cycles**[22].

Furthermore, bioethanol from Brazil is added to the results as a biofuel from outside of Europe. This result includes international ship transport to Europe.

The following table gives the results for the year 2010, where only 1st generation biofuels were included in the analysis.

Table 55 GHG emissions from biofuels in EU countries, 2010

emissions [g/kWh$_{input}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
gasoline	323.8	318.6	0.08	0.012
diesel	309.3	305.0	0.07	0.009
SVO ATC	177.7	79.5	0.10	0.324
FAME ATC	206.9	105.1	0.18	0.329
FAME CON	205.3	114.9	0.17	0.292
FAME MED	285.4	135.9	0.19	0.490
FAME PAN	299.3	142.6	0.21	0.513
EtOH (sugarbeet) ATC	226.3	163.2	0.33	0.187
EtOH (sugarcane)/from-BR	106.4	65.1	0.52	0.099
EtOH (maize) ATC	151.6	97.5	0.20	0.167
EtOH (maize) ATN	151.6	97.5	0.20	0.167
EtOH (maize) CON	151.9	105.7	0.20	0.140
EtOH (maize) MED	152.7	92.1	0.18	0.191
EtOH (maize) PAN	142.1	100.2	0.34	0.115
EtOH (wheat) ATC	153.0	99.0	0.20	0.167
EtOH (wheat) ATN	140.7	82.1	0.10	0.190
EtOH (wheat) CON	153.0	106.8	0.20	0.140
EtOH (wheat) MED	119.6	90.1	0.16	0.087
EtOH (wheat) PAN	144.8	102.8	0.35	0.115
biogas (double-crop) ATC	77.0	47.5	0.44	0.065

Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

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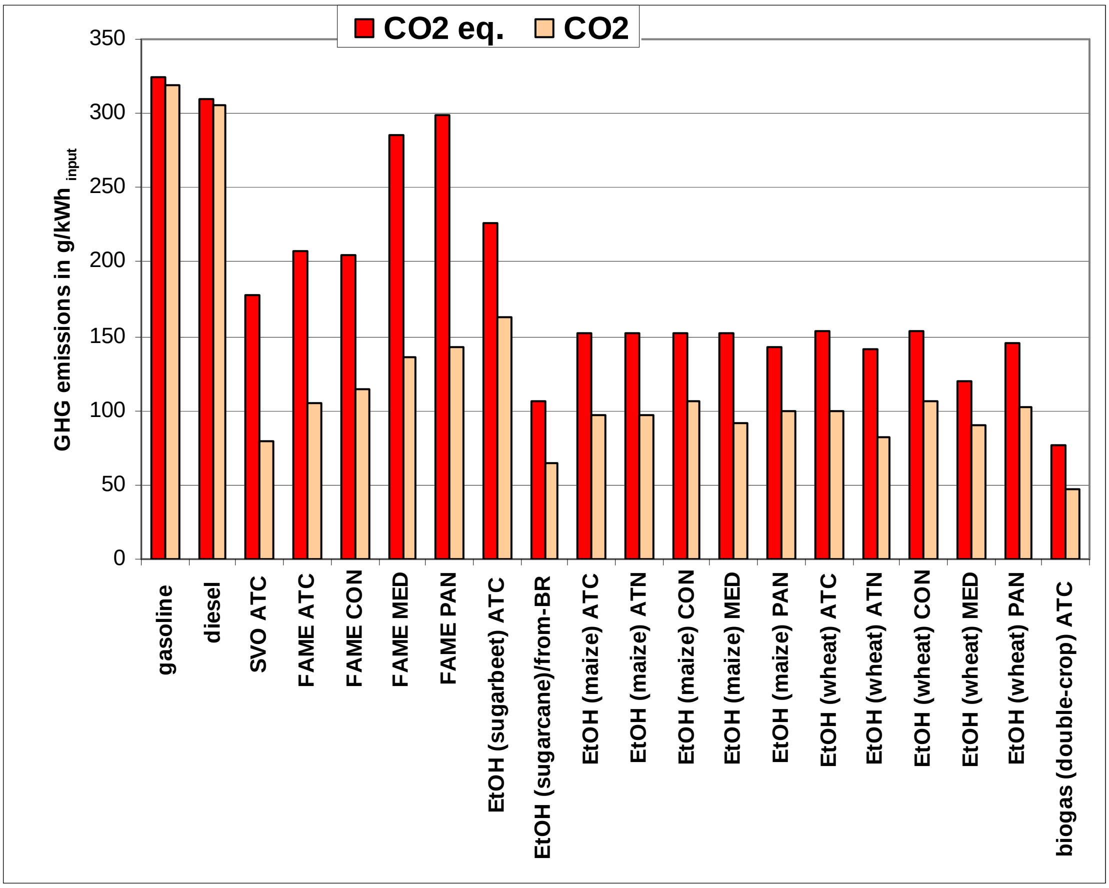
[22] For details, see footnotes 5 and 6.

The results are shown in graphical form in the following figure.

Figure 22 GHG emissions from transport fuels in EU countries, 2010



Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

Compared to fossil diesel and gasoline, all biofuels can reduce GHG emissions, but there are significant differences. The lowest emissions are for biogas from double-cropping, followed by 1st generation ethanol from Brazil, and then 1st generation ethanol from maize or wheat. Straight vegetable oil (SVO) from rapeseed has about the same emissions as FAME in ATC and CON which higher than the EtOH options, but still below the fossil fuels.

FAME in MED and PAN achieve only minor GHG reductions due to their relative high N_2O emissions.

The following table shows the results for air pollutants.

Table 56 Air pollutants from biofuels in EU countries, 2010

emissions [g/kWh$_{input}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
gasoline	0.33	0.15	0.23	0.02	1.07	0.56
diesel	0.38	0.13	0.35	0.02	0.29	0.09
SVO ATC	1.13	0.15	0.64	0.06	0.33	0.06
FAME ATC	1.19	0.18	0.68	0.06	0.35	0.06
FAME CON	1.27	0.26	0.78	0.07	0.37	0.07
FAME MED	1.70	0.25	0.93	0.09	0.42	0.07
FAME PAN	1.82	0.32	0.95	0.10	0.41	0.07
EtOH (sugarbeet) ATC	0.93	0.09	0.54	0.04	1.17	0.07
EtOH (sugarcane)/from-BR	1.10	0.38	0.97	0.15	1.38	0.53
EtOH (maize) ATC	0.61	0.07	0.37	0.03	1.10	0.04
EtOH (maize) ATN	0.61	0.07	0.37	0.03	1.10	0.04
EtOH (maize) CON	0.77	0.18	0.50	0.04	1.15	0.04
EtOH (maize) MED	0.68	0.09	0.40	0.03	1.11	0.04
EtOH (maize) PAN	0.57	0.08	0.41	0.03	1.11	0.05
EtOH (wheat) ATC	0.62	0.08	0.37	0.03	1.10	0.04
EtOH (wheat) ATN	0.65	0.08	0.37	0.03	1.09	0.04
EtOH (wheat) CON	0.78	0.19	0.51	0.04	1.15	0.04
EtOH (wheat) MED	0.51	0.07	0.42	0.02	1.12	0.04
EtOH (wheat) PAN	0.59	0.09	0.43	0.03	1.11	0.05
biogas (double-crop) ATC	0.38	0.03	0.28	0.02	1.37	0.02

*Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

The life cycle SO_2-eq. and particulate emissions of biofuels are about 1.5 to 3 times higher than those from fossil diesel and gasoline, with the sole exception of biogas which has about the same emission levels.

As regards future developments for biofuels, so-called 2nd generation systems will become available. Instead of 1st generation biodiesel, biomass-to-liquid (BtL) diesel (also known as FT-Diesel) is assumed which is a synthetic “designer” fuel from biomass gasification, and subsequent Fischer-Tropsch synthesis. This conversion route allows use of the whole plant, and is applicable to all lignocellulose materials (e.g., short-rotation coppice, perennial grasses).

For ethanol, a different 2nd generation technology is assumed which converts the hemicellulosic parts of plants into ethanol, and burns the remaining lignin parts for process energy. This ligno-EtOH can also use whole plants (including straw), but cannot (yet) convert woody material.

The following table gives the GHG emission results for the 2030 technlogies.

Table 57 GHG emissions from biofuels in EU countries, 2030

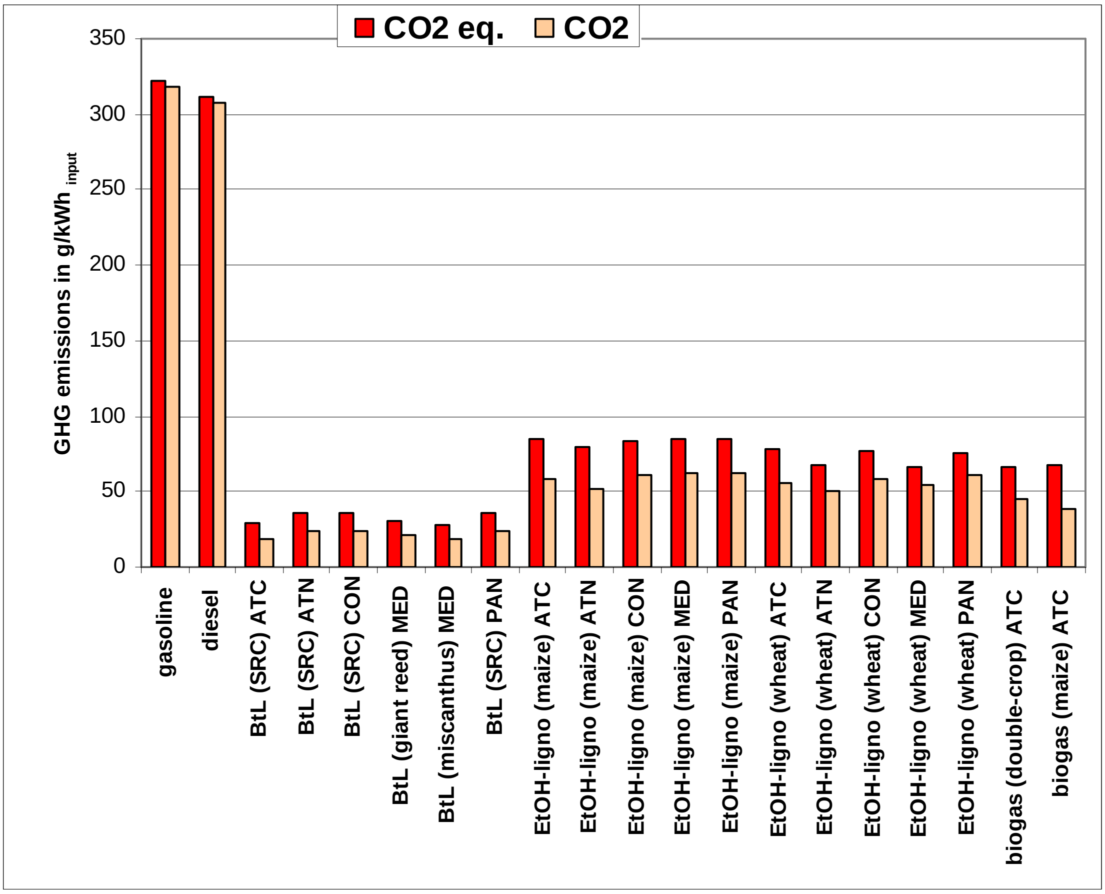
emissions [g/kWh$_{input}$]	**CO_2 eq.**	**CO_2**	**CH_4**	**N_2O**
gasoline	322.8	318.1	0.05	0.012
diesel	311.3	307.5	0.05	0.009
BtL (SRC) ATC	29.1	18.9	0.05	0.031
BtL (SRC) ATN	35.2	23.6	0.05	0.035
BtL (SRC) CON	35.6	23.9	0.05	0.035
BtL (giant reed) MED	30.6	20.8	0.03	0.031
BtL (miscanthus) MED	28.4	18.7	0.03	0.031
BtL (SRC) PAN	35.6	24.0	0.05	0.035
EtOH-ligno (maize) ATC	84.4	57.9	0.09	0.083
EtOH-ligno (maize) ATN	80.2	52.3	0.04	0.091
EtOH-ligno (maize) CON	84.0	61.3	0.09	0.070
EtOH-ligno (maize) MED	84.6	62.8	0.23	0.056
EtOH-ligno (maize) PAN	84.6	62.8	0.23	0.056
EtOH-ligno (wheat) ATC	78.2	55.6	0.09	0.069
EtOH-ligno (wheat) ATN	67.5	50.0	0.04	0.056
EtOH-ligno (wheat) CON	77.2	58.4	0.09	0.056
EtOH-ligno (wheat) MED	66.5	54.2	0.10	0.034
EtOH-ligno (wheat) PAN	75.7	60.5	0.23	0.034
biogas (double-crop) ATC	66.7	45.7	0.31	0.047
biogas (maize) ATC	68.1	38.7	0.31	0.075

Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

BtL, ligno-EtOH from various plants and processed biogas from double-cropping systems and maize could drastically reduce GHG emissions when compared to fossil gasoline and diesel.

The results are shown in graphical form in the following figure.

Figure 23 GHG emissions from transport fuels in EU countries, 2030



Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5)

As regards air pollutant emissions, the 2nd generation biofuels also achieve different results than the conventional fuels from plant oil, and 1st generation ethanol (see following table).

The SO_2-eq. emissions from ligno-EtOH from wheat are approx. the same than those from fossil diesel and gasoline, while ligno-EtOH from maize has somewhat higher emissions. BtL fuels cause about twice as much SO_2-eq. emissions than fossil diesel, while biogas from double-cropping and maize has the lowest emissions of all fuels.

Interestingly, the 2030 biofuels show also less particulate emissions than the fossil fuels (exception: BtL in ATC).

Table 58 Air pollutants from biofuels in EU countries, 2030

emissions [g/kWh$_{input}$]	**SO_2 eq.**	**SO_2**	**NO_x**	**partic.***	**CO**	**NMVOC**
gasoline	0.33	0.15	0.22	0.02	1.08	0.55
diesel	0.37	0.12	0.35	0.02	0.30	0.08
BtL (SRC) ATC	0.60	0.03	0.78	0.02	0.77	0.07
BtL (SRC) ATN	0.61	0.03	0.78	0.02	0.78	0.08
BtL (SRC) CON	0.61	0.03	0.79	0.02	0.78	0.08
BtL (giant reed) MED	0.58	0.02	0.76	0.02	0.71	0.07
BtL (miscanthus) MED	0.57	0.02	0.75	0.01	0.71	0.07
BtL (SRC) PAN	0.65	0.04	0.80	0.02	0.78	0.08
EtOH-ligno (maize) ATC	0.50	0.06	0.27	0.01	1.16	0.08
EtOH-ligno (maize) ATN	0.52	0.06	0.26	0.01	1.16	0.08
EtOH-ligno (maize) CON	0.47	0.07	0.35	0.01	1.19	0.08
EtOH-ligno (maize) MED	0.47	0.07	0.32	0.01	1.17	0.09
EtOH-ligno (maize) PAN	0.47	0.07	0.32	0.01	1.17	0.09
EtOH-ligno (wheat) ATC	0.40	0.06	0.26	0.01	1.16	0.08
EtOH-ligno (wheat) ATN	0.36	0.05	0.25	0.01	1.15	0.08
EtOH-ligno (wheat) CON	0.50	0.06	0.32	0.01	1.19	0.08
EtOH-ligno (wheat) MED	0.34	0.05	0.29	0.01	1.17	0.08
EtOH-ligno (wheat) PAN	0.35	0.07	0.30	0.01	1.16	0.09
biogas (double-crop) ATC	0.28	0.02	0.21	0.01	1.36	0.01
biogas (maize) ATC	0.34	0.02	0.16	0.01	1.34	0.01

*Note: data incl. upstream life cycles, by-product allocation by energy (source: GEMIS 4.5); * = predominantly PM_{10} (> 90%)*

These results indicate that when compared to heating, 2nd generation biofuels and biogas for transport offer significant opportunities to reduce GHG emissions and in parallel also particulate and SO_2 emissions.

10 Concluding Remarks

This brief study identified life cycle emissions from conventional and renewable energies in Europe, and their future developments until 2030. Results were given for electricity and heat generation, as well as for transport fuels, where GHG emissions and air pollutants were of interest[23].

There is some uncertainty regarding the life cycle data presented here, as the future learning is still hypothetical, and some of the future technologies are in an early state of development.

Furthermore, fuel mixes for future generation of electricity, and future import mixes for coal, natural gas, and crude oil are estimates which are subject to change.

Disregarding those uncertainties, comparing results of this study with work from others indicates that the findings presented here are well within the range of current knowledge[24].

As regard the regional representation, data for individual EU countries were grouped into environmental zones, and averaged figures derived for those. This simplification causes some bias regarding countries as e.g. AT and PL are part of the CON group, and FI, SE and the Baltic States which form the ATN group. The individual countries have quite different characteristics of their energy systems (especially electricity), so that in future refinements, sub-groups like CON-East/West, and ATN-North/East should be considered.

Finally, no detail was given for BE, CY, LU, and MT here as these countries represent only comparatively small shares of the overall EU-27 energy system.

In the GEMIS database, information on those countries can be found, though.

Note that in **this update** of the bioenergy life cycles, the substitution approach for by-products used in earlier versions of this report was **changed to energy allocation** in all life cycles which, as this is the method of the EU Directive for the Promotion of Energy from Renewable Sources (RES-D) adopted in late 2008 by the European Parliament and the EU Council.

For **GHG emissions from land use changes** (LUC) for bioenergy systems, other literature gives an indication of this important additional source[25].

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[23] It should be noted that in addition to the results given here, GEMIS also calculates other environmental indicators such as solid wastes, liquid effluents, land use, and resource requirements.

[24] see for example DLR/IE/VuV (2003); ECLIPSE (2003a+b); JRC et al. (2008).

[25] For respective data for selected bioenergy systems, see Fritsche/Wiegmann 2008; for the sensivitiy of life cycle GHG emissions of bioenergy with regard to LUC, see OEKO (2009), and for a discussion of indirect LUC see GBEP (2009).

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List of Abbreviations

a	year
AT	Austria
ATC	Atlantic Central (environmental zone)
ATN	Atlantic North (environmental zone)
BE	Belgium
BP	back-pressure
BtL	biomass-to-liquid
CC	combined-cycle
CEE	Central and Eastern Europe
CH_4	methane
CHP	combined heat & power
CIP	Conference Issue Paper (for the renewables2004 conference)
CIS	Commonwealth of Independent States (former USSR)
CO_2	carbon dioxide
CON	Continental (environmental zone)
CONCAWE	The Oil Companies' European Association for Environment, Health and Safety in Refining and Distribution
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
DLR	German Center for Air and Space (Deutsches Zentrum für Luft- und Raumfahrt - www.dlr.de)
ES	Spain
EE	Estonia
EEA	European Environment Agency (www.eea.europa.eu)
EJ	ExaJoule = 1000 PetaJoule (PJ) = 1 million TeraJoule (TJ) = 1 billion GigaJoule (GJ)
EtOH	ethanol
EU-10	New EU Member States (Accession Countries)
EU-15	EU before enlargement (until April 30, 2004)

EU-25	EU after enlargement (as of May, 2004)
EU-28	EU-25 plus Candidate countries
EUCAR	European Council for Automotive R&D
FAME	fatty acid methy ether
FI	Finland
FR	France
GEMIS	Global Emission Model for Integrated Systems (www.gemis.de)
GHG	greenhouse-gases
GJ	GigaJoule (10^9 Joule)
GR	Greece
GT	gas turbine
HU	Hungary
IT	Italy
ICE	internal combustion engine
IE	Ireland
IEA	International Energy Agency (www.iea.org)
IFEU	Institute for Energy and Environment Research (Institut für Energie- und Umweltforschung - www.ifeu.de)
IGCC	integrated gasification combined-cycle
JRC	Joint Research Centre of the EU Commission
LCA	Life cycle analysis
LT	Lithuania
LV	Latvia
LU	Luxembourg
MED	Mediterranean (environmental zone)
MT	Malta
N_2O	nitrious oxide
NL	Netherlands
NO	Norway
OECD	Organization for Economic Cooperation and Development (www.oecd.org)
OEKO	Oeko-Institut - Institute for Applied Ecology (www.oeko.de)

PAN	Pannonic-Pontic (environmental zone)
PL	Poland
PM_{10}	particulate matter below 10 µm
PME	plant oil methylester
PT	Portugal
PV	photovoltaics
PWR	pressurized water reactor
RME	rapeseed oil methylester
RO	Romania
ROR	run-of-river (hydroelectric powerplants)
RU	Russia
SE	Sweden
SEGS	solar-thermal electricity generation system (with parabolic troughs)
SI	Slovenia
SK	Slovakia
SRC	short-rotation coppice
SRF	short-rotation forestry
ST	steam-turbine
t	tonne (metric)
TJ	TeraJoule (10^{12} Joule)
TR	Turkey
UK	United Kingdom
WP	whole plant
ZA	Republic of South Africa

Appendix: Technical Data and *Direct* Emissions of Energy Processes in Europe

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
biogas (double-crop)-ICE-cogen ATC-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (double-crop)-ICE-cogen ATC-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (double-crop)-ICE-cogen ATN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (double-crop)-ICE-cogen ATN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (double-crop)-ICE-cogen CON-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (double-crop)-ICE-cogen CON-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (double-crop)-ICE-cogen PAN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (double-crop)-ICE-cogen PAN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (maize)-ICE-cogen ATC-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (maize)-ICE-cogen ATC-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (maize)-ICE-cogen ATN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (maize)-ICE-cogen ATN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (maize)-ICE-cogen CON-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (maize)-ICE-cogen CON-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (maize)-ICE-cogen MED-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (maize)-ICE-cogen MED-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (maize)-ICE-cogen PAN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (maize)-ICE-cogen PAN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (wheat)-ICE-cogen ATC-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (wheat)-ICE-cogen ATC-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (wheat)-ICE-cogen ATN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (wheat)-ICE-cogen ATN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (wheat)-ICE-cogen CON-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (wheat)-ICE-cogen CON-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
biogas (wheat)-ICE-cogen MED-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (wheat)-ICE-cogen MED-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
biogas (wheat)-ICE-cogen PAN-2010/gas50%	0.5	0.35		0.0	70.9	171.1	4.8	142.6	4.2	4.8	4.8
biogas (wheat)-ICE-cogen PAN-2030/gas50%	0.5	0.4		0.0	31.0	83.2	4.2	83.2	2.5	2.1	0.8
coal-ST-DE-2010	700.0	0.4438		213,247.8	69.9	109.0	4.1	40.4	8.1	4.0	11.3
coal-ST-DE-2020	700.0	0.4609		203,226.7	66.6	103.9	3.9	38.5	7.7	3.8	10.8
coal-ST-DE-2030	700.0	0.5009		186,347.4	61.0	63.5	3.6	14.1	3.5	3.5	3.5
coal-ST-DE-import-2010	700.0	0.4439		219,092.7	81.8	107.3	4.0	39.8	4.0	4.0	11.1
coal-ST-DE-import-2020	700.0	0.4609		211,012.4	78.8	103.4	3.9	38.3	3.8	3.8	10.7
coal-ST-DE-import-2030	700.0	0.4999		194,551.6	36.3	63.5	3.7	14.1	3.5	3.5	3.5
coal-ST-ES-2010	500.0	0.3849		245,765.3	285.1	688.6	2.4	101.0	4.5	4.5	14.5
coal-ST-ES-2020	500.0	0.3999		236,524.6	182.9	132.5	4.5	88.4	4.0	4.0	13.3
coal-ST-ES-2030	500.0	0.4149		227,974.4	176.3	127.8	4.4	85.2	3.8	3.8	12.8
coal-ST-EU-import-2010	700.0	0.4439		219,092.7	81.8	107.3	4.0	39.8	4.0	4.0	11.1
coal-ST-EU-import-2020	700.0	0.4609		211,012.4	78.8	103.4	3.9	38.3	3.8	3.8	10.7
coal-ST-EU-import-2030	700.0	0.4999		194,551.6	36.3	63.5	3.7	14.1	3.5	3.5	3.5
coal-ST-RU-2010	500.0	0.3988		252,804.7	195.7	134.5	4.9	224.2	3.9	3.9	12.6
coal-ST-RU-2020	500.0	0.4388		229,759.5	177.9	122.3	4.5	203.8	3.5	3.5	11.4
coal-ST-RU-2030	500.0	0.4638		217,374.8	168.3	115.7	4.2	192.8	3.3	3.3	10.8
coal-ST-UK-2010	500.0	0.3999		236,524.6	192.5	132.5	45.3	88.4	44.2	4.4	13.3
coal-ST-UK-2020	500.0	0.4399		215,019.8	175.0	120.5	41.2	80.3	40.2	4.0	12.0
coal-ST-UK-2030	500.0	0.4649		203,458.4	165.6	114.0	39.0	76.0	38.0	3.8	11.4
coal-ST-US-2010	500.0	0.3999		243,518.7	181.9	133.1	34.1	88.8	44.4	4.4	13.3
coal-ST-US-2020	500.0	0.4399		221,375.9	165.4	121.0	31.0	80.7	40.3	4.0	12.1
coal-ST-US-2030	500.0	0.4649		209,471.5	78.2	114.5	5.9	76.3	38.2	3.8	11.5
dieselmotor-CZ-agriculture-end (100%)-2010	1.0	1		74,139.9	46.8	969.3	80.8	210.0	3.1	3.1	3.1
dieselmotor-CZ-agriculture-end (100%)-2020	1.0	1		74,466.0	0.9	968.8	80.7	209.9	3.1	3.1	3.1
dieselmotor-CZ-agriculture-end (100%)-2030	1.0	1		74,466.8	0.5	968.8	80.7	209.9	3.1	3.1	3.1

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
dieselmotor-DE-agriculture-end (100%)-2000	1.0	1		74,395.7	77.4	968.9	80.7	209.9	3.1	3.1	3.1
dieselmotor-DE-agriculture-end (100%)-2010	1.0	1		73,669.5	1.9	798.7	63.9	159.7	3.0	1.6	1.6
dieselmotor-DE-agriculture-end (100%)-2020	1.0	1		74,466.0	0.9	645.9	64.6	161.5	3.1	1.6	1.6
dieselmotor-DE-agriculture-end (100%)-2030	1.0	1		74,466.0	0.5	645.9	64.6	161.5	3.1	1.6	1.6
dieselmotor-EU-agriculture (end-energy)-2010	1.0	1		74,416.6	46.9	807.3	64.6	161.5	3.1	1.6	1.6
dieselmotor-EU-agriculture (end-energy)-2020	1.0	1		74,466.0	0.9	645.9	64.6	161.5	3.1	1.6	1.6
dieselmotor-EU-agriculture (end-energy)-2030	1.0	1		74,466.0	0.9	645.9	64.6	161.5	3.1	1.6	1.6
dieselmotor-HU-agriculture-end (100%)-2010	1.0	1		74,139.9	46.8	969.3	80.8	210.0	3.1	3.1	3.1
dieselmotor-HU-agriculture-end (100%)-2020	1.0	1		74,466.0	0.9	968.8	80.7	209.9	3.1	3.1	3.1
dieselmotor-HU-agriculture-end (100%)-2030	1.0	1		74,466.8	0.5	968.8	80.7	209.9	3.1	3.1	3.1
dieselmotor-PL-agriculture-end (100%)-2010	1.0	1		74,139.9	46.8	969.3	80.8	210.0	3.1	3.1	3.1
dieselmotor-PL-agriculture-end (100%)-2020	1.0	1		74,466.0	0.9	807.3	80.7	209.9	3.1	3.1	3.1
dieselmotor-PL-agriculture-end (100%)-2030	1.0	1		74,466.8	0.5	807.3	80.7	209.9	3.1	3.1	3.1
dieselmotor-RO-agriculture-end (100%)-2010	1.0	1		74,054.1	93.6	968.8	80.7	209.9	3.1	3.1	3.1
dieselmotor-RO-agriculture-end (100%)-2020	1.0	1		74,416.6	46.9	968.8	80.7	209.9	3.1	3.1	3.1
dieselmotor-RO-agriculture-end (100%)-2030	1.0	1		74,416.6	46.9	968.8	80.7	209.9	3.1	3.1	3.1
farming\double-cropping-optimal-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\double-cropping-optimal-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\double-cropping-optimal-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\double-cropping-optimal-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\double-cropping-optimal-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\double-cropping-optimal-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\double-cropping-optimal-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\double-cropping-optimal-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\double-cropping-optimal-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\double-cropping-optimal-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\double-cropping-optimal-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
farming\double-cropping-optimal-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
farming\double-cropping-suboptimal-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\double-cropping-suboptimal-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\double-cropping-suboptimal-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
farming\double-cropping-suboptimal-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\double-cropping-suboptimal-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\double-cropping-suboptimal-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\double-cropping-suboptimal-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0
farming\double-cropping-suboptimal-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
farming\double-cropping-suboptimal-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
farming\double-cropping-suboptimal-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\double-cropping-suboptimal-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\double-cropping-suboptimal-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\giant-reed-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\giant-reed-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\giant-reed-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\maize-corn-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\maize-corn-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0
farming\maize-corn-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\maize-corn-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\maize-corn-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\maize-corn-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\maize-corn-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0
farming\maize-corn-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
farming\maize-corn-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
farming\maize-corn-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\maize-corn-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\maize-corn-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\maize-corn-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	[MW]		factor	g/GJ$_{out}$							
farming\maize-corn-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
farming\maize-corn-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\maize-whole-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\maize-whole-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\maize-whole-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
farming\maize-whole-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\maize-whole-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\maize-whole-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\maize-whole-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0
farming\maize-whole-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
farming\maize-whole-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
farming\maize-whole-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\maize-whole-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\maize-whole-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\maize-whole-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\maize-whole-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\maize-whole-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\miscanthus-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\miscanthus-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\miscanthus-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\miscanthus-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\miscanthus-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\miscanthus-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\miscanthus-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\miscanthus-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\miscanthus-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\rapeseed-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0
farming\rapeseed-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
farming\rapeseed-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0
farming\rapeseed-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0
farming\rapeseed-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0
farming\rapeseed-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\rapeseed-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.0
farming\rapeseed-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.0
farming\rapeseed-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.0
farming\sorghum-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
farming\sorghum-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0
farming\sorghum-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
farming\SRF (poplar)-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\SRF (poplar)-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\SRF (poplar)-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\SRF (poplar)-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
farming\SRF (poplar)-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
farming\SRF (poplar)-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\sugarbeet-DE-2010	0.0	1		2,580.5	0.5	27.8	2.4	8.2	4.6	0.1	27.4
farming\sugarbeet-DE-2020	0.0	1		2,483.2	0.5	26.8	2.3	7.9	4.5	0.1	27.4
farming\sugarbeet-DE-2030	0.0	1		2,397.6	0.5	25.8	2.2	7.6	4.3	0.1	27.3
farming\sunflowerseed-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.0
farming\sunflowerseed-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.0
farming\sunflowerseed-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
farming\switchgrass-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\switchgrass-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\switchgrass-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\switchgrass-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
farming\switchgrass-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\switchgrass-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\switchgrass-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
farming\wheat-seeds-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\wheat-seeds-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0
farming\wheat-seeds-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
farming\wheat-seeds-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
farming\wheat-seeds-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
farming\wheat-seeds-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
farming\wheat-seeds-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0
farming\wheat-seeds-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
farming\wheat-seeds-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
farming\wheat-seeds-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\wheat-seeds-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\wheat-seeds-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
farming\wheat-seeds-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\wheat-seeds-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
farming\wheat-seeds-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\wheat-whole-ATC-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
farming\wheat-whole-ATC-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
farming\wheat-whole-ATC-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
farming\wheat-whole-ATN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\wheat-whole-ATN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\wheat-whole-ATN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\wheat-whole-CON-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
farming\wheat-whole-CON-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
farming\wheat-whole-CON-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
farming\wheat-whole-MED-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
farming\wheat-whole-MED-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
farming\wheat-whole-MED-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
farming\wheat-whole-PAN-2010	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
farming\wheat-whole-PAN-2020	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
farming\wheat-whole-PAN-2030	0.0	1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2010/gross	100.0	0.55	0.041	0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2010/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2020/gross	100.0	0.55	0.041	0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2030/gross	100.0	0.6	0.041	0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATC-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATN-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-ATN-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-CON-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-CON-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-MED-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-MED-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-PAN-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (maize-WP)-PAN-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
fermentation\bio-EtOH-ligno (sorghum-WP)-MED-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (sorghum-WP)-MED-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (straw)-ATC-2030	100.0	0.55		0.0	19.2	57.1	0.0	0.0	36.1	4.6	0.8
fermentation\bio-EtOH-ligno (wheat-WP)-ATC-2020/gross	100.0	0.55	0.041	0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-ATC-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-ATC-2030/gross	100.0	0.6	0.041	0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-ATC-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-ATN-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-ATN-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-CON-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-CON-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-MED-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-MED-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-PAN-2020/net	100.0	0.55		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
fermentation\bio-EtOH-ligno (wheat-WP)-PAN-2030/net	100.0	0.6		0.0	7.9	23.7	0.0	2.8	17.6	1.9	0.3
Fermenter\biogas-double-crop-opt-ATC-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-ATC-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
Fermenter\biogas-double-crop-opt-ATC-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
Fermenter\biogas-double-crop-opt-ATN-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-ATN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-ATN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-CON-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-CON-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-CON-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-PAN-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-PAN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-opt-PAN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-ATC-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
Fermenter\biogas-double-crop-subopt-ATC-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-ATC-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-ATN-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-ATN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-ATN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-CON-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-CON-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-CON-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-PAN-2010	0.7	0.65		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-PAN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter\biogas-double-crop-subopt-PAN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATC-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATC-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATC-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATN-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-ATN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-CON-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-CON-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-CON-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-MED-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-MED-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-MED-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-PAN-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-PAN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-maize-PAN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-ATC-2010	0.7	0.63		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-ATC-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
fermenter-1500\biogas-manure-large-ATC-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-ATN-2010	0.7	0.63		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-ATN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-ATN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-CON-2010	0.7	0.63		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-CON-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-CON-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-MED-2010	0.7	0.63		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-MED-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-MED-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-PAN-2010	0.7	0.63		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-PAN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
fermenter-1500\biogas-manure-large-PAN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATC-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATC-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATC-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATN-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-ATN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-CON-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-CON-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-CON-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-MED-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-MED-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-MED-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-PAN-2010	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-PAN-2020	0.7	0.67		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
Fermenter-1500\biogas-wheat-PAN-2030	0.7	0.7		0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
fermenter-300\biogas-manure-small-ATC-2010	0.1	0.63		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-ATC-2020	0.1	0.67		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-ATC-2030	0.1	0.7		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-ATN-2010	0.1	0.63		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-ATN-2020	0.1	0.67		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-ATN-2030	0.1	0.7		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-CON-2010	0.1	0.63		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-CON-2020	0.1	0.67		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-CON-2030	0.1	0.7		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-MED-2010	0.1	0.63		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-MED-2020	0.1	0.67		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-MED-2030	0.1	0.7		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-PAN-2010	0.1	0.63		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-PAN-2020	0.1	0.67		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
fermenter-300\biogas-manure-small-PAN-2030	0.1	0.7		0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
gas-CC-AT-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-AT-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-AT-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-BE-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-BE-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-BE-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-CZ-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-CZ-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-CZ-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-DE-2000	450.0	0.55		101,491.3	0.7	152.6	0.8	76.3	7.6	7.6	4.6
gas-CC-DE-2010	450.0	0.57		98,020.5	0.7	110.3	0.7	73.5	7.4	5.5	4.4
gas-CC-DE-2020	450.0	0.58		96,401.1	0.7	72.2	0.7	54.1	7.2	3.6	3.2
gas-CC-DE-2030	900.0	0.59		94,751.2	0.7	35.4	0.7	35.4	7.1	1.8	2.1

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
gas-CC-DK-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-DK-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-DK-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-DZ-2010	100.0	0.55		100,275.2	0.8	381.7	0.8	76.3	7.6	7.6	4.6
gas-CC-DZ-2020	100.0	0.57		96,756.8	0.8	368.3	0.7	73.7	7.4	7.4	4.4
gas-CC-DZ-2030	100.0	0.58		95,088.6	0.7	361.9	0.7	72.4	7.2	7.2	4.3
gas-CC-ES-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-ES-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-ES-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-EU-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-EU-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-EU-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-FI-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-FI-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-FI-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-FR-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-FR-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-FR-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-GR-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-GR-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-GR-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-HU-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-HU-2020	100.0	0.6		91,919.0	0.7	349.9	0.7	70.0	7.0	7.0	4.2
gas-CC-HU-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-IE-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-IE-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-IE-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-IT-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
gas-CC-IT-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-IT-2030	900.0	0.59		94,751.2	0.7	35.4	0.7	35.4	7.1	1.8	2.1
gas-CC-LU-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-LU-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-LU-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-NL-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-NL-2020	100.0	0.6		91,919.0	0.7	349.9	0.7	70.0	7.0	7.0	4.2
gas-CC-NL-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-NO-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-NO-2020	450.0	0.6		91,919.0	0.7	139.9	0.7	70.0	7.0	7.0	4.2
gas-CC-NO-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-PL-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-PL-2020	100.0	0.6		91,919.0	0.7	349.9	0.7	70.0	7.0	7.0	4.2
gas-CC-PL-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-PT-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-PT-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-PT-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-RU-2020	450.0	0.6		92,116.9	0.7	139.2	0.7	69.6	7.0	7.0	4.2
gas-CC-RU-2030	900.0	0.59		93,678.2	0.7	35.4	0.7	35.4	7.1	1.8	2.1
gas-CC-SE-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-SE-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-SE-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1
gas-CC-TR-2010	450.0	0.57		96,965.1	0.7	109.9	0.7	73.3	7.3	5.5	4.4
gas-CC-TR-2020	450.0	0.58		95,293.3	0.7	72.0	0.7	54.0	7.2	3.6	3.2
gas-CC-TR-2030	900.0	0.59		94,751.2	0.7	35.4	0.7	35.4	7.1	1.8	2.1
gas-CC-UK-2010	450.0	0.57		96,756.8	0.8	110.5	0.7	73.7	7.4	5.5	4.4
gas-CC-UK-2020	450.0	0.58		95,088.6	0.7	72.4	0.7	54.3	7.2	3.6	3.3
gas-CC-UK-2030	900.0	0.59		93,476.9	0.7	35.6	0.7	35.6	7.1	1.8	2.1

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
gas-GT-North Sea-2010	10.0	0.335		170,775.9	1.1	873.7	12.5	249.6	25.0	12.5	7.5
gas-GT-North Sea-2020	10.0	0.34		168,264.5	1.1	860.8	12.3	245.9	24.6	12.3	7.4
gas-GT-North Sea-2030	10.0	0.35		163,456.9	1.1	836.2	11.9	238.9	23.9	11.9	7.2
gas-heating-CZ-2010	0.0	0.86		64,252.5	0.0	25.9	0.3	16.2	0.8	1.3	0.4
gas-heating-CZ-2030	0.0	0.86		64,252.5	0.0	25.9	0.3	16.2	0.8	1.3	0.4
gas-heating-DE-2010	0.0	0.86		64,967.1	0.5	26.0	0.3	16.2	0.8	1.3	0.4
gas-heating-DE-2020	0.0	0.88		63,537.1	0.5	25.4	0.3	15.9	0.8	1.3	0.3
gas-heating-DE-2030	0.0	0.9		62,114.7	0.4	24.8	0.3	15.5	0.8	1.2	0.3
gas-heating-ES-2010	0.0	0.86		64,129.5	0.5	26.0	0.3	16.3	0.8	1.3	0.4
gas-heating-ES-2030	0.0	0.9		61,279.3	0.5	24.9	0.3	15.5	0.8	1.2	0.3
gas-heating-PL-2010	0.0	0.86		64,655.1	0.1	26.1	0.3	16.3	0.8	1.3	0.4
gas-heating-PL-2030	0.0	0.86		64,655.1	0.1	26.1	0.3	16.3	0.8	1.3	0.4
gas-heating-SE-2010	0.0	0.86		66,523.2	0.4	25.9	0.3	16.2	0.8	1.3	0.4
gas-heating-SE-2030	0.0	0.9		63,566.6	0.4	24.8	0.3	15.5	0.8	1.2	0.3
gasifier-aCFB+cleaning\gas-giant-reed-MED-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-giant-reed-MED-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-giant-reed-MED-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-ATC-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-ATC-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-ATC-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-MED-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-MED-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-MED-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-PAN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-PAN-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-miscanthus-PAN-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-ATC-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-ATC-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
gasifier-aCFB+cleaning\gas-straw-ATC-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-ATN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-ATN-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-ATN-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-CON-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-CON-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-CON-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-MED-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-MED-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-MED-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-PAN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-PAN-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-straw-PAN-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-ATC-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-ATC-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
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gasifier-aCFB+cleaning\gas-switchgrass-ATN-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-ATN-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-CON-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-CON-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-CON-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-PAN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-PAN-2020	9.7	0.9	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-switchgrass-PAN-2030	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-ATC-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-ATC-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-ATC-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
gasifier-aCFB+cleaning\gas-wood-forest-ATN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-ATN-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-ATN-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-CON-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-CON-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-CON-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-MED-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-MED-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-MED-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-PAN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-PAN-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-forest-PAN-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATC-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATC-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATC-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATN-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-ATN-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-CON-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-CON-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-CON-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-PAN-2010	9.7	0.81	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-PAN-2020	9.7	0.925	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-aCFB+cleaning\gas-wood-SRF-PAN-2030	9.7	0.95	0.1679	181.8	0.6	0.4	0.1	1.0	0.3	0.2	0.1
gasifier-EF+FT-synthesis\BtL-giant reed-MED-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-ATC-2020 (Diesel)/gross	500.0	0.4513	0.25	0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-ATC-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-ATC-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
gasifier-EF+FT-synthesis\BtL-miscanthus-MED-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-MED-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-PAN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-miscanthus-PAN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-ATC-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-ATC-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-ATN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-ATN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-CON-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-CON-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-MED-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-MED-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-PAN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-straw-PAN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-ATC-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-ATC-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-ATN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-ATN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-CON-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-CON-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-PAN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-switchgrass-PAN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-ATC-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-ATC-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-ATN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-ATN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-CON-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-CON-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9

	Power	eta	by-product	CO_2	SO_2	NO_X	Particulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
gasifier-EF+FT-synthesis\BtL-wood-forest-MED-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-MED-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-PAN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-forest-PAN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-ATC-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-ATC-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-ATN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-ATN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-CON-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-CON-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2010 (Diesel)/gross	500.0	0.4513	0.0306	0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2010 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2020 (Diesel)/gross	500.0	0.4513	0.0306	0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2030 (Diesel)/gross	500.0	0.4513	0.0306	0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-DE 2030 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-PAN-2020 (Diesel)/net	500.0	0.4513		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
gasifier-EF+FT-synthesis\BtL-wood-SRF-PAN-2030 (Diesel)/net	500.0	0.5		0.0	1.0	198.1	1.0	198.1	9.9	9.9	5.9
geothermal-ST-IT	20.0	1		34,000.0	750.0	0.0	0.0	0.0	0.0	0.0	0.0
giant-reed-heat plant MED-2010	1.0	0.85		0.0	167.0	66.0	12.5	89.1	13.2	5.9	1.2
giant-reed-heat plant MED-2030	1.0	0.88		0.0	161.3	47.8	3.7	62.1	3.2	3.2	0.6
landfill-gas-ICE-cogen 1 MW/gas	1.0	0.35		0.0	66.2	193.3	0.0	39.3	4.3	5.8	4.8
landfill-gas-ICE-cogen 1 MW/gas50%	1.0	0.35		0.0	66.2	193.3	0.0	39.3	4.3	5.8	4.8
landfill-gas-ICE-cogen 1 MW/gross	1.0	0.35	1.3143	0.0	66.2	193.3	0.0	39.3	4.3	5.8	4.8
landfill-gas-ICE-cogen 1 MW/oil50%	1.0	0.35		0.0	66.2	193.3	0.0	39.3	4.3	5.8	4.8
landfill-gas-ICE-cogen 1 MW-2010/gas	1.0	0.37		0.0	62.6	319.7	4.4	162.2	4.0	5.2	5.3
landfill-gas-ICE-cogen 1 MW-2010/gross	1.0	0.37	1.2162	0.0	62.6	319.7	4.4	162.2	4.0	5.2	5.3
landfill-gas-ICE-cogen 1 MW-2020/gas	1.0	0.39		0.0	59.4	126.3	4.2	153.9	3.7	4.9	5.0

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
landfill-gas-ICE-cogen 1 MW-2020/gross	1.0	0.39	1.1282	0.0	59.4	126.3	4.2	153.9	3.7	4.9	5.0
landfill-gas-ICE-cogen 1 MW-2030/gas	1.0	0.42		0.0	55.2	78.2	3.9	78.2	3.3	2.0	0.8
landfill-gas-ICE-cogen 1 MW-2030/gross	1.0	0.42	1	0.0	55.2	78.2	3.9	78.2	3.3	2.0	0.8
landfill-gas-ICE-cogen 200 OxCat-2020/gas	0.2	0.34		0.0	68.1	144.9	4.8	120.7	4.3	4.8	1.9
landfill-gas-ICE-cogen 200 OxCat-2020/gross	0.2	0.34	1.4412	0.0	68.1	144.9	4.8	120.7	4.3	4.8	1.9
landfill-gas-ICE-cogen 200 OxCat-2030/gas	0.2	0.37		0.0	62.6	88.8	4.4	88.8	4.0	2.2	0.9
landfill-gas-ICE-cogen 200 OxCat-2030/gross	0.2	0.37	1.2703	0.0	62.6	88.8	4.4	88.8	4.0	2.2	0.9
landfill-gas-ICE-cogen 200-OxCat/gas	0.2	0.3		0.0	7.7	225.5	5.6	45.8	5.1	6.8	5.6
landfill-gas-ICE-cogen 200-OxCat/gas50%	0.2	0.3		0.0	7.7	225.5	5.6	45.8	5.1	6.8	5.6
landfill-gas-ICE-cogen 200-OxCat/gross	0.2	0.3	1.7	0.0	7.7	225.5	5.6	45.8	5.1	6.8	5.6
landfill-gas-ICE-cogen 200-OxCat/oil	0.2	0.3		0.0	7.7	225.5	5.6	45.8	5.1	6.8	5.6
landfill-gas-ICE-cogen 200-OxCat/oil50%	0.2	0.3		0.0	7.7	225.5	5.6	45.8	5.1	6.8	5.6
landfillgas-ICE-cogen 200-OxCat-2010/gas	0.2	0.32		0.0	7.2	205.3	5.1	41.7	4.6	6.2	5.1
landfillgas-ICE-cogen 200-OxCat-2010/gross	0.2	0.32	1.65	0.0	7.2	205.3	5.1	41.7	4.6	6.2	5.1
landfill-gas-ICE-cogen 50-OxCat/gas	0.1	0.27		0.0	8.6	243.3	6.3	197.7	5.6	7.5	6.3
landfill-gas-ICE-cogen 50-OxCat/gross	0.1	0.27	2	0.0	8.6	250.6	6.3	197.7	5.6	7.5	6.3
landfill-gas-ICE-cogen 50-OxCat-2010/gas	0.1	0.29		0.0	79.9	203.9	5.7	169.9	4.8	5.7	5.7
landfill-gas-ICE-cogen 50-OxCat-2010/gross	0.1	0.29	1.8276	0.0	79.9	203.9	5.7	169.9	4.8	5.7	5.7
landfill-gas-ICE-cogen 50-OxCat-2020/gas	0.1	0.31		0.0	74.7	158.9	5.3	132.4	3.8	5.3	2.1
landfill-gas-ICE-cogen 50-OxCat-2020/gross	0.1	0.31	1.6774	0.0	74.7	158.9	5.3	132.4	3.8	5.3	2.1
landfill-gas-ICE-cogen 50-OxCat-2030/gas	0.1	0.34		0.0	68.1	96.6	4.8	96.6	2.8	2.4	1.0
landfill-gas-ICE-cogen 50-OxCat-2030/gross	0.1	0.34	1.4706	0.0	3.4	96.6	4.8	96.6	2.8	2.4	1.0
lignite-ST-BG-2010	300.0	0.3835		283,366.0	1639.7	557.2	38.3	175.1	5.8	5.8	8.9
lignite-ST-BG-2020	300.0	0.3985		272,700.7	1578.0	536.2	36.9	168.5	5.6	5.6	8.6
lignite-ST-BG-2030	800.0	0.4584		237,074.6	171.5	88.8	32.1	44.4	3.3	3.3	6.7
lignite-ST-DE-2010-Lausitz	800.0	0.4181		273,582.2	193.3	99.9	10.8	50.0	3.7	3.7	7.5
lignite-ST-DE-2010-rhine	600.0	0.4181		277,081.1	52.5	100.2	11.2	50.1	3.7	3.7	7.5
lignite-ST-DE-2020-Lausitz	800.0	0.4381		261,093.2	184.5	95.4	10.3	47.7	3.5	3.5	7.2

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
lignite-ST-DE-2020-rhine	600.0	0.4381		264,431.5	50.1	95.6	10.7	47.8	3.5	3.5	7.2
lignite-ST-DE-2030-Lausitz	800.0	0.4581		249,694.7	176.5	91.2	9.8	45.6	3.4	3.4	6.8
lignite-ST-DE-2030-rhine	600.0	0.4581		252,886.4	47.9	91.5	10.2	45.7	3.4	3.4	6.9
lignite-ST-EE-2010	95.0	0.3788		274,417.6	398.5	388.3	51.8	284.7	8.0	8.0	13.0
lignite-ST-EE-2020	95.0	0.3888		267,360.4	388.2	378.3	50.4	277.4	7.8	7.8	12.7
lignite-ST-EE-2030	95.0	0.4088		254,281.5	184.6	119.9	48.0	239.9	6.7	6.7	11.5
lignite-ST-GR-2010	300.0	0.3689		281,515.2	408.8	557.6	26.6	175.3	5.8	5.8	8.9
lignite-ST-GR-2020	300.0	0.3789		274,084.5	398.0	542.9	25.9	170.6	5.7	5.7	8.7
lignite-ST-GR-2030	300.0	0.3989		260,341.0	189.0	103.1	24.6	147.3	4.9	4.9	7.9
lignite-ST-HU-2010	1800.0	0.3863		281,307.5	313.4	347.1	19.0	178.8	5.0	5.0	29.6
lignite-ST-HU-2020	1800.0	0.4163		261,037.5	290.8	214.7	17.7	150.8	4.2	4.2	26.2
lignite-ST-HU-2030	1800.0	0.4363		249,072.7	138.7	204.9	16.8	143.9	4.0	4.0	25.0
lignite-ST-PL-2010	300.0	0.3684		294,988.0	341.4	580.0	69.1	182.3	6.1	6.1	9.3
lignite-ST-PL-2020	300.0	0.3784		287,192.9	332.4	564.7	67.3	177.5	5.9	5.9	9.0
lignite-ST-PL-2030	800.0	0.4584		237,074.6	171.5	88.8	32.1	44.4	3.3	3.3	6.7
lignite-ST-RO-2010	300.0	0.3835		283,366.0	1639.7	557.2	38.3	175.1	5.8	5.8	8.9
lignite-ST-RO-2020	300.0	0.3985		272,700.7	1578.0	536.2	36.9	168.5	5.6	5.6	8.6
lignite-ST-RO-2030	800.0	0.4584		237,074.6	171.5	88.8	32.1	44.4	3.3	3.3	6.7
lignite-ST-SK-2020	300.0	0.3784		287,192.9	332.4	403.3	67.3	177.5	5.9	5.9	9.0
lignite-ST-TR-2010	300.0	0.3826		238,520.0	7447.6	513.5	85.0	161.4	5.4	5.4	8.2
lignite-ST-TR-2020	300.0	0.3883		235,015.7	1467.6	506.0	8.4	159.0	5.3	5.3	8.1
lignite-ST-TR-2030	300.0	0.4133		220,799.2	689.4	95.1	7.9	135.8	4.5	4.5	7.2
miscanthus-cofiring coal-ST-2010	70.0	0.4439		0.0	39.0	107.6	4.0	39.9	4.0	4.0	11.2
miscanthus-cofiring-coal-cogen-BP-2010/gas	2.5	0.2789		0.0	46.5	254.9	7.2	68.0	6.8	1.4	134.6
miscanthus-cofiring-coal-cogen-BP-2010/gross	2.5	0.2789		0.0	46.5	254.9	7.2	68.0	6.8	1.4	134.6
miscanthus-cofiring-coal-cogen-BP-2020/gas	2.5	0.2989		0.0	43.4	237.9	6.7	63.4	6.3	1.3	125.6
miscanthus-cofiring-coal-cogen-BP-2020/gross	2.5	0.2989		0.0	43.4	237.9	6.7	63.4	6.3	1.3	125.6
miscanthus-cofiring-coal-cogen-BP-2030/gas	2.5	0.3189		0.0	40.7	222.9	6.3	59.5	5.9	1.2	117.7

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
miscanthus-cofiring-coal-cogen-BP-2030/gross	2.5	0.3189		0.0	40.7	222.9	6.3	59.5	5.9	1.2	117.7
miscanthus-gas-aCFB-ICE-cogen 1 MW-2010/gas	1.0	0.37		0.0	0.2	222.4	6.2	185.3	5.6	6.2	6.2
miscanthus-gas-aCFB-ICE-cogen 1 MW-2010/gross	1.0	0.37		0.0	0.2	222.4	6.2	185.3	5.6	6.2	6.2
miscanthus-gas-aCFB-ICE-cogen 1 MW-2020/gas	1.0	0.39		0.0	0.2	175.8	5.9	146.5	5.3	5.9	2.3
miscanthus-gas-aCFB-ICE-cogen 1 MW-2020/gross	1.0	0.39		0.0	0.2	175.8	5.9	146.5	5.3	5.9	2.3
miscanthus-gas-aCFB-ICE-cogen 1 MWW-2030/gas	1.0	0.42		0.0	0.2	108.8	5.4	108.8	5.0	2.7	1.1
miscanthus-gas-aCFB-ICE-cogen 1 MWW-2030/gross	1.0	0.42		0.0	0.2	108.8	5.4	108.8	5.0	2.7	1.1
miscanthus-heat plant ATC-2010	1.0	0.85		0.0	200.6	64.9	12.4	87.6	13.0	5.8	1.2
Miscanthus-heat plant ATC-2030	1.0	0.88		0.0	193.8	47.0	3.6	61.1	3.1	3.1	0.6
miscanthus-heat plant MED-2010	1.0	0.85		0.0	202.3	65.4	12.5	88.4	13.1	5.9	1.2
Miscanthus-heat plant MED-2030	1.0	0.88		0.0	195.4	47.4	3.7	61.6	3.2	3.2	0.6
miscanthus-heat plant PAN-2010	1.0	0.85		0.0	202.3	65.4	12.5	88.4	13.1	5.9	1.2
Miscanthus-heat plant PAN-2030	1.0	0.88		0.0	195.4	47.4	3.7	61.6	3.2	3.2	0.6
oil-heating-CZ-2010	0.0	0.85		87,498.4	82.7	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-CZ-2020	0.0	0.85		87,528.5	55.1	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-CZ-2030	0.0	0.85		87,558.5	27.6	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-DE-2000	0.0	0.85		87,503.8	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-DE-2010	0.0	0.85		87,528.5	55.1	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-DE-2020	0.0	0.85		87,558.5	27.6	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-DE-2030	0.0	0.85		87,660.6	5.5	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-ES-2010	0.0	0.85		87,503.8	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-ES-2030	0.0	0.85		87,503.8	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-HU-2000	0.0	0.85		87,488.9	110.4	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-HU-2010	0.0	0.85		87,498.4	82.7	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-HU-2020	0.0	0.85		87,528.5	55.1	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-HU-2030	0.0	0.85		87,558.5	27.6	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-PL-2010	0.0	0.85		87,498.4	82.7	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-PL-2020	0.0	0.85		87,483.3	91.0	27.0	1.9	30.4	1.5	0.1	0.7

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
oil-heating-PL-2030	0.0	0.85		87,558.5	27.6	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-RO-2010	0.0	0.85		87,498.4	82.7	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-RO-2020	0.0	0.85		87,483.3	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-RO-2030	0.0	0.85		87,558.5	27.6	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-SE-2010	0.0	0.85		87,503.8	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heating-SE-2030	0.0	0.85		87,503.8	91.0	27.0	1.9	30.4	1.5	0.1	0.7
oil-heavy-ST-CY-2010	50.0	0.3968		197,927.2	248.1	254.6	18.2	174.6	8.0	8.0	7.6
oil-heavy-ST-CY-2020	50.0	0.4168		188,429.5	118.1	242.4	17.3	166.2	7.6	7.6	7.3
oil-heavy-ST-CY-2030	50.0	0.4418		177,766.7	111.4	228.7	16.3	156.8	7.2	7.2	6.9
oil-heavy-ST-DE-2020	450.0	0.4168		188,974.4	117.8	103.2	13.3	68.8	7.2	7.2	7.2
oil-heavy-ST-MT-2010	50.0	0.3958		198,400.7	373.1	255.2	9.1	175.0	8.0	8.0	7.7
oil-heavy-ST-MT-2020	50.0	0.4108		191,157.1	359.4	123.0	8.8	140.5	7.0	7.0	7.0
oil-heavy-ST-MT-2030	50.0	0.4168		188,429.5	118.1	121.2	17.3	138.5	6.9	6.9	6.9
oil-heavy-ST-NL-2010	450.0	0.4168		187,912.1	212.0	103.7	10.4	69.1	7.3	7.3	7.3
oil-heavy-ST-NL-2020	450.0	0.4418		177,278.9	200.0	97.8	9.8	65.2	6.8	6.8	6.8
oil-heavy-ST-NL-2030	450.0	0.4418		177,278.9	200.0	97.8	9.8	65.2	6.8	6.8	6.8
oil-heavy-ST-RU-2020	400.0	0.4418		177,400.5	222.9	163.3	9.8	195.9	7.5	7.5	7.2
RME-heating ATC-2010	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
RME-heating ATC-2030	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
RME-heating CON-2010	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
RME-heating CON-2030	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
RME-heating PAN-2010	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
RME-heating PAN-2030	0.0	0.85		0.0	3.2	27.1	1.9	30.5	1.5	0.1	0.7
sewage-gas-ICE-cogen 200-oxcat-2010/gas	0.2	0.32		0.0	0.0	187.1	5.2	32.5	3.6	2.6	5.2
sewage-gas-ICE-cogen 200-oxcat-2010/gross	0.2	0.32	1.5625	0.0	0.0	187.1	5.2	32.5	3.6	2.6	5.2
sewage-gas-ICE-cogen 200-OxCat-2020/gas	0.2	0.34		0.0	0.0	146.7	4.9	30.6	3.4	2.4	2.0
sewage-gas-ICE-cogen 200-OxCat-2020/gross	0.2	0.34	1.4412	0.0	0.0	146.7	4.9	30.6	3.4	2.4	2.0
sewage-gas-ICE-cogen 200-OxCat-2030/gas	0.2	0.37		0.0	0.0	89.9	4.5	22.5	2.5	1.1	0.9

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
sewage-gas-ICE-cogen 200-OxCat-2030/gross	0.2	0.37	1.2703	0.0	0.0	89.9	4.5	22.5	2.5	1.1	0.9
sewage-gas-ICE-cogen 50-oxcat-2010/gas	0.1	0.29		0.0	0.0	206.4	5.7	43.0	4.8	2.9	5.7
sewage-gas-ICE-cogen 50-oxcat-2010/gross	0.1	0.29	1.8276	0.0	0.0	206.4	5.7	43.0	4.8	2.9	5.7
sewage-gas-ICE-cogen 50-OxCat-2020/gas	0.1	0.31		0.0	0.0	160.9	5.4	134.1	3.8	5.4	2.1
sewage-gas-ICE-cogen 50-OxCat-2020/gross	0.1	0.31	1.6774	0.0	0.0	160.9	5.4	134.1	3.8	5.4	2.1
sewage-gas-ICE-cogen 50-OxCat-2030/gas	0.1	0.34		0.0	0.0	97.8	4.9	97.8	2.8	2.4	1.0
sewage-gas-ICE-cogen 50-OxCat-2030/gross	0.1	0.34	1.4706	0.0	0.0	97.8	4.9	97.8	2.8	2.4	1.0
SME-heating MED-2010	0.0	0.85		0.0	6.3	26.6	1.8	30.0	1.5	0.1	0.7
SME-heating MED-2030	0.0	0.85		0.0	6.3	26.6	1.8	30.0	1.5	0.1	0.7
straw-bales-cofiring coal-ST-2010	35.0	0.4439		0.0	9.7	108.1	3.7	40.0	4.0	4.0	11.2
straw-bales-cofiring-coal-ST-2020	35.0	0.4609		0.0	9.3	104.1	3.6	38.6	3.9	3.9	10.8
straw-bales-cofiring-coal-ST-2030	35.0	0.4999		0.0	8.6	64.0	3.3	14.2	3.6	3.6	3.6
switchgrass-heat plant ATC-2010	1.0	0.85		0.0	146.3	71.3	27.1	96.2	14.3	6.4	1.3
switchgrass-heat plant ATC-2030	1.0	0.88		0.0	141.3	51.6	7.9	67.1	3.4	3.4	0.7
switchgrass-heat plant ATN-2010	1.0	0.85		0.0	146.3	71.3	27.1	96.2	14.3	6.4	1.3
switchgrass-heat plant ATN-2030	1.0	0.88		0.0	141.3	51.6	7.9	67.1	3.4	3.4	0.7
switchgrass-heat plant CON-2010	1.0	0.85		0.0	146.3	71.3	27.1	96.2	14.3	6.4	1.3
switchgrass-heat plant CON-2030	1.0	0.88		0.0	141.3	51.6	7.9	67.1	3.4	3.4	0.7
switchgrass-heat plant PAN-2010	1.0	0.85		0.0	146.3	71.3	27.1	96.2	14.3	6.4	1.3
switchgrass-heat plant PAN-2030	1.0	0.88		0.0	141.3	51.6	7.9	67.1	3.4	3.4	0.7
wood-chips-forest-cofiring coal-ST-2010	70.0	0.4437		0.0	3.9	110.2	0.4	40.8	4.1	4.1	11.4
wood-chips-forest-cofiring-coal-ST-2020	70.0	0.4607		0.0	3.7	106.1	0.4	39.3	3.9	3.9	11.0
wood-chips-forest-cofiring-coal-ST-2030	70.0	0.4997		0.0	3.4	65.2	0.3	14.5	3.6	3.6	3.6
wood-chips-forest-cogen-ORC/gas	0.8	0.11		0.0	296.8	493.8	81.0	740.7	246.9	24.7	4.9
wood-chips-forest-cogen-ORC/gas50%	0.8	0.11		0.0	296.8	493.8	81.0	740.7	246.9	24.7	4.9
wood-chips-forest-cogen-ORC/gross	0.8	0.11	6.3636	0.0	296.8	493.8	81.0	740.7	246.9	24.7	4.9
wood-chips-forest-cogen-ORC/oil	0.8	0.11		0.0	296.8	493.8	81.0	740.7	246.9	24.7	4.9
wood-chips-forest-cogen-ORC/oil50%	0.8	0.11		0.0	296.8	493.8	81.0	740.7	246.9	24.7	4.9

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
wood-chips-forest-cogen-ORC-2010/gas	0.8	0.12		0.0	272.1	452.7	44.6	509.2	169.7	22.6	4.5
wood-chips-forest-cogen-ORC-2010/gross	0.8	0.12	5.75	0.0	272.1	452.7	44.6	509.2	169.7	22.6	4.5
wood-chips-forest-cogen-ORC-2020/gross	0.8	0.14	4.9286	0.0	233.2	388.0	25.5	291.0	97.0	14.5	2.9
wood-chips-forest-cogen-ORC-2020/gs	0.8	0.14		0.0	233.2	388.0	25.5	291.0	97.0	14.5	2.9
wood-chips-forest-cogen-ORC-2030/gas	0.8	0.15		0.0	217.7	362.1	11.9	135.8	45.3	9.1	1.8
wood-chips-forest-cogen-ORC-2030/gross	0.8	0.15	4.6	0.0	217.7	362.1	11.9	135.8	45.3	9.1	1.8
wood-chips-forest-cogen-SE/gas	0.8	0.12		0.0	272.1	452.7	74.3	679.0	226.3	22.6	4.5
wood-chips-forest-cogen-SE/gas50%	0.8	0.12		0.0	272.1	452.7	74.3	679.0	226.3	22.6	4.5
wood-chips-forest-cogen-SE/gross	0.8	0.12	5.6667	0.0	272.1	452.7	74.3	679.0	226.3	22.6	4.5
wood-chips-forest-cogen-SE/oil	0.8	0.12		0.0	272.1	452.7	74.3	679.0	226.3	22.6	4.5
wood-chips-forest-cogen-SE/oil50%	0.8	0.12		0.0	272.1	452.7	74.3	679.0	226.3	22.6	4.5
wood-chips-forest-cogen-SE-2010/gas	0.8	0.14		0.0	233.2	388.0	38.2	436.5	145.5	19.4	3.9
wood-chips-forest-cogen-SE-2010/gross	0.8	0.14	4.7143	0.0	233.2	388.0	38.2	436.5	145.5	19.4	3.9
wood-chips-forest-cogen-SE-2020/gas	0.8	0.16		0.0	204.1	339.5	22.3	254.6	84.9	12.7	2.5
wood-chips-forest-cogen-SE-2020/gross	0.8	0.16	4.125	0.0	204.1	339.5	22.3	254.6	84.9	12.7	2.5
wood-chips-forest-cogen-SE-2030/gas	0.8	0.17		0.0	192.1	319.5	10.5	119.8	39.9	8.0	1.6
wood-chips-forest-cogen-SE-2030/gross	0.8	0.17	3.8824	0.0	192.1	319.5	10.5	119.8	39.9	8.0	1.6
wood-chips-forest-cogen-stirling/gas	0.1	0.12		0.0	272.1	679.0	144.0	565.8	226.3	28.3	11.3
wood-chips-forest-cogen-stirling/gas50%	0.1	0.12		0.0	272.1	679.0	144.0	565.8	226.3	28.3	11.3
wood-chips-forest-cogen-stirling/gross	0.1	0.12	5.6667	0.0	272.1	679.0	144.0	565.8	226.3	28.3	11.3
wood-chips-forest-cogen-stirling/oil	0.1	0.12		0.0	272.1	679.0	144.0	565.8	226.3	28.3	11.3
wood-chips-forest-cogen-stirling/oil50%	0.1	0.12		0.0	272.1	679.0	144.0	565.8	226.3	28.3	11.3
wood-chips-forest-cogen-stirling-2030/gas	0.1	0.21		0.0	155.5	388.0	82.3	323.3	129.3	16.2	6.5
wood-chips-forest-cogen-stirling-2030/gross	0.1	0.21	2.9524	0.0	155.5	388.0	82.3	323.3	129.3	16.2	6.5
wood-chips-forest-heating ATC-2010	0.1	0.87		0.0	29.6	105.4	43.6	105.4	35.1	35.1	1.4
wood-chips-forest-heating ATC-2030	0.1	0.9		0.0	28.6	73.6	20.7	73.6	18.9	18.9	0.8
wood-chips-forest-heating ATN-2010	0.1	0.87		0.0	29.6	105.4	43.6	105.4	35.1	35.1	1.4
wood-chips-forest-heating ATN-2030	0.1	0.9		0.0	28.6	73.6	20.7	73.6	18.9	18.9	0.8

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ$_{out}$**							
wood-chips-forest-heating CON-2010	0.1	0.87		0.0	29.6	105.4	43.6	105.4	35.1	35.1	1.4
wood-chips-forest-heating CON-2030	0.1	0.9		0.0	28.6	73.6	20.7	73.6	18.9	18.9	0.8
wood-chips-forest-heating MED-2010	0.1	0.87		0.0	29.6	105.4	43.6	105.4	35.1	35.1	1.4
wood-chips-forest-heating MED-2030	0.1	0.9		0.0	28.6	73.6	20.7	73.6	18.9	18.9	0.8
wood-chips-forest-heating PAN-2010	0.1	0.87		0.0	29.6	105.4	43.6	105.4	35.1	35.1	1.4
wood-chips-forest-heating PAN-2030	0.1	0.9		0.0	28.6	73.6	20.7	73.6	18.9	18.9	0.8
wood-chips-SRC-heating ATC-2010	0.1	0.87		0.0	34.6	105.3	127.3	105.3	35.1	35.1	1.4
wood-chips-SRC-heating ATC-2030	0.1	0.9		0.0	33.4	73.5	61.1	73.5	18.9	18.9	0.8
wood-chips-SRC-heating ATN-2010	0.1	0.87		0.0	34.6	105.3	127.3	105.3	35.1	35.1	1.4
wood-chips-SRC-heating ATN-2030	0.1	0.9		0.0	33.4	73.5	61.1	73.5	18.9	18.9	0.8
wood-chips-SRC-heating CON-2010	0.1	0.87		0.0	34.6	105.3	127.3	105.3	35.1	35.1	1.4
wood-chips-SRC-heating CON-2030	0.1	0.9		0.0	33.4	73.5	61.1	73.5	18.9	18.9	0.8
wood-chips-SRC-heating PAN-2010	0.1	0.87		0.0	34.6	105.3	127.3	105.3	35.1	35.1	1.4
wood-chips-SRC-heating PAN-2030	0.1	0.9		0.0	33.4	73.5	61.1	73.5	18.9	18.9	0.8
wood-chips-SRF-poplar-cofiring coal-ST-2010	70.0	0.4437		0.0	9.0	110.1	4.1	40.8	4.1	4.1	11.4
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2010/gas	5.0	0.2789		0.0	10.8	260.8	9.6	69.5	7.0	1.4	166.9
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2010/gross	5.0	0.2789	2.1	0.0	10.8	260.8	9.6	69.5	7.0	1.4	166.9
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2020/gas	5.0	0.2989		0.0	10.1	243.3	9.0	64.9	6.5	1.3	155.7
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2020/gross	5.0	0.2989	2	0.0	10.1	243.3	9.0	64.9	6.5	1.3	155.7
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2030/gas	5.0	0.2989		0.0	10.1	243.3	9.0	64.9	6.5	1.3	155.7
wood-chips-SRF-poplar-cofiring-coal-cogen-BP-2030/gross	5.0	0.2989	1.8	0.0	10.1	243.3	9.0	64.9	6.5	1.3	155.7
wood-chips-SRF-poplar-cofiring-coal-ST-2020	70.0	0.4607		0.0	8.7	106.1	4.0	39.3	3.9	3.9	11.0
wood-chips-SRF-poplar-cofiring-coal-ST-2030	70.0	0.4997		0.0	4.0	65.2	3.7	14.5	3.6	3.6	3.6
wood-chips-SRF-poplar-cogen-ORC-SNCR-2010/gas	0.8	0.13		0.0	293.1	835.4	42.1	469.9	156.6	20.9	4.2
wood-chips-SRF-poplar-cogen-ORC-SNCR-2010/gross	0.8	0.13	5.2308	0.0	293.1	835.4	42.1	469.9	156.6	20.9	4.2
wood-chips-SRF-poplar-cogen-ORC-SNCR-2020/gas	0.8	0.15		0.0	254.1	724.0	36.5	271.5	90.5	13.6	2.7
wood-chips-SRF-poplar-cogen-ORC-SNCR-2020/gross	0.8	0.15	4.5333	0.0	254.1	724.0	36.5	271.5	90.5	13.6	2.7
wood-chips-SRF-poplar-cogen-ORC-SNCR-2030/gas	0.8	0.16		0.0	238.2	678.7	34.2	127.3	42.4	8.5	1.7

	Power	eta	by-product	CO_2	SO_2	NO_X	Partic-ulates	CO	NMVOC	CH_4	N_2O
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
wood-chips-SRF-poplar-cogen-ORC-SNCR-2030/gross	0.8	0.16	4.25	0.0	238.2	678.7	34.2	127.3	42.4	8.5	1.7
wood-chips-SRF-poplar-cogen-SE-SNCR-2010/gas	0.8	0.14		0.0	272.2	775.7	39.1	436.3	145.4	19.4	3.9
wood-chips-SRF-poplar-cogen-SE-SNCR-2010/gross	0.8	0.14	4.7143	0.0	272.2	775.7	39.1	436.3	145.4	19.4	3.9
wood-chips-SRF-poplar-cogen-SE-SNCR-2020/gas	0.8	0.16		0.0	238.2	678.7	34.2	254.5	84.8	12.7	2.5
wood-chips-SRF-poplar-cogen-SE-SNCR-2020/gross	0.8	0.16	4.125	0.0	238.2	678.7	34.2	254.5	84.8	12.7	2.5
wood-chips-SRF-poplar-cogen-SE-SNCR-2030/gas	0.8	0.17		0.0	224.2	638.8	32.2	119.8	39.9	8.0	1.6
wood-chips-SRF-poplar-cogen-SE-SNCR-2030/gross	0.8	0.17	3.8824	0.0	224.2	638.8	32.2	119.8	39.9	8.0	1.6
wood-chips-SRF-poplar-heat plant ATC-2010	1.0	0.85		0.0	44.8	63.9	25.5	86.2	12.8	5.7	1.1
wood-chips-SRF-poplar-heat plant ATC-2030	1.0	0.88		0.0	43.3	46.3	12.3	60.2	3.1	3.1	0.6
wood-chips-SRF-poplar-heat plant ATN-2010	1.0	0.85		0.0	44.8	63.9	25.5	86.2	12.8	5.7	1.1
wood-chips-SRF-poplar-heat plant ATN-2030	1.0	0.88		0.0	43.3	46.3	12.3	60.2	3.1	3.1	0.6
wood-chips-SRF-poplar-heat plant CON-2010	1.0	0.85		0.0	44.8	63.9	25.5	86.2	12.8	5.7	1.1
wood-chips-SRF-poplar-heat plant CON-2030	1.0	0.88		0.0	43.3	46.3	12.3	60.2	3.1	3.1	0.6
wood-chips-SRF-poplar-heat plant PAN-2010	1.0	0.85		0.0	44.8	63.9	25.5	86.2	12.8	5.7	1.1
wood-chips-SRF-poplar-heat plant PAN-2030	1.0	0.88		0.0	43.3	46.3	12.3	60.2	3.1	3.1	0.6
wood-forest-chips-cofiring-coal-cogen-BP/gas	5.0	0.2677		0.0	9.6	271.7	12.9	72.5	7.2	1.4	191.3
wood-forest-chips-cofiring-coal-cogen-BP/gas50%	5.0	0.2677		0.0	9.6	271.7	12.9	72.5	7.2	1.4	191.3
wood-forest-chips-cofiring-coal-cogen-BP/gross	5.0	0.2677	2.22	0.0	9.6	271.7	12.9	72.5	7.2	1.4	191.3
wood-forest-chips-cofiring-coal-cogen-BP/oil	5.0	0.2677		0.0	9.6	271.7	12.9	72.5	7.2	1.4	191.3
wood-forest-chips-cofiring-coal-cogen-BP/oil50%	5.0	0.2677		0.0	9.6	271.7	12.9	72.5	7.2	1.4	191.3
wood-forest-chips-cofiring-coal-cogen-BP-2010/gas	5.0	0.2789		0.0	9.2	260.9	12.4	69.6	7.0	1.4	183.6
wood-forest-chips-cofiring-coal-cogen-BP-2010/gross	5.0	0.2789	2.1	0.0	9.2	260.9	12.4	69.6	7.0	1.4	183.6
wood-forest-chips-cofiring-coal-cogen-BP-2020/gas	5.0	0.2989		0.0	8.6	243.4	11.6	64.9	6.5	1.3	171.4
wood-forest-chips-cofiring-coal-cogen-BP-2020/gross	5.0	0.2989	2	0.0	8.6	243.4	11.6	64.9	6.5	1.3	171.4
wood-forest-chips-cofiring-coal-cogen-BP-2030/gas	5.0	0.2989		0.0	8.6	243.4	11.6	64.9	6.5	1.3	171.4
wood-forest-chips-cofiring-coal-cogen-BP-2030/gross	5.0	0.2989	1.8	0.0	8.6	243.4	11.6	64.9	6.5	1.3	171.4
wood-forest-chips-cofiring-coal-ST	70.0	0.3787		0.0	9.1	57.4	0.5	47.8	9.6	4.8	13.4
wood-forest-syngas-CC-big-2010	216.0	0.54		0.0	0.0	159.9	0.8	80.0	8.0	8.0	4.8

	Power	**eta**	**by-product**	**CO_2**	**SO_2**	**NO_X**	**Partic-ulates**	**CO**	**NMVOC**	**CH_4**	**N_2O**
Process Name	**[MW]**		**factor**	**g/GJ_{out}**							
wood-forest-syngas-CC-big-2020	216.0	0.58		0.0	0.0	159.9	0.8	80.0	8.0	8.0	4.8
wood-forest-syngas-CC-big-2030	216.0	0.59		0.0	0.0	159.9	0.8	80.0	8.0	8.0	4.8
woodgas-aCFB-wood-SRF-ICE-cogen-ATC-2010/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-ATC-2030/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-ATN-2010/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-ATN-2030/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-CON-2010/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-CON-2030/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-PAN-2010/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
woodgas-aCFB-wood-SRF-ICE-cogen-PAN-2030/gas	1.0	0.37		0.0	0.2	225.2	6.3	202.2	5.6	8.4	3.8
wood-pellet-wood-industry-heating ATC-2010	0.0	0.86		0.0	36.6	82.9	19.7	69.1	15.3	3.5	1.4
wood-pellet-wood-industry-heating ATC-2030	0.0	0.88		0.0	35.8	67.5	19.2	48.7	9.4	1.9	0.7
wood-pellet-wood-industry-heating ATN-2010	0.0	0.86		0.0	36.6	82.9	19.7	69.1	15.3	3.5	1.4
wood-pellet-wood-industry-heating ATN-2030	0.0	0.88		0.0	35.8	67.5	19.2	48.7	9.4	1.9	0.7
wood-pellet-wood-industry-heating CON-2010	0.0	0.86		0.0	36.6	82.9	19.7	69.1	15.3	3.5	1.4
wood-pellet-wood-industry-heating CON-2030	0.0	0.88		0.0	35.8	67.5	19.2	48.7	9.4	1.9	0.7
wood-pellet-wood-industry-heating MED-2010	0.0	0.86		0.0	36.6	82.9	19.7	69.1	15.3	3.5	1.4
wood-pellet-wood-industry-heating MED-2030	0.0	0.88		0.0	35.8	67.5	19.2	48.7	9.4	1.9	0.7
wood-pellet-wood-industry-heating PAN-2010	0.0	0.86		0.0	36.6	82.9	19.7	69.1	15.3	3.5	1.4
wood-pellet-wood-industry-heating PAN-2030	0.0	0.88		0.0	35.8	67.5	19.2	48.7	9.4	1.9	0.7