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Link to International Energy Agency (IEA)

1 Description of IEA Task 38

The IEA Task "Greenhouse Gas Balances of Biomass and Bioenergy Systems" lasts for the period 2001 – 2003.

Interest in reducing emissions of greenhouse gases to the atmosphere has increased recently, largely due to awareness of the risk of climate change, and due to the adoption of the Kyoto Protocol. Countries are preparing to implement programs that aim at limiting emissions of greenhouse gases. Bioenergy is a very attractive option to pursue this goal. In particular, the IEA Bioenergy position paper on bioenergy and greenhouse gases[1] states: "Biomass can play a dual role in greenhouse gas mitigation related to the objectives of the UFCCC, i.e. as an energy source to substitute for fossil fuels, and as a carbon reservoir ... Modern bioenergy options offer significant, cost-effective and perpetual opportunities toward meeting emission reduction targets ... Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential for resolving some of the critical issues surrounding long-term maintenance of biotic carbon stocks. Finally, wood products can act as substitutes for more energy-intensive products, can constitute carbon sinks, and can be used as biofuels at the end of their lifetime". This statement sets the frame for the following proposal.

The Task builds on the achievements of its predecessor, Task 25 (Greenhouse Gas Balances of Bioenergy Systems). While the previous Task 25 has been concentrating on scientific-technical and on methodological issues, there has been increasing demand for information that aids decision makers in implementing programs to limit emissions or enhance removals of greenhouse gases. Therefore the scope of this Tasks concentrates more on the application of methods, and on aiding the implementation of mitigation projects and programs. In addition, the work of Task 25 has increasingly been looking at activities that enhance carbon stocks, or limit the loss of carbon stocks, in the terrestrial biosphere.

The objectives of the Task can be split into scientific/methodological objectives and objectives relating to implementation.

1.1 Scientific/methodological objectives

- Develop, compare and make available, integrated computer models for assessing greenhouse gas (GHG) balances of bioenergy and carbon sequestration systems on the project, activity, and regional levels, and address scaling issues between these levels.
- Assess the life-cycle GHG balance of such systems, including leakage, additionality, and uncertainties. These analyses must integrate forest and agricultural sectors, bioenergy production and conversion, and carbon sequestration considerations. The work will include comparisons of bioenergy systems with "conventional" and other energy systems (e.g., fossil, nuclear, and renewable), as well as comparisons of wood products with products from other materials such as steel and concrete.
- Analyse the country-level, and regional potentials of bioenergy, forestation, and other biomass-based mitigation strategies, including implications for the atmospheric CO_2 concentration.

[1] Position Paper on "The Role of Bioenergy in Greenhouse Gas Mitigation" that was prepared and widely distributed through the predecessor of the proposed Task, IEA Bioenergy Task 25 (www.joanneum.ac.at/iea-bioenergy-task38/pospapa4.pdf).

- Identify and analyze the synergies between afforestation and other land-based activities for carbon sequestration and the enhanced use of bioenergy.
- In pursuit of the listed above, collaborate with other Tasks of IEA Bioenergy, for example, on conventional forestry, short-rotation forestry, techno-economic assessment, socio-economic aspects. The Task proposed here is cross-cutting in nature, and will rely heavily on exchange of information with these other Tasks

1.2 Objectives related to implementation

The following objectives relate to implementation of projects and of GHG inventories at various levels (including corporate and national), and national/international environmental agreements such as the Kyoto Protocol.

- Aid decision makers in developing policies and selecting appropriate mitigation strategies that optimise GHG benefits, e.g. how to maximise bioenergy production while maintaining carbons stocks at high levels, or how to allocate biomass to energy vs. uses as raw material. Consider cost/benefit analyses and the practicalities of different mitigation strategies.
- Assist in the implementation of land use, land-use change and forestry (LULUCF) articles of the Kyoto Protocol as they relate to bioenergy and carbon sequestration. This applies at the project, region, and country level. Specifically articles 3.3, 3.4, 3.7, 6 and possibly 12. Development of procedures, methods and models that enable participating countries in the Task to address issues covered by these articles.
- Contribute to the work of IPCC/OECD/IEA related to GHG inventories of systems involving carbon sequestration, wood products, bioenergy, baselines in LULUCF. Contribute to the achievement of goals stated in Kyoto Protocol Article 5.1 through development of procedures, methods and models, that enable countries to develop national- and project-scale systems for estimating GHG sources and sinks related to LULUCF and biomass energy.
- Contribute to the development of international standards for GHG accounting and verification in the LULUCF sectors.
- Help elaborate a GHG accounting framework for bioenergy projects and carbon sequestration projects in a “joint implementation” or “CDM” setting. This includes baselines, leakage, uncertainty, and requires consideration of both reduction in fossil fuel emission and changes in terrestrial carbon stocks.

2 Greenhouse gas emissions of CHP plants - Austrian case Study

This case study is taken from Jungmeier et al. 1999.

One important aspect of environmental and energy policy in most of the European countries is the reduction of greenhouse gas emissions, in particular these gases are carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O). Possibilities for the reduction in the energy sector are an improvement in energy efficiency and the use of renewable energy like hydro power, biomass, solar energy and wind instead of fossil energy.

This Austrian case study deals with the quantification of greenhouse gas emissions of bioenergy systems and the comparison with the greenhouse gas emissions of fossil energy systems. Bioenergy systems are defined as a combination of different technical installations, that use solid, liquid and gaseous fuels from biogenic resources to supply heat and electricity. These resources originate from forestry, agriculture, trade and industry. Bioenergy systems

for the combined supply of heat and electricity that are expected for the Austrian situation in the year 2000 and 2020, are analysed.
This case study follows the international standard ISO 14 040 „Life Cycle Assessment".

2.1 Scope and goal of the study

The goal of the study was to analyse different bioenergy systems for the combined electricity and heat supply from various biomass sources. The emissions of greenhouse gases are calculated over the entire life cycle including land use change and by-products. The emissions are compared to fossil energy systems. Because of the increased use of bioenergy as one promising option to reduce greenhouse gas emissions, this comparison may help policy makers, utilities and industry to identify effective biomass options to reach emission reduction targets e. g. Kyoto Protocol.
The bioenergy systems and fossil energy systems are chosen from all possible energy systems, that are or might be important for electricity and heat supply in Austria in the year 2000 and 2020. The different modules of which the bioenergy systems and the fossil energy systems may consist, are shown in Figure 1 and Figure 2. In addition to these modules there are modules for the extraction (e. g. cultivation and harvesting), for transport and for conversion at the consumer side (e. g. heat pump). For example the considered bioenergy systems are combinations of biomass production, processing, transport, fuels and conversion.
The comparison is made for heat and electricity supply at the consumer side, that means electricity at the socket and heat in the room where it is needed. The function of the energy systems is to supply heat at a temperature of 35 - 60°C for space heating and electricity with 230 V and 50 Hz. The functional unit is the greenhouse gas emissions of CO_2, CH_4 and N_2O in CO_2-eq. systems with combined heat and power production per 0,33 kWh of electricity and 0,67 kWh of heat (g CO_2-eq. (0,33 $kWh_{electricity}$ + 0,33 $kWh_{heat})^{-1}$).

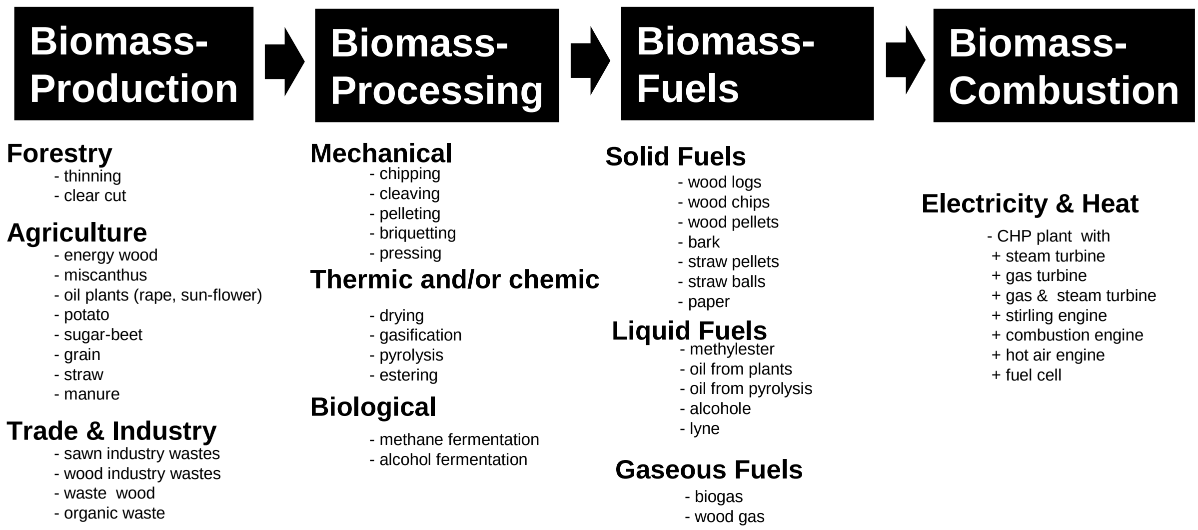

Figure 1: Modules of bioenergy systems

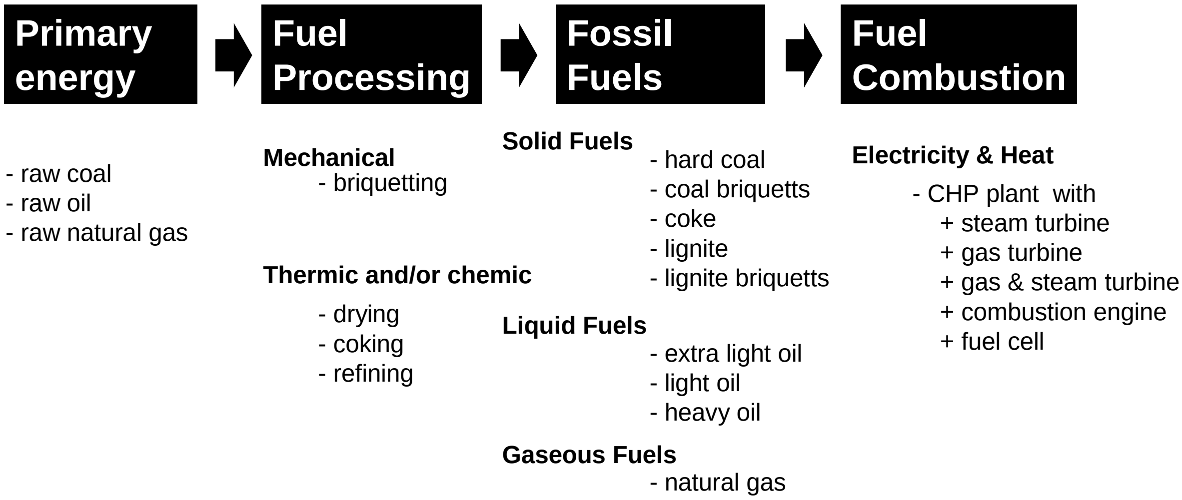

Figure 2: Modules of fossil energy systems

On the basis of a life cycle analyses the greenhouse gas emissions of the construction phase, the operation phase and the dismantling phase of the energy systems with CHP plants are analysed including the use of by-products. The reference systems with fossil energy systems also include the avoided reference use of the biomass or the area (Figure 3). The reference use describes what happens with the biomass, if it is not used for energy or what happens on an arable area, if no biogenic resources are produced. For example in the case of biogas production the avoided reference use of biomass is the storage of the manure, in the case of short rotation forestry the avoided reference use of the area is set aside land[2]. By-products are compulsorily produced during the supply of fuels, e. g. cake during the production of vegetable oil, that is used as feeding material substituting other feed like soya. The emissions from the production of these substituted products are subtracted from the energy system. In the system boundaries all processes are included that take part in the electricity or/and heat supply, starting with the extraction of raw materials from nature and ending with the disposal from energy and material to the environment.

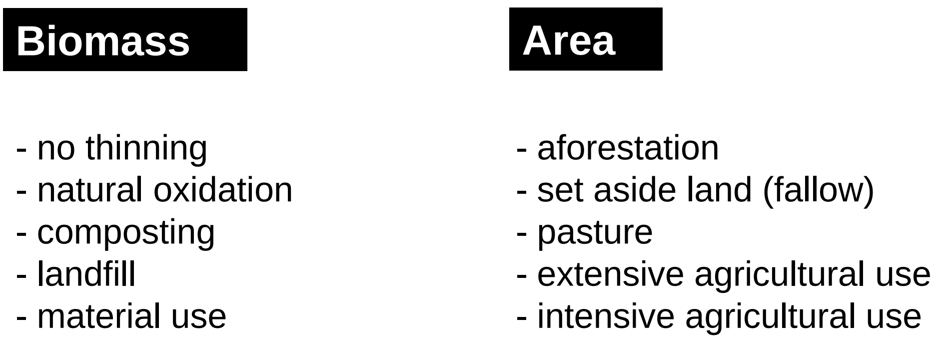

Figure 3: Modules of reference use of biomass and area

The adequate combination of these modules enables the description of all possible energy systems. As an example the combination of fuel and combustion is shown in Figure 4 for bioenergy, that shows, which fuel is used in which combustion plant, the analysed combination are marked with “C” for current technology in the year 2000 and “F” for future technology in the year 2020.

[2] The reference use of fossil energy carrier is to remain in the ground, which has no effect on greenhouse gas emissions and therefore no further regard is necessary.

In total 34 bioenergy systems for combined heat and electricity supply and for comparison 18 fossil energy systems for combined heat and electricity supply are analysed.

	Combustion								
	heat and electricity								
Fuel	CHP plant steam turbine	CHP plant steam engine	CHP plant ORC-prozess	CHP plant stirling engine	CHP plant hot air turbine	CHP plant fuel cell	CHP plant gas turbine	CHP plant steam & gas turbine	CHP plant combustion engine
Solid fuels									
wood cips	C, F	C, F	F	F	F	F	F	F	
bark	C								
savings	C, F	C, F	F	F	F	F	F	F	
waste paper	C								
sewage sludge	C								
Liquid fuels									
methylester									C, F
oil from plants									C, F
oil from pyrolysis									F
alcohole									C, F
black lliquer	C, F								
gaseous fuels									
biogas									C, F
wood-gas									F

C.....current technology 2000
F.....future technology 2020

Figure 4: Fuel/combustion combination for bioenergy systems with CHP plants

The amount of greenhouse gases that is emitted the combined supply of 0,33 kWh electricity and 0,67 kWh heat in systems with combined heat and power plants, are calculated in a life cycle analyses of the bioenergy systems and the fossil energy systems. The results are the greenhouse gas emission factors. The difference between the greenhouse gas emission factor of the bioenergy system and the fossil energy system is a proportion for the change of greenhouse gas emissions by substituting fossil energy systems with bioenergy systems.

2.2 Inventory analyses

The inventory analyses is the calculation of all inputs and outputs of an energy system during its entire life cycle. The results of the inventory are the emission factors for CO_2, CH_4 and N_2O.

Carbon dioxide (CO_2), an odourless and tasteless carbon-oxygen-combination, originates as the main product of carbon combustion. The amount of CO_2 per energy unit emitted is dependent above all on the carbon content of the fuel. CO_2 originates from the natural oxidation of biomass. In the process of photosynthesis CO_2 from the atmosphere is fixed in the plants (biomass) again.

Methane (CH_4), an inflammable carbon-hydrate combination, is the main product of natural gas and a product of the incomplete combustion. Further on CH_4 originates from the anaerobic digestion of biomass. CH_4-emissions also arise from coal mining and from exploration of oil and gas.

Nitrogen oxide (N_2O) is a colourless and toxic nitrogen-oxygen combination, that arise from certain conditions during combustion processes. Thereby the amount of emitted N_2O depends on the nitrogen content of the fuel and the combustion temperature. N_2O-emissions also originate from nitrification- and denitrification processes especially in soil after the application of mineral nitrogen fertiliser and during the storage of manure.

The inventory analysis is used for the impact assessment by using the Global Warming Potential for 100 years to calculate the cumulative effect on global warming, that gives the contribution of different gases to the greenhouse effect as an equivalent amount of CO_2 [1]. This concept was developed to make the contribution of different greenhouse gases to Global Warming comparable. The effect on Global Warming of one kilogram of the different gases is shown as a multiple of the effect of one kilogram of CO_2 (“equivalent factors”). With these equivalent factors the amounts of CH_4 and N_2O are calculated as equivalent amounts of CO_2-equivalent (CO_2-eq.).

Because CH_4 and N_2O have different lifetimes in the atmosphere compared to CO_2 the greenhouse potential depends on the years of time horizon. The herewith given time dependence of the equivalent factors are shown in

Table 1. The greenhouse gas emission factors of the life cycle analyses have therefore the dimension of g CO_2-eq. kWh^{-1}. According to international agreements the equivalent factors after 100 years are used in this paper.

Table 1: Equivalent factors of different greenhouse gases (Houghton et al., 1995)

Greenhouse gas	Years time horizon		
	20 years	100 years	500 years
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	56	21	6,5
Nitrogen oxide (N_2O)	280	310	170

The energy systems consist of different modules (especially from Figure 1 and Figure 2) as it is shown in Figure 5. The modules are connected with other modules and the environment via flows of materials (like carbon, greenhouse gases, raw materials) and energy flows. On the left side in Figure 5 there are the bioenergy systems and on the right side the fossil energy systems. On the bottom both systems supply electricity and/or heat to the consumer.

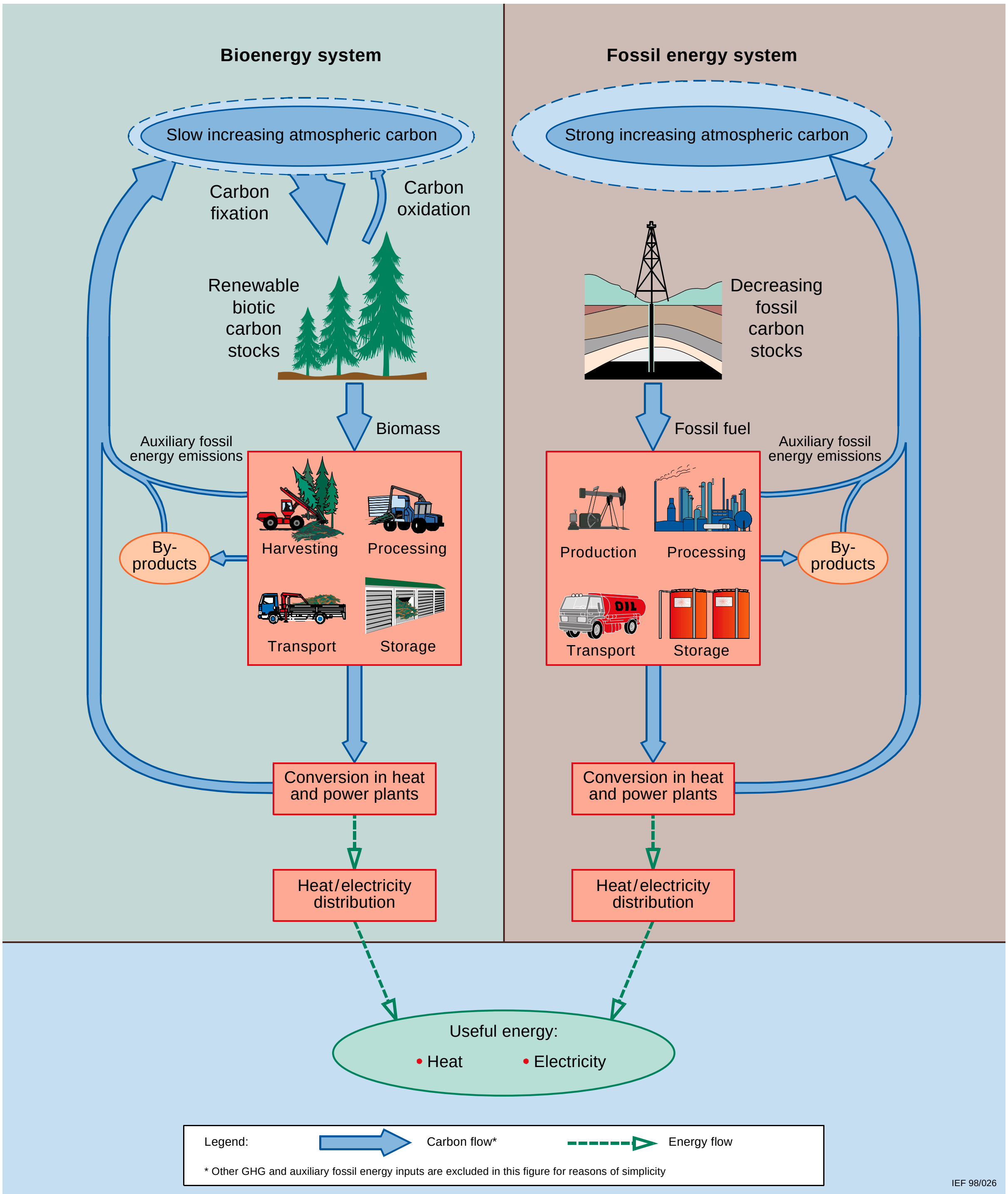

Figure 5: Schematic material and energy flows of the energy systems for the inventory analyses, auxiliary energy flows are needed for the construction, the operation and the dismantling of the energy systems, adapted from (Schlamadinger et al., 1997 and IEA 1998)

In the analyses all involved materials and processes are considered: auxiliary energy (e. g. electricity), auxiliary materials (e. g. fertiliser during the production of arable plants), construction and dismantling of the compounds and plants, combustion, use of by-products, substitution of other products via by-products, material losses and reference use of biomass and of area. For the biogenic carbon of energetic biomass use it is assumed, that the balance of net CO_2-fixation via photosynthesis, the carbon storage and the combustion of biomass is

zero, as it is set for the energy sector in the guidelines of the Intergovernmental Panel on Climate Change (IPCC) (Houghton et al., 1995).
The computer model GEMIS (Global-Emissions-Model-of Integrated-Systems) is used as a calculation tool. GEMIS is developed by the Öko-Institut in Darmstadt/Germany and is free available via internet (GEMIS, 1999). As input the Austrian database from the Austrian federal agency are used completed with data from national and international literature (GEMIS-A, 1998). Data are considered to be "default values" for best average calculation for the Austrian situation in the year 2000. The data quality is proven with plausibility criteria. The modules of the energy systems are figured in GEMIS and connected for the life cycle analyses.

2.3 Results and Interpretation

In this summary one examples for the comparison of different CHP pants is chosen from the 34 bioenergy systems and 18 fossil energy systems to show the most important results. Then some selected results for CHP plants with solid, liquid and gaseous biomass are shown. Then the comparisons based on CO_2-equivalents for the most important energy systems for the Austrian situation in the year 2000 and 2020 are given, followed by the most important conclusions.
Example: Wood chip combined heat and power (CHP) plant with steam turbine compared to a natural CHP plant with combustion engine

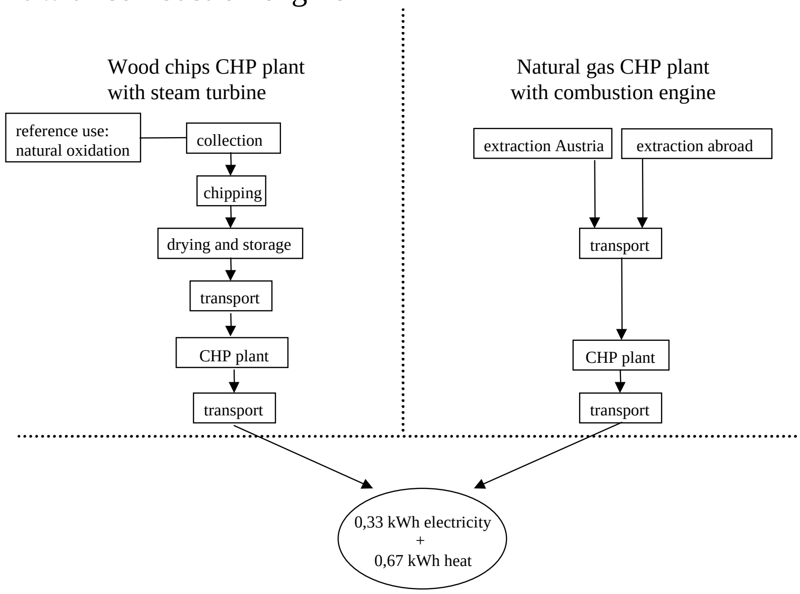

Figure 6: Process chains of a wood chip CHP plant with steam turbine and a natural gas CHP plant with combustion engine

The process chains of both systems are shown in Figure 6. The combined electricity and heat supply with a wood chip CHP plant with steam turbine causes greenhouse gas emissions of 33,6 g CO_2-eq. (0,33 $kWh_{electricity}$+0,67 $kWh_{heat})^{-1}$, those with the natural gas CHP plant with combustion engine are 372 g CO_2-eq. (0,33 $kWh_{electricity}$+0,67 $kWh_{heat})^{-1}$ (
Figure 7). This means, that the greenhouse gas emissions of the wood chip CHP plant are 91% lower referring to the natural gas CHP plant. The consideration of the single greenhouse gases shows, that the N_2O-emissions of the wood chip CHP plant are higher because of the nitrogen content of the fuel and the combustion conditions, the CH_4-emissions of the natural gas CHP plant are higher because of the losses during extraction and transportation and the

CO_2-Emissionen of the natural gas CHP plant are significantly higher because of the combustion of a fossil fuel.

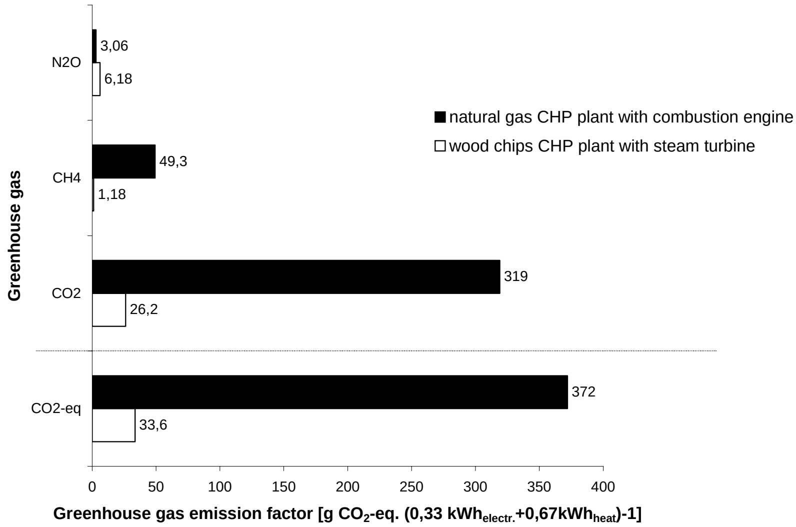

Figure 7: Comparison of the greenhouse gas emission factors of the combined electricity and heat supply with a wood chip CHP plant with steam turbine and a natural gas CHP plant with combustion engine

2.4 Results for solid biomass CHP plants

In Figure 8 the greenhouse gas emissions of CHP plants with solid biomass and current technologies are shown. The combined heat and power production with bark in a steam cycle with a steam engine has the lowest emissions 8 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}), whereas the CHP plant with wheat has the highest emissions 131 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}), where about 50% of these emissions derive from N_2O-Emissions during production form the use of Nitrogen fertilizer.
In Figure 9 the greenhouse gas emissions of CHP plants with wood chips from forestry biomass and future technologies are shown. For this relation of heat and electricity the CHP plant with the steam turbine has the lowest emissions 32 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}), whereas the CHP plant with organic Rankine cycle has the highest emissions 71.5 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWhheat).

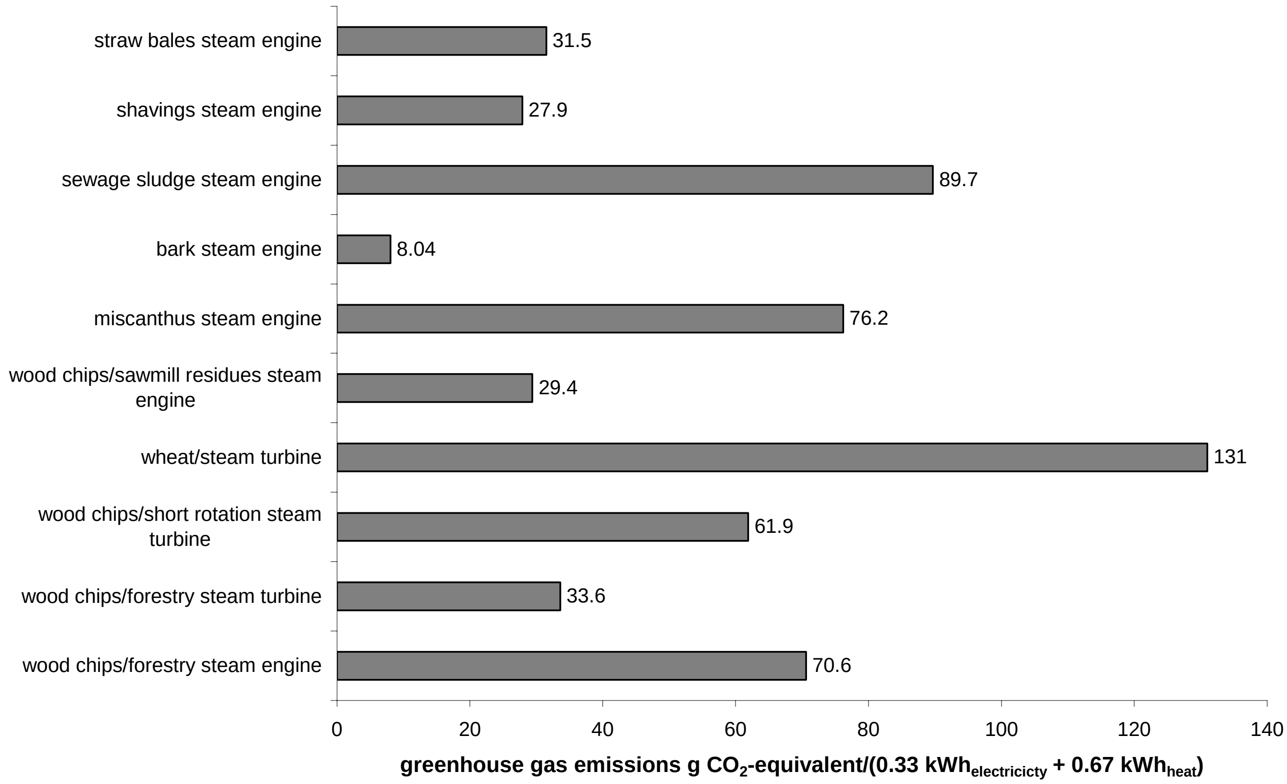

Figure 8: Greenhouse gas emissions of CHP plants with solid biomass and current technologies

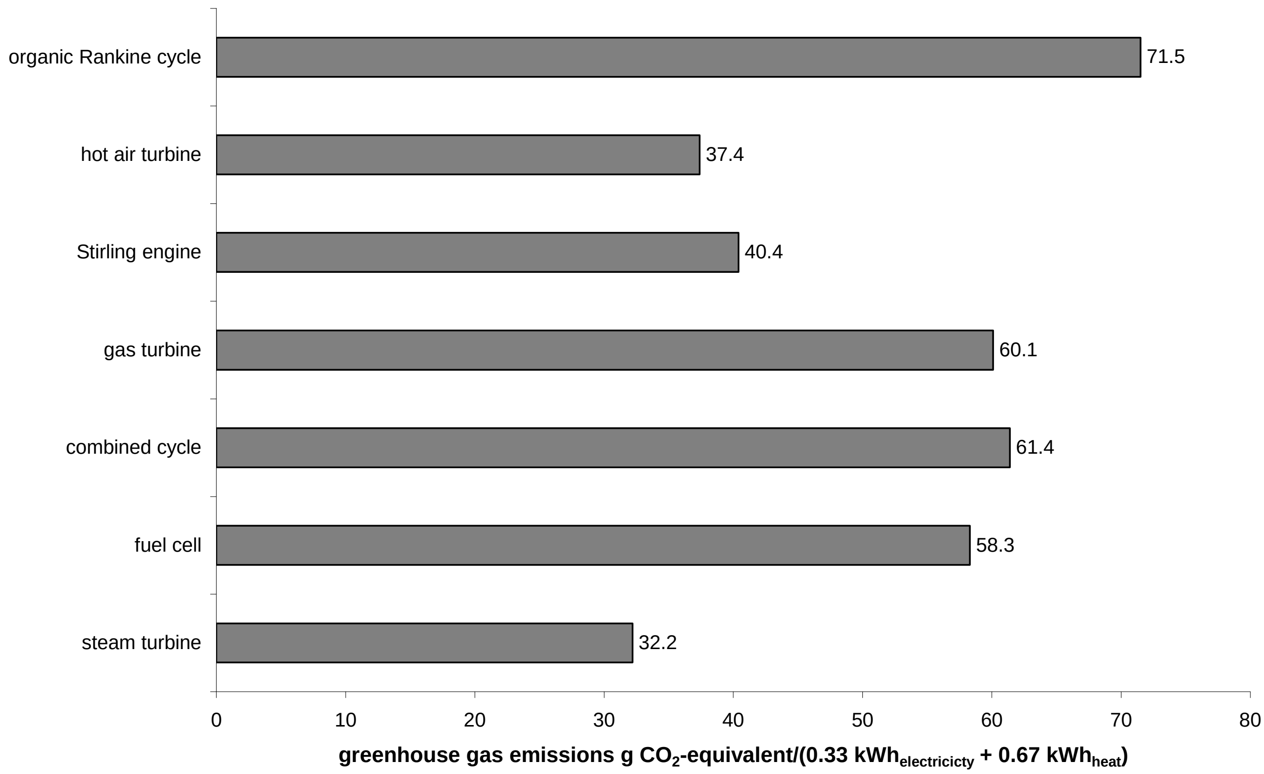

Figure 9: Greenhouse gas emissions of CHP plants with wood chips from forestry biomass and future technologies

2.5 Results for liquid and gaseous biomass CHP plants

In

Figure 10 the greenhouse gas emissions of CHP plants with liquid and gaseous biomass and a current available combustion engine are shown. The combined heat and power production with biogas from manure has the lowest emissions – 467 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}), whereas the CHP plant with vegetable plant oil has the highest emissions 274 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}). The negative emissions from the biogas systems with manure derive from the avoided reference use of the manure storage, where a high rate of CH_4-emissions from manure storage is avoided. The negative emissions from the biodiesel from waste oil derive from the from the avoided reference use of composting waste oil, where CH_4-emissions from composting are avoided.

In Figure 11 the greenhouse gas emissions of CHP plants with liquid and gaseous biomass and a future available combustion engine are shown. The combined heat and power production with biogas from manure has the lowest emissions – 437 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}), this is a higher emission compared to the current technology (Figure 10), because of a higher efficiency of the total system, less CH_4-emissions from manure storage are reduced. The CHP plant with vegetable plant oil has the highest emissions 256 g CO_2-eq/(0.33 $kWh_{electricity}$ + 0.67 kWh_{heat}). The negative emissions from ethanol from sugar beet derive from the use of the by-product of the ethanol production as animal feed, that substitutes the import of soya feed.

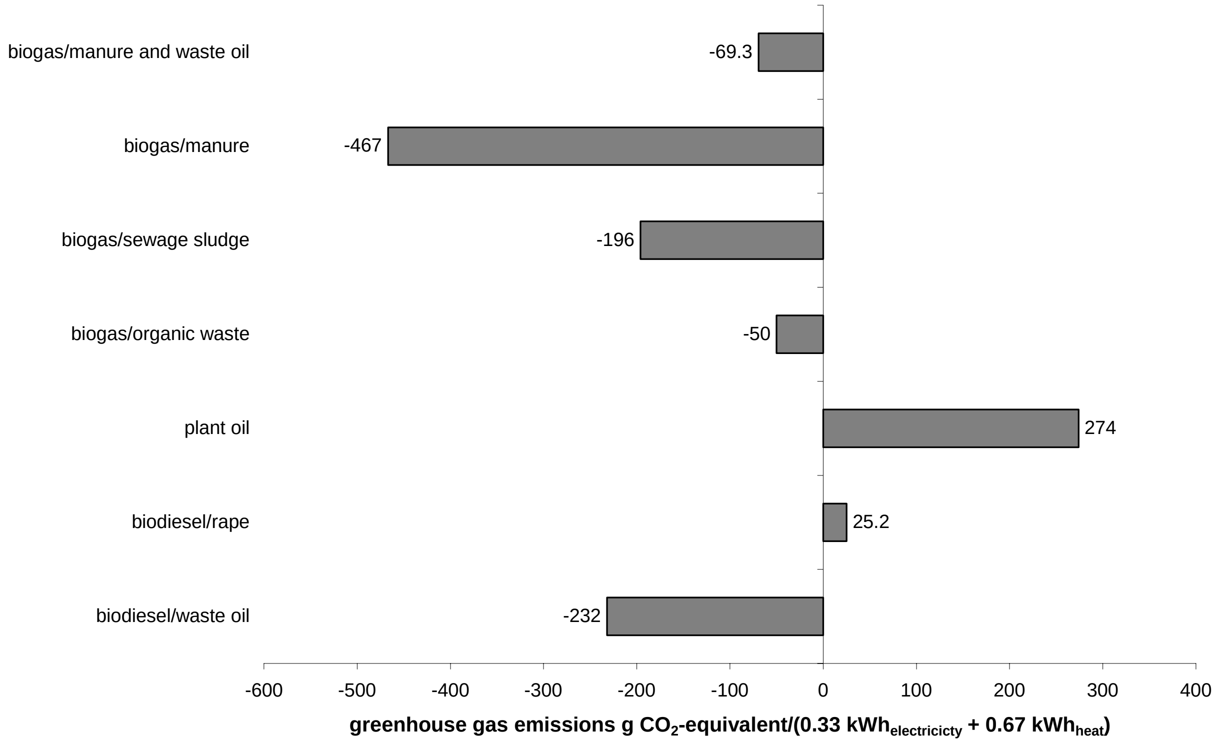

Figure 10: Greenhouse gas emissions of CHP plants with liquid and gaseous biomass and current combustion engine

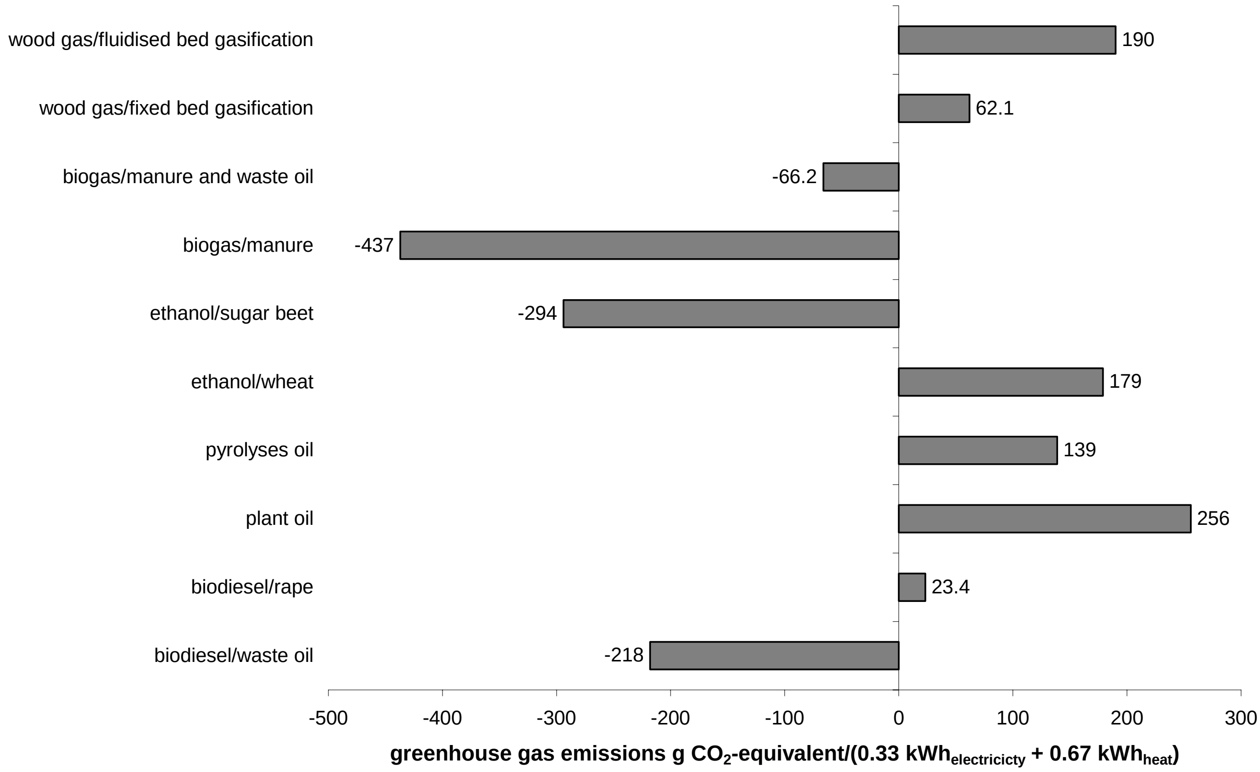

Figure 11: Greenhouse gas emissions of CHP plants with liquid and gaseous biomass and future combustion engine

2.6 Summary of results

In Table 2 the comparisons based on CO_2-equivalents for the most important Austrian energy systems in the year 2000 and 2020 are shown for combined heat and electricity supply as a percentage of CO_2-equivalent reduction.

Table 2: Comparison of the greenhouse gas emission factors of combined electricity and heat supply between bioenergy systems and fossil energy systems in Austria in the year 2000 and 2020

Year 2020		coal/CHP plant steam turbine (F)	coal/CHP plant gas a. steam turbine (F)	coal/CHP plant fuel cell (F)	lignite/CHP plant steam turbine (F)	extra light oil/CHP plant fuel cell (F)	extra light oil/CHP plant combustion engine (F)	heavy oil/CHP plant steam turbine (F)	heavy oil/CHP plant fuel cell (F)	natural gas/CHP plant gas a. steam turbine (F)	natural gas/CHP plant fuel cell (F)	natural gas/CHP plant combustion engine (F)
[g CO_2-eq. (0,33 $kWh_{electricity}$+0,67$kWh_{heat)}$-1]		471	477	470	472	408	373	397	426	297	317	329
wood chips/forestry/CHP plant steam turbine (F)	32,2	-93%	-93%	-93%	-93%	-92%	-91%	-92%	-92%	-89%	-90%	-90%
wood chips/forestry/CHP plant fuel cell (F)	58,3	-88%	-88%	-88%	-88%	-86%	-84%	-85%	-86%	-80%	-82%	-82%
wood chips/forestry/CHP plant gas a. steam turbine (F)	61,4	-87%	-87%	-87%	-87%	-85%	-84%	-85%	-86%	-79%	-81%	-81%
wood chips/forestry/CHP plant gas turbine (F)	60,1	-87%	-87%	-87%	-87%	-85%	-84%	-85%	-86%	-80%	-81%	-82%
wood chips/forestry/CHP plant stirling engine (F)	40,4	-91%	-92%	-91%	-91%	-90%	-89%	-90%	-91%	-86%	-87%	-88%
wood chips/forestry/CHP plant ho air turbine (F)	37,4	-92%	-92%	-92%	-92%	-91%	-90%	-91%	-91%	-87%	-88%	-89%
wood chips/forestry/CHP plant ORC-process (F)	71,5	-85%	-85%	-85%	-85%	-82%	-81%	-82%	-83%	-76%	-77%	-78%
methylester/waste oil/CHP plant combustion engine (F)	-218	-146%	-146%	-146%	-146%	-153%	-158%	-155%	-151%	-173%	-169%	-166%
methylester/rape/CHP plant combustion engine (F)	23,4	-95%	-95%	-95%	-95%	-94%	-94%	-94%	-95%	-92%	-93%	-93%
vegetable oil/rape/CHP plant combustion engine (F)	256	-46%	-46%	-45%	-46%	-37%	-31%	-35%	-40%	-14%	-19%	-22%
pyrolyses oil/CHP plant combustion engine (F)	139	-71%	-71%	-70%	-71%	-66%	-63%	-65%	-67%	-53%	-56%	-58%
alcohol/wheat/CHP plant combustion engine (F)	179	-62%	-62%	-62%	-62%	-56%	-52%	-55%	-58%	-40%	-44%	-46%
alcohol/sugar beet/CHP plant combustion engine (F)	-294	-162%	-162%	-163%	-162%	-172%	-179%	-174%	-169%	-199%	-193%	-189%
biogas/manure/CHP plant combustion engine (F) 1)	-437	-193%	-192%	-193%	-193%	-207%	-217%	-210%	-203%	-247%	-238%	-233%
biogas/oil co-digest. manure/CHP plant combustion engine (F) 1)	-66,2	-114%	-114%	-114%	-114%	-116%	-118%	-117%	-116%	-122%	-121%	-120%
wood gas/fixe bed gasification/CHP plant combustion engine (F) 1)	62,1	-87%	-87%	-87%	-87%	-85%	-83%	-84%	-85%	-79%	-80%	-81%
wood gas/fluidised bed gasification/CHP plant combustion engine (F) 1)	190	-60%	-60%	-60%	-60%	-53%	-49%	-52%	-55%	-36%	-40%	-42%

1) "negative" emission factor because of reference use or of use of by-products

2.7 Conclusions

The CO_2-emissions of bioenergy systems come from fossil auxiliary energy and auxiliary materials, as the CO_2-emissions from biomass combustion are fixed again through photosynthesis in the plants. The CH_4- and N_2O-emissions of bioenergy systems come in particular from the combustion of the biogenic fuels.

Beside the CO_2-emissions of fossil energy systems from combustion the CH_4-emissions of natural gas extraction and transportation are significant.

The results demonstrate, that most of the bioenergy systems cause significantly lower greenhouse gas emissions than fossil energy systems. The emission reduction of CO_2-equivalents by substituting fossil energy systems is estimated to be 87 - 92% in combined electricity and heat supply

Whereas the consideration of CO_2-equivalents always leads to a reduction, the detailed analyses of the single greenhouse gases show different effects. In some cases there is an increase in N_2O-emissions.

The avoided reference use and the use of by-products of the bioenergy systems might lead to a further reduction of greenhouse gas emissions. So energy supply with biogas provides a significant reduction without substituting fossil energy.

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