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Greenhouse Gas Balances for VERBIO Ethanol as per the German Biomass Sustainability Ordinance (BioNachV)

Final report

By order of:

**VERBIO Vereinigte BioEnergie AG,
Leipzig**

Heidelberg, 4 June 2008

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Table of Contents

1 Introduction

Background information and study aims

The search for alternatives to fossil fuels has gained increasing importance in recent years. Fuels produced from biomass, such as biodiesel, pure vegetable oil or bioethanol are now receiving more public attention worldwide, especially in the political and research areas. After an initial boom and general euphoria over the possibility of replacing fossil fuels with renewable raw materials, the undesirable side effects of this approach are now becoming more evident.

As a result of increased pressure on the German Federal Government, on 5th of December 2007 the Federal Cabinet passed a draft for the so-called Biomass Sustainability Ordinance (BioNachV) within the scope of a climate and energy program [BioNachV 2007]. The ordinance is to ensure that, in the generation of biomass for biofuels, (1) minimum requirements of a sustainable cultivation of agricultural areas are met, (2) the protection of natural biotopes is ensured, (3) biofuels provide a specific potential for reducing greenhouse gas emissions with regard to the entire production chain.

In the light of this situation, the VERBIO Vereinigte BioEnergie AG (Leipzig) commissioned Institut für Energie- und Umweltforschung Heidelberg (IFEU) to prepare greenhouse gas balances in line with the German BioNachV ordinance for bioethanol made from wheat or rye and produced in Zörbig (Saxony-Anhalt) and Schwedt (Brandenburg).

Aim of the study

The aim of the study is the determination of the greenhouse gas reduction potential as per the BioNachV ordinance for bioethanol made from wheat or rye for each of the VERBIO plants in Zörbig (MBE) and Schwedt (NBE), whereby two different variants must be taken into account for the Schwedt plant. Based on the business model of the client, the following issues are to be analysed for these six processes:

- Does the greenhouse gas reduction potential of VERBIO ethanol reach the basic value of at least 30 % specified in the BioNachV ordinance (valid until 31/12/2010), and by how much is this value not reached or exceeded?
- What are the effects the individual process steps in the VERBIO ethanol production chain have on the emission of greenhouse gases and what are the relative proportions of the individual greenhouse gases?
- How do the results for VERBIO ethanol compare to the so-called default values defined in the BioNachV ordinance?
- How are the results for VERBIO ethanol influenced by taking advantage of the latitude resulting from the specifications in the BioNachV ordinance?

Basic approach

To prepare greenhouse gas balances as per the BioNachV ordinance, the production and consumption chains of the biofuel, namely the entire life cycle of the fuel, were compared to the same chains of the so-called fossil reference system. Fig. 1-1 shows this comparison between VERBIO ethanol from grain and the conventional petrol that is replaced by bioethanol.

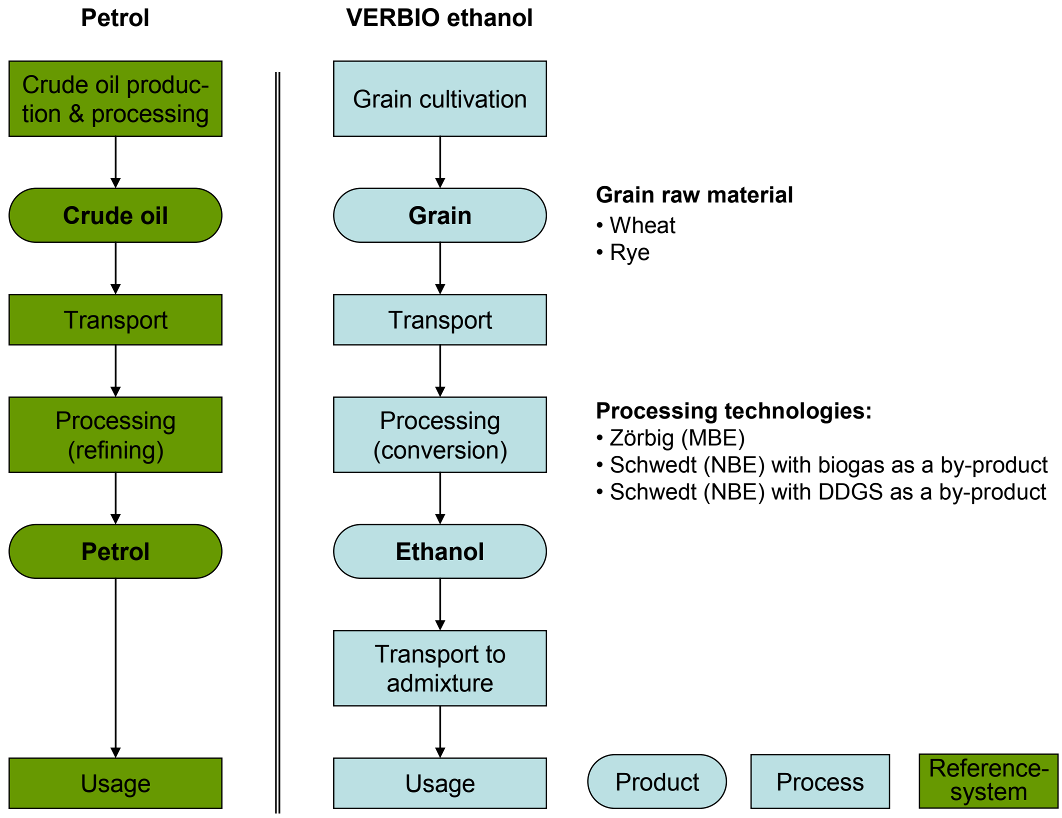

Fig. 1-1 Schematic comparison of the life cycles of VERBIO ethanol and petrol, its fossil equivalent

Comprehensive descriptions of the details of the methods used are provided in Section 2. The results of the greenhouse gas balances of the ethanol production processes examined are then introduced and discussed in detail. Section 3 first examines the basic system descriptions of the selected ethanol production processes and the corresponding greenhouse gas balances. To support the validity of the results, the influence of particular elements such as individual processes, system boundary selection or specific basic data on the results are also examined. Section 4 examines the consequences for the greenhouse gas balances when wider system boundaries, which are permitted within the scope of the BioNachV ordinance are used. Finally, the central results are summarised and conclusions are drawn (Section 5).

2 Approach

After the aim of the project and the scope of the study have been described in Section 1 the main focus of this second section is a more detailed explanation of the approach used. For example, the basic methodology used and the origin of the basic data are explained.

Details on the approach

The specifications of the BioNachV draft were used as the basis for the preparation of the greenhouse gas balances in this study. The central elements of this draft are the balancing of the entire life cycle of the fuels, i. e. in the case of biofuel the cycle from the cultivation of the biomass, through all transport and processing steps, to the final use, while also including by-products through allocation based on the lower heating values. With this type of allocation, all the materials and the energy used and all emissions of a process step are distributed between ("allocated to") the main products and the by-products that leave the system. This can be done based on different parameters such as market price, lower heating value or (less suitable) mass, whereby the BioNachV ordinance specifies the lower heating value as the basis.

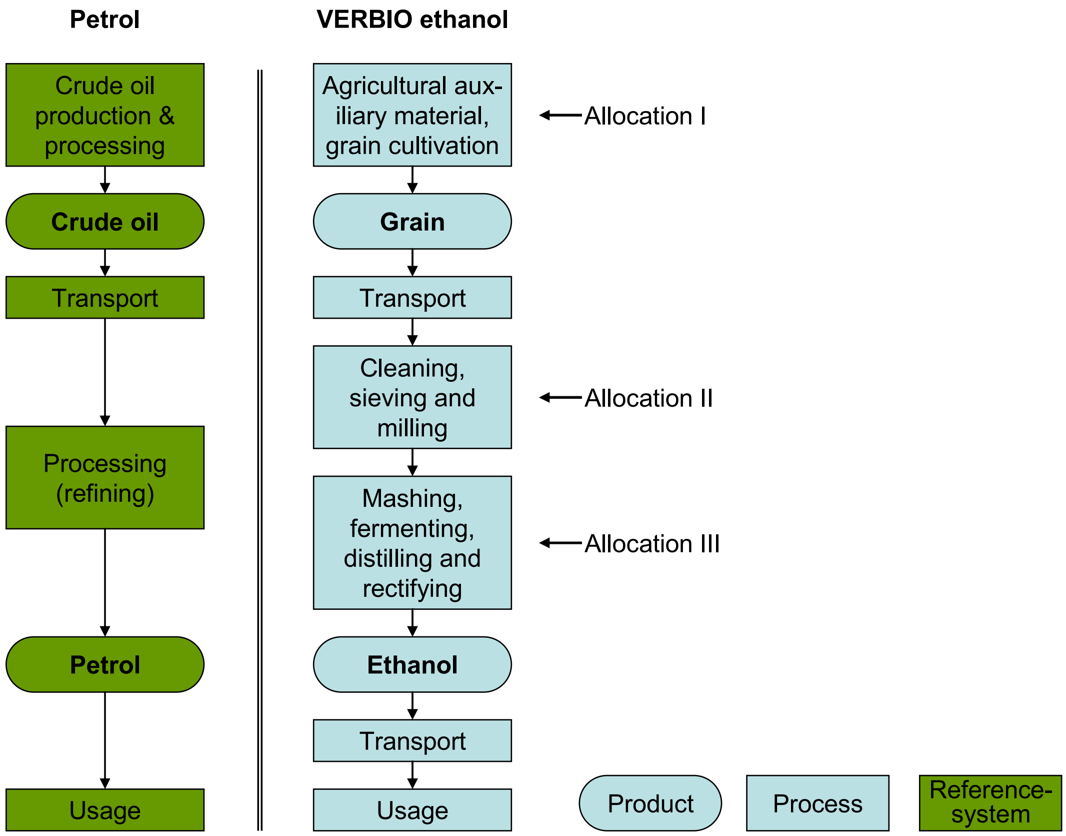

Fig. 2-1 Schematic comparison of the life cycle stages of VERBIO ethanol and conventional petrol. The three allocations are marked with arrows

Fig. 2-1 is a summary of the individual process steps showing those stages for which an allocation was done, e. g. in the grain cultivation process, which consists of various processes, allocation is done between grain and straw.

Apart from the clear definition of these central elements, the draft ordinance also has a number of inexact formulations providing a certain amount of latitude in the greenhouse gas balance calculations. For example, the BioNachV ordinance does not exactly specify whether the lower heating value is to be based on the wet mass (dry material plus water content) or the dry mass (dry material only) of a by-product. Especially with ethanol production, this is very important due to the large number of watery intermediate products and by-products such as stillage sludge.

The inexact definition of the system boundaries in the draft of the BioNachV ordinance also provides a certain amount of latitude in the balances. For example, the stillage sludge created could also be directly sold as animal feed – in contrast to the VERBIO AG business model, which defines subsequent processing into biogas or DDGS. Due to the different by-products, this variation affects the allocation and thus the final greenhouse gas balance results.

For this reason, Section 4 of this study examines how the results for VERBIO ethanol can be influenced by making use of these two latitudes.

In addition to these analyses according to the BioNachV ordinance, so-called sensitivity analyses were performed to support and validate the results (see Subsection 3.3). In these sensitivity analyses, specific individual parameters were varied in order to determine their influence on the overall results.

Environmental impacts considered: greenhouse effect

The environmental impact considered here is the warming of the atmosphere due to the release of climatically-active gases by human activity. In addition to carbon dioxide (CO_2) as the most important greenhouse gas (released when fossil fuels are burnt), these also includes a number of trace gases such as methane and laughing gas.

This definition is based on current life cycle assessment methods. The indicators, inventory analysis factors and equivalence factors for these environmental effects are presented in Table 2-1.

Table 2-1 Indicators, LCI parameter and cahracterisation factors of the greenhouse effect

Environmental impact	Category indicator	Life cycle inventory parameter	Formula	Characterisation factor
Greenhouse effect	CO_2 equivalent (carbon dioxide equivalent)	Fossil carbon dioxide	CO_2	1
		Laughing gas (nitrous oxide)	N_2O	310
		Fossil methane*	CH_4	21
		Non-fossil methane**	CH_4	18.25

* including CO_2 effects after CH_4 oxidation in the atmosphere

** without CO_2 effects after CH_4 oxidation in the atmosphere

[IPCC 1996]

Data

The data used for calculating the greenhouse gas balances for all scenarios (without sensitivity analyses) came from the following sources.

- **Production of biomass**: data for wheat cultivation was taken from [Fehrenbach et al. 2007]. Since the draft of the BioNachV ordinance does not contain default values for ethanol made from rye, the data for rye cultivation comes from [Kaltschmitt & Reinhardt 1997].
- **Transport of the biomass**: information on transportation methods, distances and rated loads comes from [VERBIO 2007/08].
- **Processing:**
  - All process-specific data for the Zörbig MBE plant and the two process variants at the Schwedt NBE plant was provided by [VERBIO 2007/08] and checked for completeness and consistency by IFEU.
  - The lower heating values of all by-products were taken from either [Fehrenbach et al. 2007] or, if they were not be found there, provided by [VERBIO 2007/08] with reference to their wet mass, or derived from these figures. For the sensitivity analysis, these figures were converted by IFEU into heating values with reference to the dry mass. Further information on the material properties of the by-products, for example their nutrient content, was also taken from [VERBIO 2007/08].
  - All inputs and outputs for which [VERBIO 2007/08] could not provide specific emission data and which were not contained in [Fehrenbach et al. 2007], were obtained from [IFEU 2008]. Examples of these were values for enzymes, flocculants or straw burning processes.
- **Transport to admixture**: information on transportation methods, distances, rated loads and the fuels used comes from [VERBIO 2007/08].
- **Usage**: the value for the fossil reference system was taken from [BioNachV 2007].

The variations of individual values within the scope of the sensitivity analysis were based on IFEU internal calculations and database queries [IFEU 2008].

Presentation of results

The results, i. e. the determined greenhouse gas emissions are specified per GJ of produced ethanol.

For the purposes of clarification and easy reading, the main results are compared to each other in bar diagrams, whereby the fossil reference product (conventional petrol) is often also shown: all of these result diagrams also contain a red line showing the base value for greenhouse gas potential reduction, as specified in the BioNachV ordinance up to and including the year 2010. If a specific result lies below this value then the ethanol satisfies this requirement of the ordinance.

3 Basic GHG balances for VERBIO ethanol

Subsection 3.1 first describes the VERBIO processes for producing ethanol and then combines these with the system boundaries defined by the customer's business model into basic scenarios. Subsection 3.2 then introduces the greenhouse gas balances for the basic scenarios and discusses them in detail. Finally, Subsection 3.3 contains the sensitivity analyses of selected parameters.

3.1 VERBIO ethanol: processes and basic scenarios

This study examines six different processes for producing so-called bioethanol, which can be produced using a combination of two raw materials, i. e. rye or wheat, and three different plant concepts. These six processes are first described here in more detail. A basic scenario is then defined for each of the three plant concepts. Each of these includes particular processes and process steps in its system boundaries, and is used in order to compare the six processes. These basic scenarios follow the current business model of VERBIO AG. This model is a completely vertically integrated value chain, ranging from the local farmer to rural trading companies, to the nearby production plant, with the aim of biofuel production. In this model, the material flows are optimised so that the materials not converted into biofuel (e. g. nitrogen, phosphates and potassium) are returned as fertilizer to the farmers, thus forming an almost complete material cycle.

3.1.1 Process overview

As previously mentioned, this study examines a number of different methods of producing ethanol from grain. These are the result of a combination of three plant concepts using wheat or rye as raw materials. The type of grain used only affects the quantitative material and energy flows, i. e. the input and output volumes, but not the qualitative material and energy flows. Detailed input/output charts for both raw materials are provided in the appendix (7.1).

MBE bioethanol from wheat or rye (Zörbig)

At its Zörbig location (Saxony-Anhalt), the Mitteldeutsche BioEnergie GmbH & Co. KG (MBE) has been producing ethanol from wheat, rye or triticale in a large-scale industrial plant since September 2004. A special feature of this plant is that the stillage sludge created in the ethanol production process is used to produce biogas, which is then used in an integrated combined heat and power plant (CHP plant) to generate part of the steam required for the ethanol production. The rest of the required steam is produced by a straw-fired boiler. All the power generated by the CHP plant is fed into the mains grid and is remunerated as per EEG (German Renewable Energy Sources Act). The required process power is thus purchased, whereby the VERBIO business model stipulates the use of "green" electricity.

This study examines the MBE process at Zörbig for wheat and rye inputs. Fig. 3-1 provides a qualitative overview of this ethanol production process.

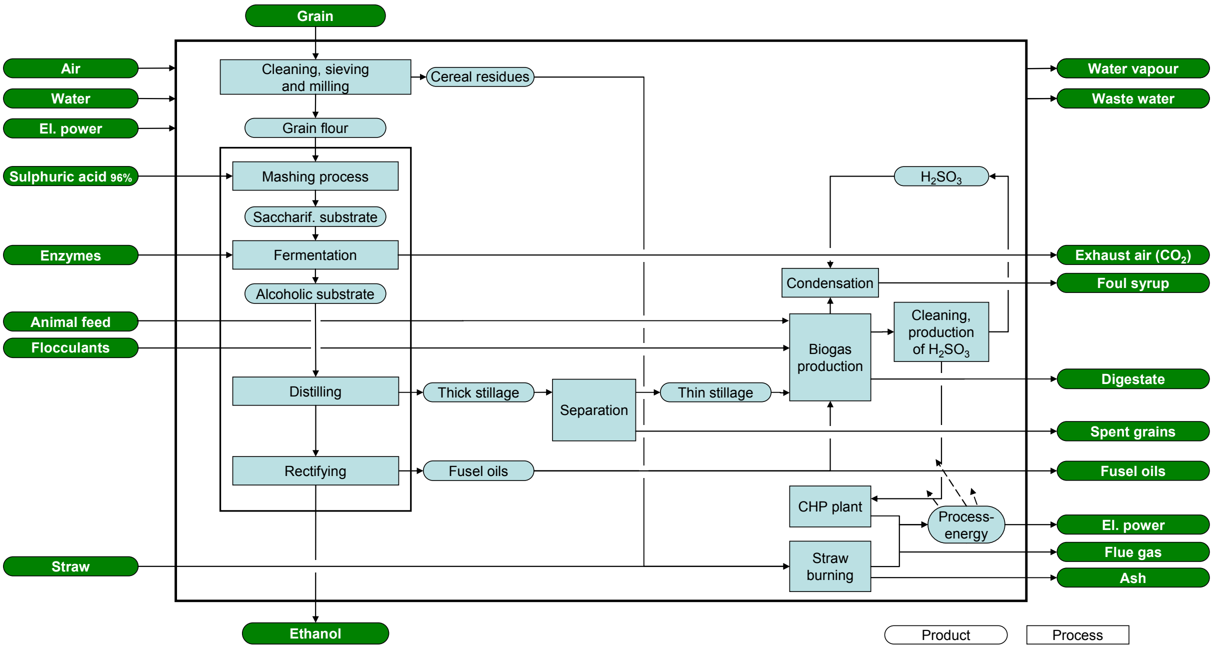

Fig. 3-1 Qualitative flow diagram of the MBE process for producing ethanol from wheat or rye at the Zörbig plant.

NBE bioethanol from wheat or rye (Schwedt)

In August of 2005, the company BioEnergie GmbH & Co. KG (NBE) (North Brandenburg) commissioned a plant for ethanol production in Schwedt (Brandenburg), located near a mineral oil refinery from which it obtains all the necessary process steam. There are two process variants possible at this location, which differ in the by-products produced. The stillage sludge can be used to either generate biogas as it is done in the Zörbig MBE process (in contrast to the MBE process, the NBE gas cleaned and then fed into the natural gas network), or it can be used to produce a high-protein animal feed (DDGS).

These two characteristic by- products are used below to distinguish between the two process variants:

- **Schwedt biogas**: with this variant a biogas plant is integrated in the ethanol production plant, whereby the generated biogas is not used in a CHP plant but rather cleaned and fed into the natural gas network. A qualitative overview of this ethanol production process is provided in Fig. 3-2.
- **Schwedt DDGS**: this bioethanol production variant produces a storable high-protein animal feed as a by-product, commonly known as DDGS (Distiller's Dried Grains with Solubles). Fig. 3-3 provides a qualitative overview of the major process steps and by-products of this variant.

Both Schwedt variants are also examined for wheat and rye inputs in this study.

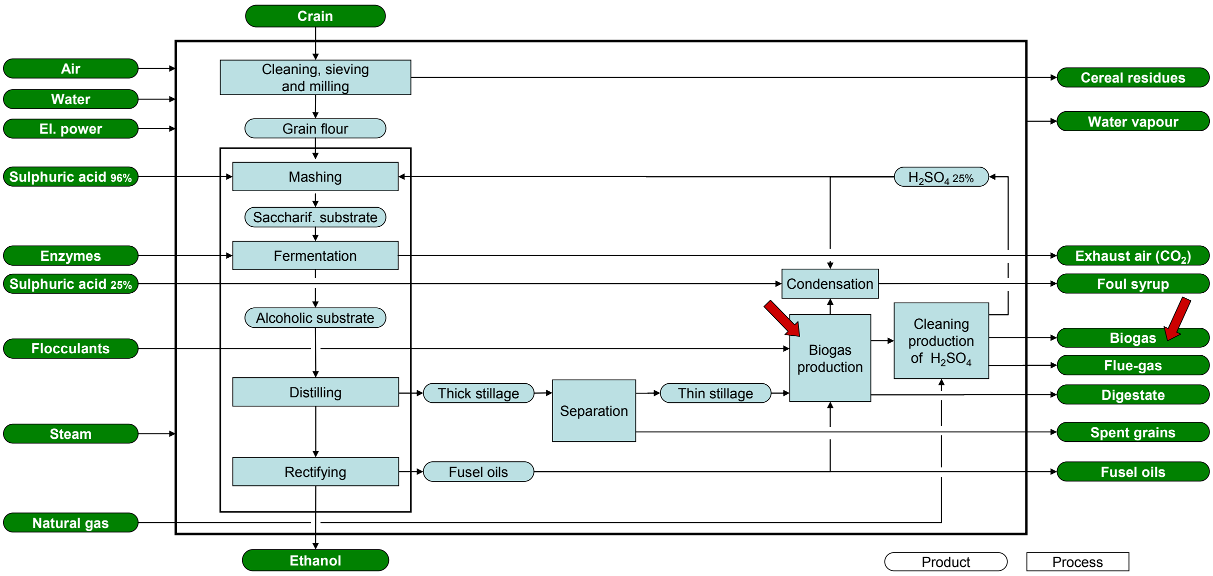

Fig. 3-2 Qualitative flow diagram of the NBE Biogas process for producing ethanol from wheat or rye at the Schwedt plant. The wide (red) arrows indicate the main differences to the NBE DDGS process.

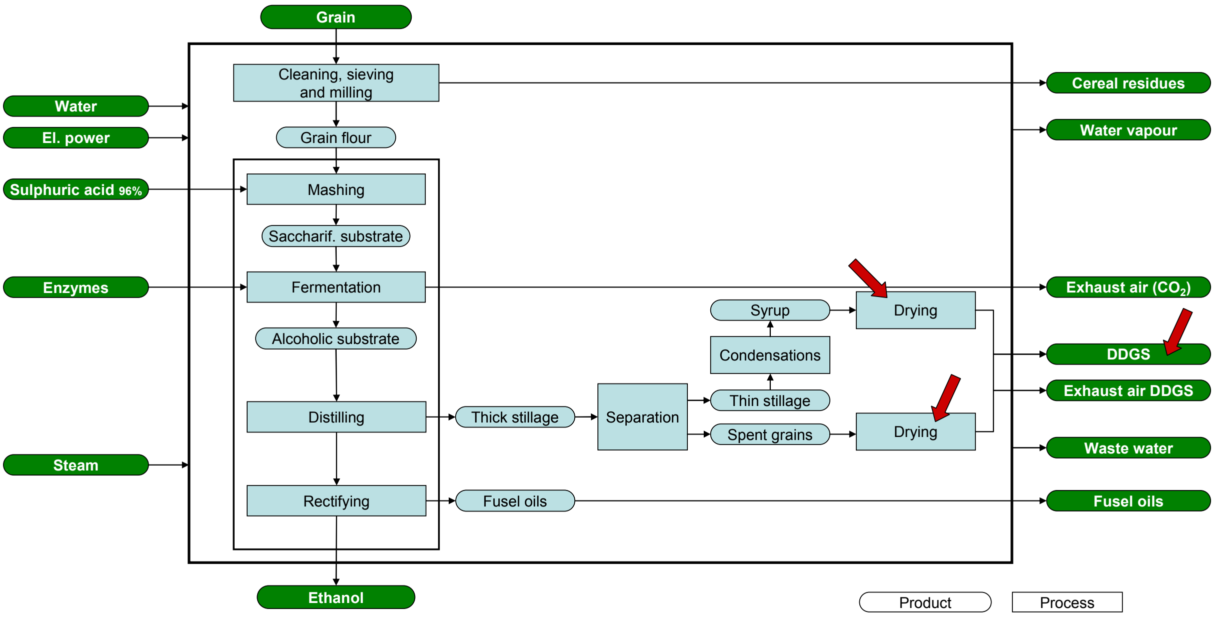

Fig. 3-3 Qualitative flow diagram of the NBE DDGS process for producing ethanol from wheat or rye at the Schwedt plant. The wide (red) arrows indicate the main differences to the NBE Biogas process.

Special definitions for the VERBIO ethanol production chain

According to the BioNachV ordinance, the bioethanol production chain typically contains the following parts: direct land-use change, production of biomass, transport of the biomass, processing and transport to the refinery. Deviating from or in addition to the above, the following points apply to all the processes under examination, in accordance with [VERBIO 2007/08]:

- **Direct land-use change:** direct land-use change as specified in the BioNachV ordinance [Fehrenbach et al. 2007], for example ploughing of grassland, is not carried out for the grain cultivation. According to the VERBIO AG, this is ensured through supply contracts with primary producers [VERBIO 2007/08].
- **Production of biomass**: the grain is cultivated in the region near to the processing plant. In addition to the grain, this also results in a quite large amount of straw. However, for reasons of humus reproduction most of the straw must remain on the fields or returned to the fields as solid dung after being used as bedding in livestock farming. For this reason, the IFEU limits the proportion of straw used for other purposes, such as electricity and heat generation, to one third [Münch 2008].
- **Processing:** the following points equally apply to all VERBIO ethanol production processes:
  - Drying: contrary to the default values specified in the BioNachV ordinance, which assumes that the grain is dried before use [Fehrenbach et al. 2007], the VERBIO AG uses the harvested grain immediately, i. e. without further drying, in the production process [VERBIO 2007/08]. According to the manufacturer, this is possible due to the continental climate in East Germany, which results in a lower moisture content upon harvesting.
  - Process electricity: the electricity requirement of the plant is exclusively covered by electricity from renewable energy sources ("green electricity") [VERBIO 2007/08]. In contrast to this, the default values in the BioNachV ordinance are based on the German power mix [Fehrenbach et al. 2007].
  - Digestate store: in the BioNachV ordinance, the default value for ethanol is based on the assumption that the resulting stillage sludge is processed into DDGS. However, the VERBIO AG has two plant concepts for biogas production. This results in "foul syrup" and digestate as by-products (subsequently referred to as "digestate"), which must be kept in storage since they keep emitting gases. According to [VERBIO 2007/08] this digestate store – as is the case with all other process steps in the biogas flow – is sealed gas-tight and also has an extraction system that subsequently burns the gases[1]. The small quantities of laughing gas (N_2O) produced are only partially burnt and the IFEU therefore assumes an N_2O emission of 0.01 % relative to the nitrogen content of the digestate [IFEU 2008].

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[1] A biofilter alone would not be suitable to prevent greenhouse gas emissions, because methane and nitrous oxide (laughing gas) pass through the filter unchanged.

- **Transport to the refinery**: most of the ethanol is transported by rail and a small amount is transported by HGV. According to [VERBIO 2007/08], the HGVs are fuelled exclusively with rapeseed biodiesel (rapeseed methyl ester, RME).

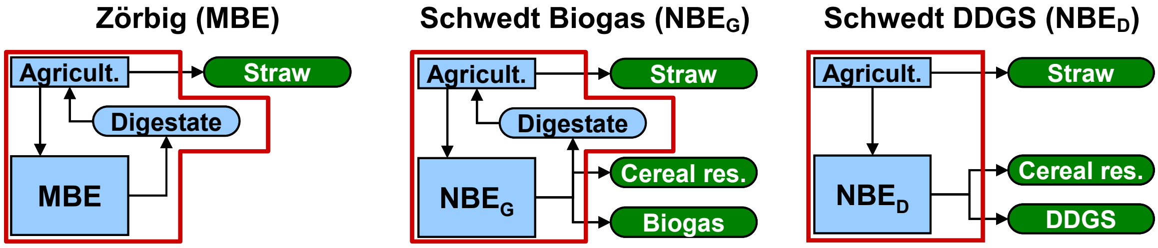
3.1.2 System boundary: basic scenarios

The system boundaries of the basic scenarios encompass all the previously described steps of the ethanol production chain, ranging from production of the biomass, through transport and processing, to transport to the refinery. Two further basic assumptions apply here:

- The straw resulting from the grain cultivation is sold and used for energy purposes, i. e. it leaves the system.
- The two by-products digestate and foul syrup are returned to exactly the same fields the processed grain originated from, replacing mineral fertilizer and thus remaining in the system. A 100 % plant availability of the mineral nitrogen proportion contained in the digestate is assumed; the plant availability of the proportion of organic nitrogen is only 20 %. This does not affect the Schwedt NBE DDGS process because it does not produce digestate.

These processes and system boundaries are based on the current business model of the VERBIO AG [VERBIO 2007/08] and are therefore defined as basic scenarios.

The central life cycle sections and characteristic features of the system boundaries defined in the basic scenarios are illustrated in the following diagrams. For reasons of clarity, other by-products such as spent grains and fusel oils, and the main product ethanol, which are the same in all plant concepts, are not shown here (for more details see Subsection 3.1.1).


Zörbig (MBE)

Schwedt Biogas (NBE_G)

Schwedt DDGS (NBE_D)

3.2 Results: basic scenarios

In the following sections, the greenhouse gas emissions determined for each of the basic scenarios in the examined VERBIO ethanol production processes are introduced and discussed in detail. Central conclusions based on these results are then formulated. The red line in the result diagrams marks the basic value required to be met according to the BioNachV ordinance.

3.2.1 Emissions from the individual processes

As described in Subsection 3.1, the life cycles of the six processes examined involve the provision of the grain, its processing to ethanol and additional processes such as the storage of by-products and transport. When these individual processes that together form entire life cycle are examined, the contribution of each process to the total greenhouse gas emissions can be determined.

Fig. 3-4 shows the proportions of the total results for the individual process steps. The VERBIO processes are directly compared to each other and to the greenhouse gas emissions of the fossil equivalent, conventional petrol.

Results

- The basic value of greenhouse gas reduction potential specified in the BioNachV ordinance is achieved in all six processes, i. e. the results based on the basic scenario were all below the required value.
- The use of wheat as a raw material led to somewhat lower greenhouse gas emissions than producing ethanol from rye. This is due to the fact that, according to the BioNachV ordinance in [Fehrenbach et al. 2007], a relatively low specific quantity is estimated for nitrogen fertilizers in wheat cultivation, which comes very close to the value for rye in [Kaltschmitt & Reinhardt 1997] despite significantly higher area yields. In addition to this, more rye is required for each unit of ethanol (see appendix 7.1). This is why the total emissions are higher.

Besides, the results clearly indicate that the greenhouse gas emissions can vary depending on the process (plant) used:

- With all examined VERBIO processes, both the grain cultivation and the process steps within the processing are decisive in the emission of greenhouse gases.
- In the Schwedt process, steam production has a very large influence because since, in contrast to the Zörbig process, no biomass (straw) is used and all process steam is generated using fossil fuels.
- In the Schwedt plant model, which includes the production of DDGS, fertilization is a major contributor because the process does not produce digestate or foul syrup and these can therefore not be returned to the fields and be used in place of mineral fertilizer.

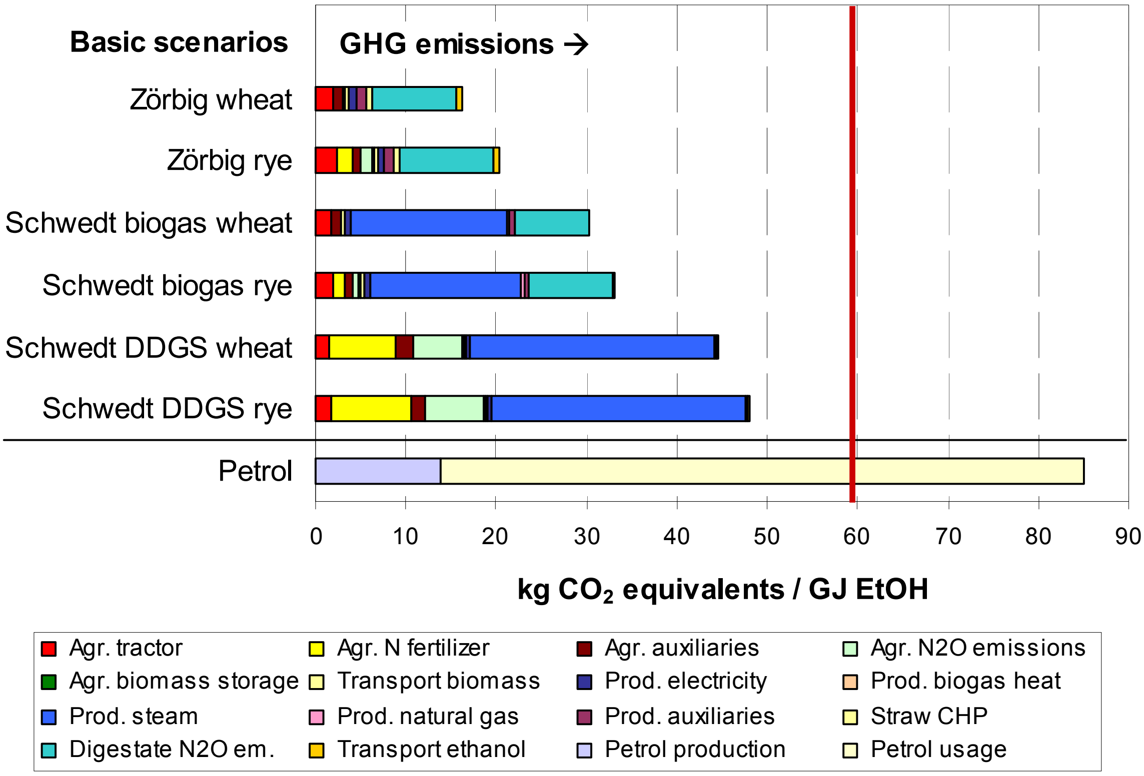


Fig. 3-4 Greenhouse gas emissions of the individual ethanol production process steps: Zörbig MBE process and the two Schwedt NBE variants with biogas or DDGS by-products. Comparison of the basic scenarios. Red line: BioNachV basic value

Example (top bar)

The production of ethanol from wheat in the Zörbig MBE plant causes total greenhouse gas emissions of approx. 16 kg CO_2 equivalents per GJ of ethanol, i. e. the greenhouse gas reduction potential when compared to petrol is 81 %.

Conclusion

All of the ethanol production processes based on the VERBIO AG business model cause significantly lower emissions than conventional petrol, the fossil reference product. In addition, all results for each of the basic scenarios lie below the basic value specified in the BioNachV ordinance. Of the two alternative variants in the Schwedt plant, the method producing biogas causes lower greenhouse gas emissions than the method producing DDGS. For all processes the use of wheat as a grain raw material produces better results than rye.

3.2.2 Individual greenhouse gas emissions

The individual processes can also be analysed with regard to the relative quantities of each greenhouse gas they produce. Fig. 3-5 shows the corresponding ratios of the gases for the results shown in 3.2.1.

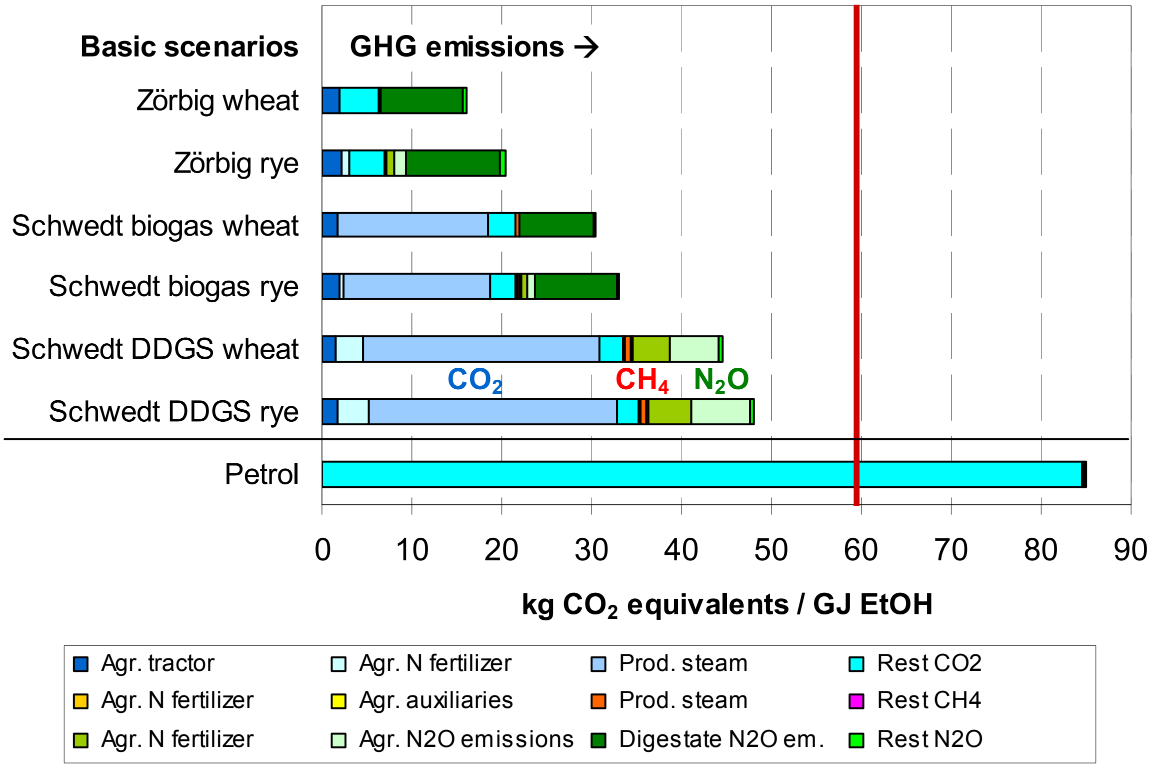


Fig. 3-5 Emissions of individual greenhouse gases from single process steps in ethanol production using the Zörbig and Schwedt processes: CO_2 (blue bar section), CH_4 (yellow-red), N_2O (green). Comparison of the basic scenarios.

Example (top bar)

The production of ethanol from wheat in the Zörbig MBE process causes total greenhouse gas emissions of approx. 16 kg CO_2 equivalents per GJ of ethanol, with approx. 6 kg CO_2 equivalents as CO_2 and approx. 10 kg CO_2 equivalents as N_2O.

Results

- In all examined VERBIO processes, CO_2 and N_2O greenhouse gas emissions are decisive whereas CH_4 plays a comparatively minor role.
- The CO_2 emissions originate from farming, for example from the provision of nitrogen fertilizer, as well as from the provision of electricity and steam for the respective processing plant. Yet, next to the production and use of mineral nitrogen fertilizer, the N_2O emissions are caused especially by returning the digestate to the fields.

- The composition of the greenhouse gas emissions varies significantly according to the process used: in the Zörbig MBE process the balance is dominated by the N_2O emissions from the digestate, whereas the CO_2 emissions from the steam production are clearly the dominant factor in the Schwedt NBE process.

Conclusion

The gas-specific examination of the individual processes clearly shows that the proportions of each of the greenhouse gases in the total emissions are different for each process. This means that optimisations to achieve significant reductions in greenhouse gas emissions must be considered individually for each process. Avoiding the use of mineral nitrogen fertilizers in farming, as in ecological farming, would reduce both CO_2 and N_2O emissions and would thus mean an improvement, especially for the Zörbig process.

Using less electricity and steam produced from fossil energy sources – as in the Zörbig process – or not drying the DDGS lead to a significant reduction in CO_2 emissions at the Schwedt plant.

3.2.3 Comparison with the default values for ethanol from wheat

If the numerous individual processes described in sections 3.2.1 and 3.2.2 are combined to into stages as specified in the BioNachV ordinance, a direct comparison with the so-called default values is possible. However, the lack of default values for ethanol from rye means that this is only possible for the three wheat-based processes and this is shown in Table 3-1 and Fig. 3-6.

Results

- With the exception of transport to the refinery, the values for VERBIO ethanol for the Zörbig process are significantly better than the default values specified in the BioNachV ordinance.
- The sale of straw, and especially the return of the digestate (nutrient cycle), with Zörbig and Schwedt biogas – as used in the basic scenario – lead to significantly lower emissions for the aspect of grain cultivation.
- The use of straw in Zörbig results in significantly lower processing emissions.

Table 3-1 Ethanol from wheat: comparison of the basic scenarios of the VERBIO process with the corresponding default values specified in the BioNachV ordinance.

	Production of biomass	Transport of the biomass	Processing (conversion)	Transport to the refinery
Zörbig wheat	3.3	0.4	11.8	0.7
Schwedt biogas wheat	2.9	0.4	26.9	0.2
Schwedt DDGS wheat	16.4	0.3	27.7	0.2
Default BioNachV	22.3	0.7	34.3	0.4

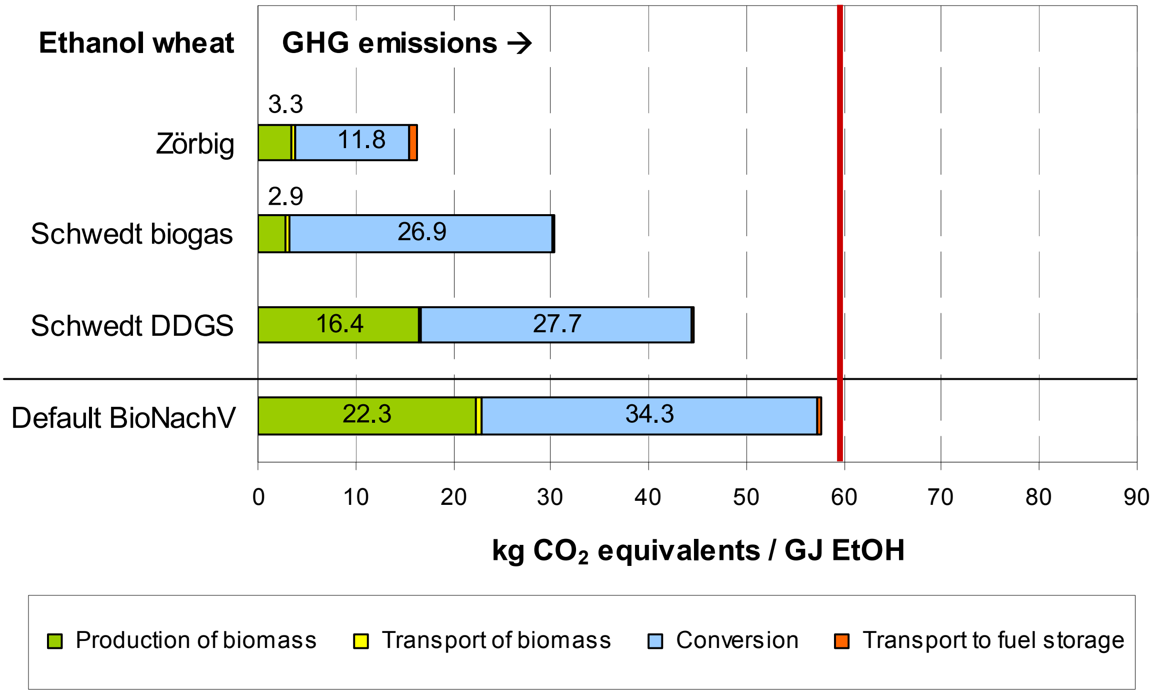


Fig. 3-6 Greenhouse gas emissions from the individual stages of the ethanol production chain (wheat). Comparison of the basic scenarios for the Zörbig and Schwedt VERBIO processes with the corresponding default values specified in the BioNachV ordinance (ethanol from European wheat)

Example (top bar)

The production of ethanol from wheat in the Zörbig MBE process causes total greenhouse gas emissions of approx. 16 kg CO_2 equivalents per GJ of ethanol, with approx. 3.3 kg resulting from grain production and approx. 11.8 kg from processing.

Conclusion

Compared to the default values, the results for VERBIO ethanol are very good, which is mainly due to the system boundaries used (the basic scenario with straw sales and the nutrient cycle) but, for the Zörbig plant, also due to the generation of process energy from straw with respect to greenhouse gas reduction.

3.2.4 Excursus: allocation of greenhouse gas emissions

As discussed in Section 2, all materials used and all emissions of a process are divided (allocated) into main products and by-products on the basis of their lower heating value. Whereas all the other figures only display the greenhouse gas emissions allocated to the main product ethanol, Fig. 3-7 shows an example of the complete distribution of greenhouse gases for the basic scenarios.

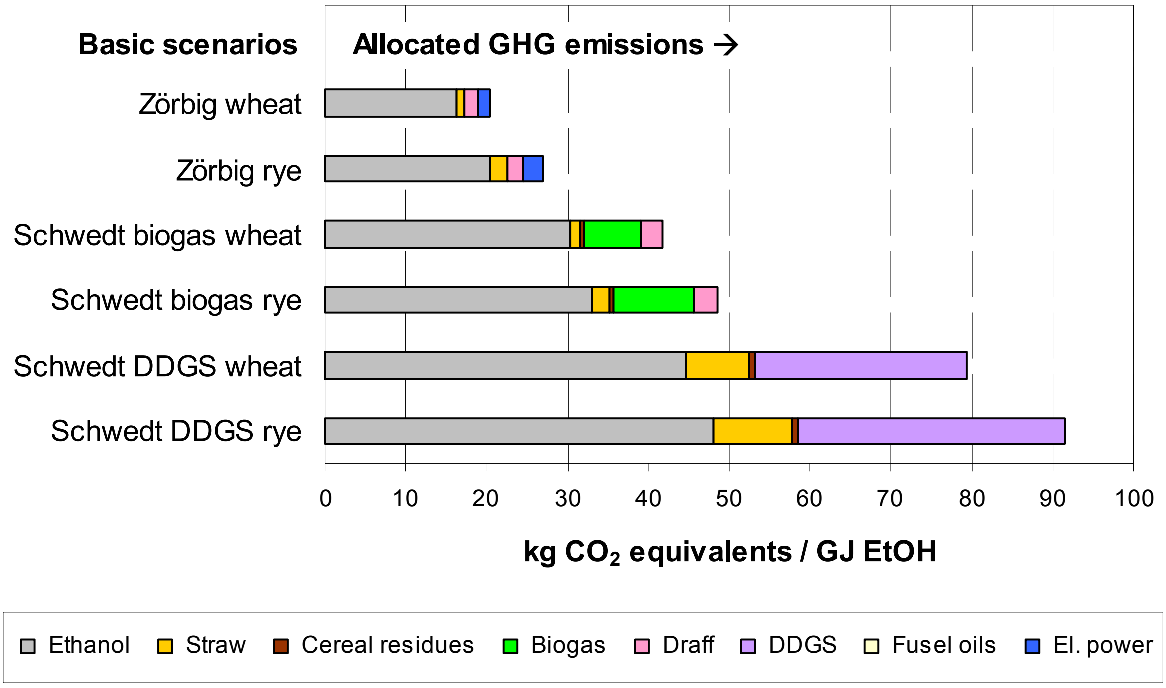


Fig. 3-7 Allocation of greenhouse gas emissions between the main product (ethanol) and the by-products of the Zörbig and Schwedt processes – comparison of the different basic scenarios

Example (3rd bar from the top)

The production of 1 GJ ethanol from wheat in the Schwedt biogas process causes greenhouse gas emissions in total of approximately 42 kg CO_2 equivalents, of which approx. 30 kg CO_2 equivalents are allocated to the main product ethanol and approx. 7 kg CO_2 equivalents, to the by-product biogas.

Results:

- There are clear differences in total emissions levels between the three VERBIO processes:
  - The Schwedt DDGS process generates the highest total emissions due to the high level of fossil fuels used. The emissions are then divided into main and by-products in proportion to their heating value. Since DDGS has a relatively high heating value, a large proportion of the emissions is allocated to this process.
  - The two biogas processes (Zörbig and Schwedt biogas) generate lower total emissions due to among other things the returning of digestate and the related saving of mineral fertilizer. In comparison, however, a distinctly higher proportion of the emissions is allocated to the main product ethanol. This can be ascribed to the fact that the by-products in this case have either a relatively low heating value and/or occur in relatively small quantities.

Analogous to the figures in the previous Section (3.2.3.), it is also possible to determine the allocation of greenhouse gas emissions for the by-products with respect to the production steps. From this point of view, Fig. 3-8 compares the typical by-products of the two Schwedt processes – biogas and DDGS.

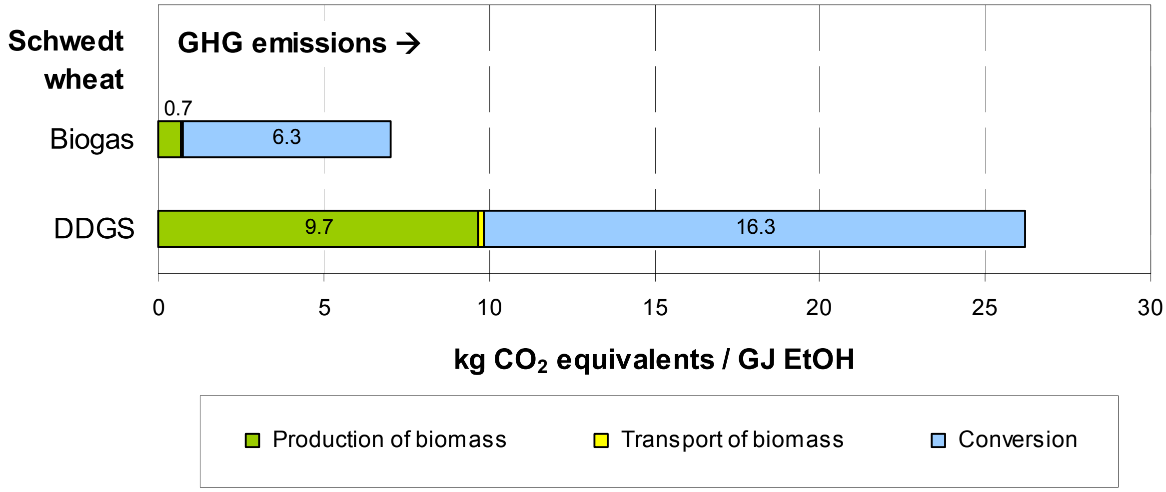


Fig. 3-8 Distribution of the greenhouse gas emissions allocated to the by-products biogas and DDGS with respect to production steps – comparison of the basic scenarios for ethanol production from wheat using the Schwedt process

Example (top bar)

The production of 1 GJ ethanol from wheat in the Schwedt biogas process causes greenhouse gas emissions in total of approximately 7 kg CO_2 equivalents allocated to biogas, 10 % of which result from grain cultivation and 90 % from processing.

Results

- With biogas, farming produces comparatively much lower emissions by returning digestate and the resulting decreased use of mineral fertilizers.
- If the biogas is fed into the gas network as intended and then used at other sites, for example at a CHP plant, an additional “handicap” of 7 kg CO_2 equivalents per GJ has to be taken into account for the greenhouse gas balance of the CHP plant. Even after adding 0.4 kg CO_2 equivalents per GJ from the biogas use, this method would still be clearly more favourable than an alternative use of natural gas, for which a total of 65 kg CO_2 equivalents would have to be estimated.

Conclusion

The greenhouse gas emissions allocated to the main product and the by-products depend on the process itself (inputs and outputs) with regard to the absolute level and the relative distribution, the selected system boundary as well as the heating value of the products. If biogas is used elsewhere to generate energy, its “greenhouse gas handicap” from the ethanol production has to be taken into consideration in the greenhouse gas balance of that site.

3.3 Sensitivity analyses: basic scenarios

To support and validate the results presented so far, so-called sensitivity analyses were performed, in which specific individual parameters were varied to determine their influence on the overall results. If the results do not change significantly, then the conclusion can be drawn that the results are stable with regard to possible deviations of the respective parameter from the originally defined base value. In order to carry out the analyses, individual values were changed based on queries of the internal IFEU database [IFEU 2008] with regard to the original values provided by the customer (see Subsection 3.1.1). These variations especially concern the processing step and cover possible greenhouse gas losses from the plant and digestate stores, a possibly higher total process energy requirement and the production of the process electricity. The following sections describe these "sensitive parameters", define the scenarios examined, including the origin of the data, and present and discuss the respective results for the greenhouse gas emissions of the VERBIO processes. The red line in the result diagrams marks the basic value required to be met according to the BioNachV ordinance.

3.3.1 Greenhouse gas losses from the plant and digestate store

Methane and laughing gas losses usually occur in biogas production, including the downstream processes such as usage in CHP plants or preparation and feed-in. According to information in [VERBIO 2007/08] this is not the case at the Zörbig and Schwedt plants. Despite the burning of the gases produced, a small amount of laughing gas (N_2O) escapes into the atmosphere from the digestate store but the quantities are marginal (see Subsection 3.1.1). In order to check the effects of such greenhouse gas losses on the results, this sensitivity analysis used average Germany-wide values for biogas plants and downstream processes instead of the values provided by the customer [VERBIO 2007/08]. Table 3-2 contains detailed information:

Table 3-2 Greenhouse gas losses from biogas production for the Zörbig and Schwedt VERBIO ethanol production process: basic and average values used. Values given in percent relate to the volume of biogas (CH_4) produced or the nitrogen content in the digestate (N_2O).

System component	Gas	Basic value (basic scenario)	Average values (sensitivity analysis)
Biogas plant (MBE & NBE biogas)	CH_4	0%	1.0%
CHP plant (MBE only)	CH_4	0%	0.5%
Preparation (NBE only)	CH_4	0%	2.0%
Digestate store (MBE & NBE biogas)	CH_4	0%	2.5%
	N_2O	0.01%	0.1%

Greenhouse gas losses can occur at different places in the Zörbig MBE and the Schwedt NBE biogas plants. Their effects on the total results of the greenhouse gas balance for each process are illustrated in Fig. 3-9.

Results

- As expected, higher greenhouse gas losses than those specified in the basic scenario result in a worsening of the balance: with Zörbig wheat, the greenhouse gas emissions increase by almost one third.
- The percent increase is not as obvious with Schwedt biogas because the biogas plant, preparation, feed-in and digestate store are minor contributors to the total emissions, and steam production dominates the final balance.

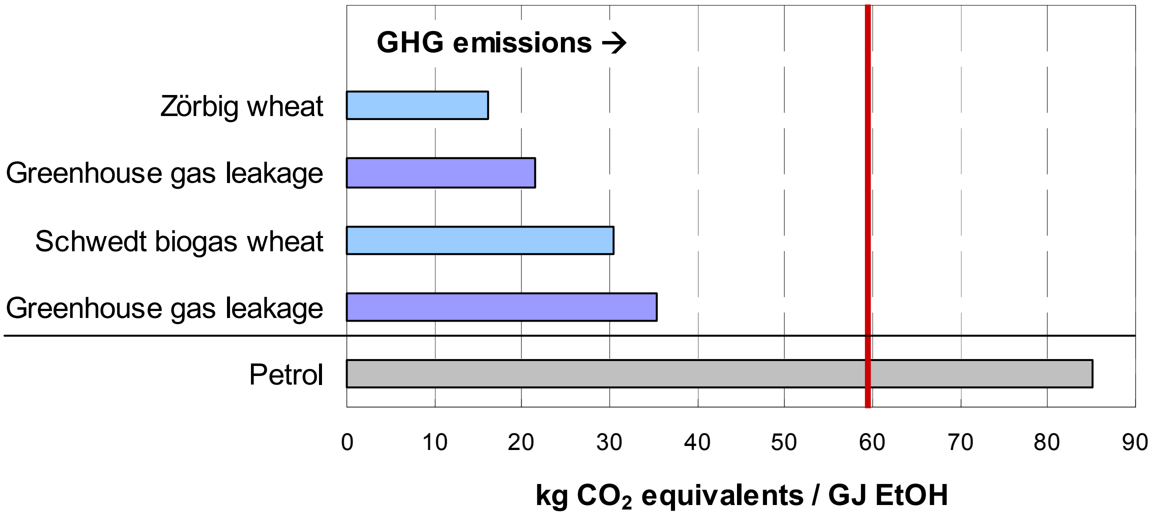


Fig. 3-9 Greenhouse gas emissions for ethanol production from wheat using the VERBIO processes in which biogas is produced. Comparison of the respective basic scenario and the sensitivity analysis on greenhouse gas losses in plant-specific processes (greenhouse gas losses)

Example (2nd bar from the top)

When higher greenhouse gas losses occur in the production of ethanol from wheat at the Zörbig plant, this results in total greenhouse gas emissions of approx. 21 kg CO_2 equivalents per GJ ethanol.

Conclusion

Even though the total greenhouse gas balance is worsened by greenhouse gas losses occurring in the individual steps of processing grain to ethanol, or in the storage or the subsequent treatment of by-products, the results are still significantly below the basic value required by the BioNachV ordinance.

3.3.2 Higher process energy requirement

In order to validate the influence of process energy generation, this sensitivity analysis examined the effects of a 20 % increase in the process energy requirement on the greenhouse gas balance compared to the values provided by the customer (see Subsection 3.1.1). Fig. 3-10 provides a sample illustration of this variation for the Zörbig MBE process.

Results

- In all VERBIO ethanol production plants examined, increasing the process energy requirement leads to greater emissions of greenhouse gases.
- For the Zörbig process, the consequences are comparatively small since only green electricity is additionally purchased. In both Schwedt process variants the higher steam requirement makes the effects much more significant.

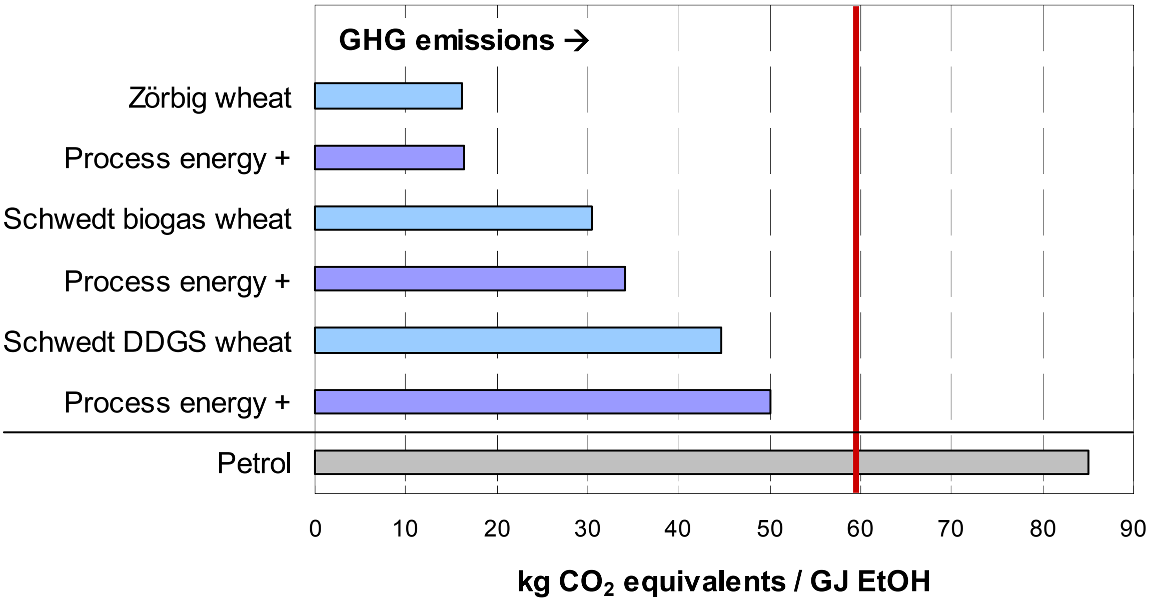


Fig. 3-10 Greenhouse gas emissions for ethanol production from wheat using the three processes examined. Comparison between the respective basic scenario and those requiring 20 % more process energy

Example (4th bar from the top)

If 20 % more process energy is required for producing ethanol from wheat using the Schwedt biogas process, this results in total greenhouse gas emissions of approx. 34 kg CO_2 equivalents per GJ of ethanol, which is equivalent to an increase of 12 % compared to the basic scenario (3rd bar from the top).

Conclusion

Even with a 20 % higher process energy requirement, VERBIO ethanol still conforms to the 30 % basic value required by the BioNachV ordinance.

3.3.3 Provision of process electricity

The process electricity required by ethanol production plants can be obtained from various sources. As alternatives to the basic scenario described in Subsection 3.1.1, where the electricity requirement is covered by green electricity in accordance with the VERBIO business model, two other possibilities were examined. The effects of these variations are illustrated in Fig. 3-11.

- **Internal power** (Zörbig plant only): the process electricity requirement is completely covered by internally generated electricity from the CHP plant. Since more electricity is produced than required by the process, no external electricity input is required and the values caused by electricity are correspondingly lower.
- **Power mix**: the electricity input, i. e. the additionally purchased electricity (not produced by the CHP plant) comes from the public power grid (German power mix).

Results

The provision of the required process electricity clearly influences the greenhouse gas balance when producing ethanol from grain. Whereas internal use of the produced electricity in the Zörbig MBE process produces results similar to those of the basic scenario, the use of the normal power mix from the public power grid leads to significantly higher greenhouse gas emissions.

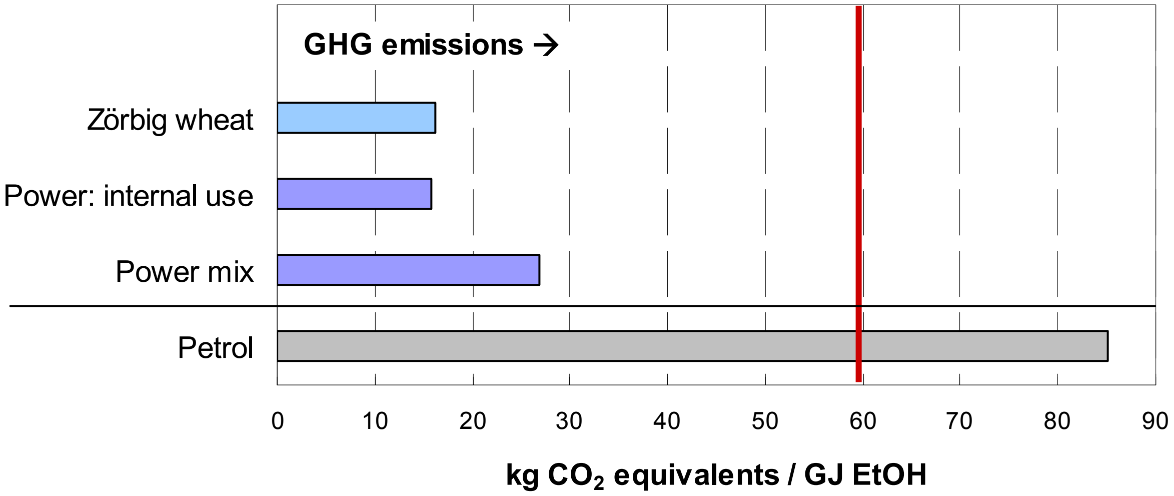


Fig. 3-11 Greenhouse gas emissions of ethanol production from wheat using the Zörbig MBE process. Comparison of the basic scenario with two variants, in which the process electricity is internally generated (power: internal) or in which the conventional power mix from the grid is used instead of green electricity (power: mix)

Example (2^{nd} bar from the top)

If the electricity produced in the Zörbig MBE plant during the production of ethanol from wheat is fed back to provide the process energy, this results in total greenhouse gas emissions of approx. 16 kg CO_2 equivalents per GJ of ethanol.

Conclusion

The provision of process electricity heavily influences the total greenhouse gas emissions of VERBIO ethanol production from grain. The use of electricity from renewable energy sources, whether plant-internally generated electricity or additionally purchased green electricity, is clearly better than using the average German power mix. But even then the specifications of the BioNachV ordinance are still met.

4 Further GHG balances as per the BioNachV ordinance

In addition to the basic scenarios examined in the previous sections, several other methods of examination and calculation can be applied. This section presents and analyses a selection of such alternatives, all of which conform to the specifications of the BioNachV draft. The results thus show the latitudes permitted by the draft ordinance in calculating greenhouse gas balances.

4.1 Alternatives to the basic scenario

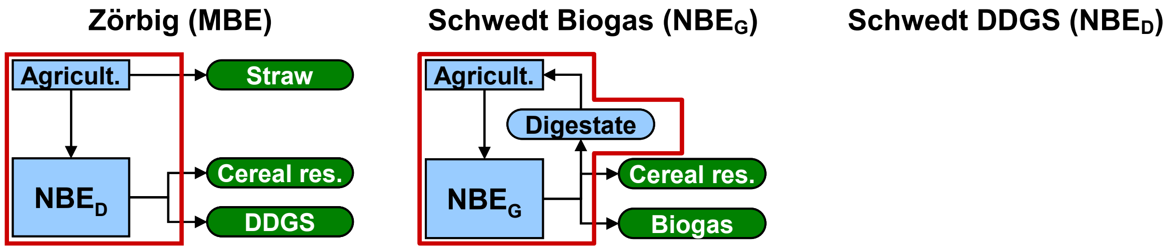
Two variations of the examination and calculation methods used in the basic scenario are conceivable: on the one hand the selection of different system boundaries, and on the other the methods used to analyze individual parameters. These variations all have an important common element: they all conform to the specifications of the BioNachV draft.

4.1.1 Variation of the system boundaries

The following sections provide short descriptions of possible and reasonable variations to the system boundaries for VERBIO ethanol, which go beyond those used in the basic scenario. The main differences, the details of which depend on the plant concepts, are illustrated in diagrams. For reasons of clarity, other by-products such as spent grains and fusel oils, and the main product ethanol, which are the same in all plant concepts, are not shown here.

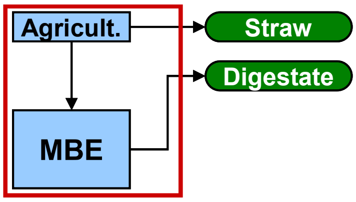
Nutrient cycle

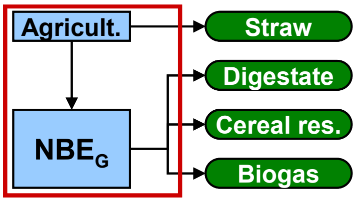
The two by-products of ethanol production, digestate and foul syrup (subsequently referred to as "digestate"), are used to replace fertilizer on the same fields where the grain was grown. The straw from the grain cultivation remains in the system. This scenario cannot be used for the Schwedt NBE DDGS process because this does not produce digestate.

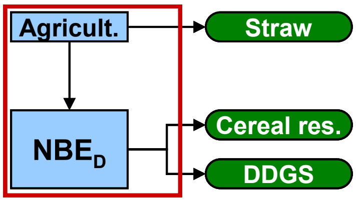


Straw sale

The digestate is sold and used outside the system. The by-product straw resulting from the grain cultivation is sold, i. e. it is used (by third-parties) outside the system. The straw requirement of the Zörbig MBE process is covered by purchasing (system) external products.

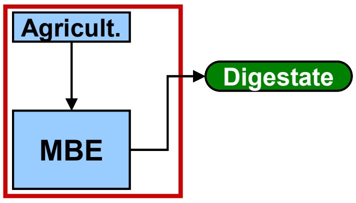


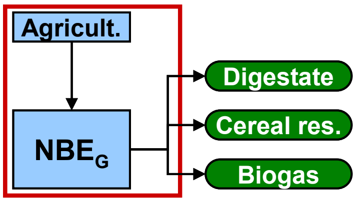


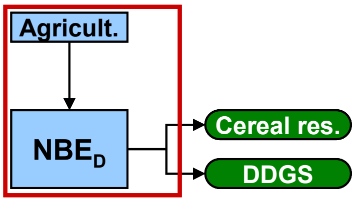


Processing facility

The digestate is sold and used outside the system. However, the straw from the grain cultivation remains in the system.

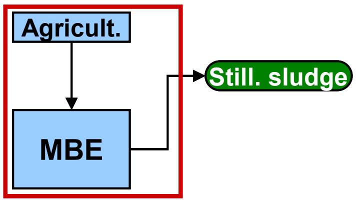






Stillage sludge sale

The stillage sludge resulting from ethanol production leaves the system and is neither processed to biogas nor DDGS. This reflects the strictest possible definition of system boundaries within the scope of the BioNachV ordinance. For the purposes of this study, the stillage sludge sale scenario is examined for the Zörbig MBE process as an example.



4.1.2 Variation of the heating value reference

According to appendix 1 of the BioNachV ordinance (2.2), by-products are included via allocation based on the lower heating values. However, the BioNachV ordinance does not exactly specify whether the lower heating value is to be based on the wet mass (dry material plus water content) or the dry mass (dry material only) of a by-product. This is especially important when considering watery materials such as stillage sludge. In this study, the wet mass is always used as the basic reference. As a variation, sample calculations using heating values based on the dry mass are performed for the Zörbig MBE plant.

4.2 Results: alternatives to the basic scenario

As described in Subsection 4.1, a number of different balancing possibilities exist within the scope of the BioNachV ordinance. The results of the greenhouse gas balance for ethanol produced from grain can change when the system boundaries or individual calculation parameters are varied. The central findings of this sample examination are derived from the Zörbig MBE process but these can also be applied to the Schwedt NBE process. The result diagrams for the latter are shown in the appendix (7.2). The red line in the result diagrams marks the basic value required to be met according to the BioNachV ordinance.

4.2.1 Variation of the system boundaries: emissions by process

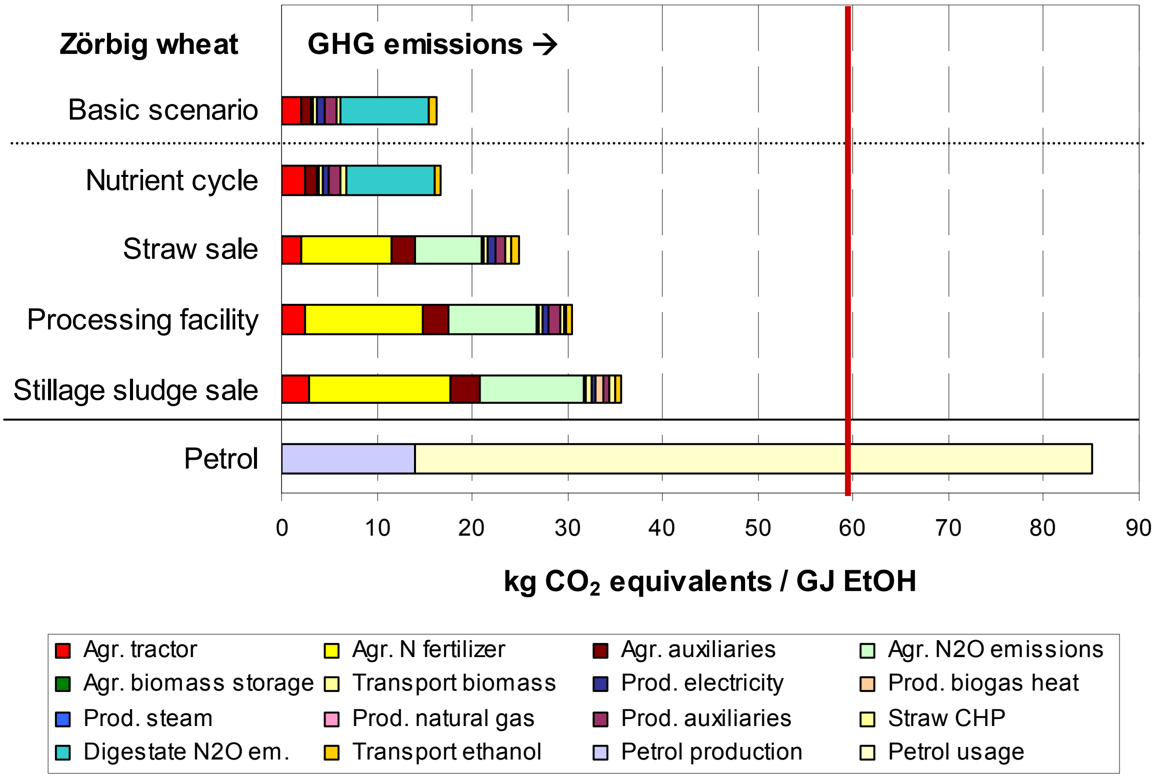


Fig. 4-1 Greenhouse gas emissions of ethanol production from wheat using the Zörbig MBE process. Comparison of the results for different system boundaries in line with the BioNachV ordinance. Red line: BioNachV basic value

Example (5th bar from the top, stillage sludge sales)

If the stillage sludge is not subsequently processed into biogas in the Zörbig MBE process, this results in approx. 36 kg CO_2 equivalents per GJ of VERBIO ethanol produced from wheat.

Fig. 4-1 shows the greenhouse gas emissions determined for wheat-based Zörbig VERBIO ethanol using selected alternative system boundaries and compares these to the results of the basic scenario (see Subsection 3.2). The central conclusions that can be derived from this comparison are then presented.

Results

- The selection of the system boundaries used for calculating the greenhouse gas emissions of VERBIO ethanol has a decisive influence on the results. In all cases, varying the balancing method leads to an increase in greenhouse gas emissions compared to the respective basic scenario.
- In all cases, the basic value of greenhouse gas reduction potential specified in the BioNachV ordinance was maintained for wheat-based ethanol: compared to conventional petrol, the fossil equivalent of VERBIO ethanol, all examined system boundaries show lower greenhouse gas emissions.

The results also show that the "main cause" of greenhouse gas emissions can vary depending on the system boundaries chosen – even for the same product or production process:

- For the examined scenarios containing a system-internal feedback of the digestate, these by-products cause the major portion of greenhouse gas emissions. However, this method of calculation results in the lowest total emissions.
- In all scenarios in which the fields are fertilized with additionally purchased nitrogen fertilizer (N fertilizer), this results in significantly higher greenhouse gas emissions.

Conclusion

All examined alternative system boundaries result in higher greenhouse gas emissions than the boundaries used in the basic scenario for ethanol production based on the VERBIO AG business model. However, these are still significantly below the values for conventional petrol and also lower than the basic value specified in the BioNachV ordinance. The Zörbig process produces the best results by ensuring that the two by-products digestate and foul syrup, which originate in the process, are returned to the same fields used for growing the processed grain.

4.2.2 Variation of the system boundaries: emissions by greenhouse gases

Fig. 4-2 analyses the individual processes of the process results shown in 4.2.1 considering the quantities of each greenhouse gas produced.

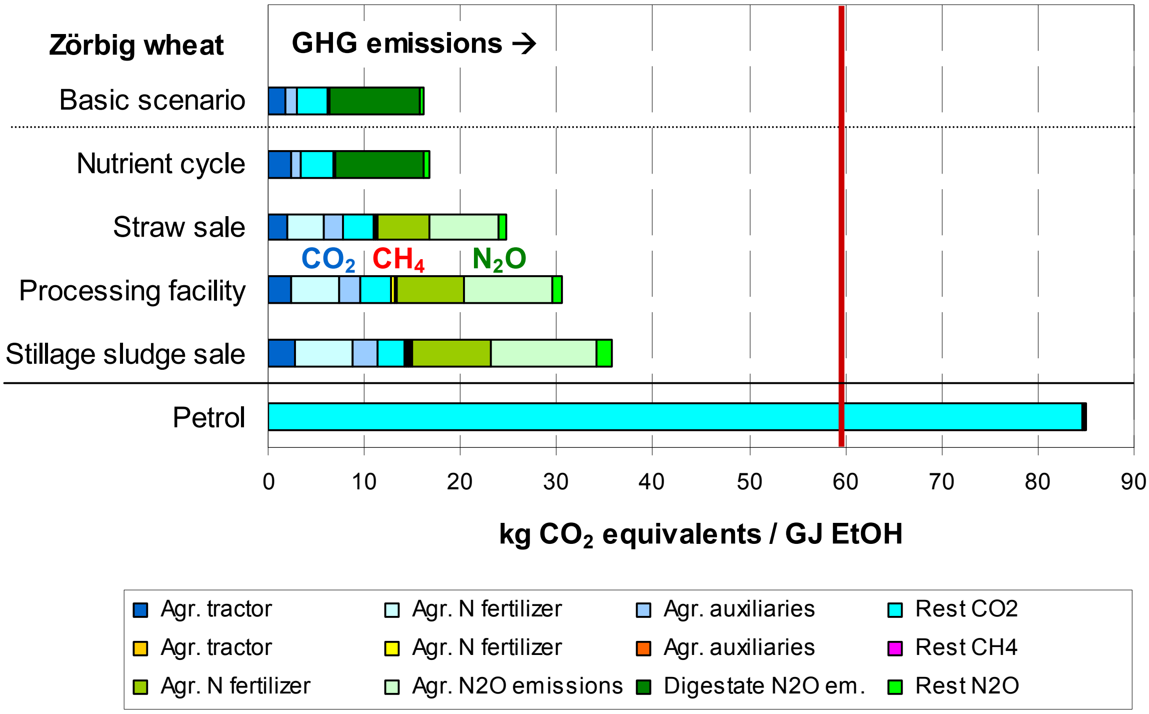


Fig. 4-2 Emissions of individual greenhouse gases from single process steps in ethanol production using the Zörbig MBE process: CO_2 (blue bar section), CH_4 (yellow-red), N_2O (green). Comparison of the results for the different system boundaries in line with the BioNachV ordinance

Example (5th bar from the top, stillage sludge sales)

If the stillage sludge is not processed into biogas in the Zörbig MBE process, this produces approx. 36 kg CO_2 equivalents per GJ, with approx. 14 kg CO_2 equivalents (40 %) as CO_2.

Results

This presentation of the results indicates that the "composition" of the greenhouse gas emissions can also vary depending on the system boundaries chosen:

- In all examined scenarios, CO_2 and N_2O greenhouse gas emissions are decisive whereas CH_4 plays a comparatively minor role.
- The CO_2 emissions mainly originate from grain cultivation, whereas the N_2O emissions are caused by the production and the use of mineral nitrogen fertilizers, and especially by returning the digestate to the fields.

- However, the composition of the greenhouse gases remains relatively constant, independent of the system boundaries chosen: in the Zörbig process, N_2O emissions from the digestate dominate the balance in all cases.

Conclusion

The composition of the greenhouse gas emissions varies with the process used (see Subsection 3.2.2), but does not depend on the choice of the system boundaries. The results for the Zörbig process could still be significantly improved for the system boundaries straw sales, processing facility and stillage sludge sales if nitrogen fertilizer was not used, i. e. if "green" grain was used for ethanol production, but in the light of the already high price for raw material this is not economically feasible.

4.2.3 Variation of the heating value reference

If the by-products are allocated to the end product based their (lower) heating value as specified in the BioNachV ordinance, then this heating value assumes a central role. If a different reference is chosen, the greenhouse gas balance for VERBIO ethanol changes accordingly. In order to quantify this change, the dry mass of the by-products was used as the reference instead of using their wet mass, as specified in Section 2.

Fig. 4-3 shows the results of the previously determined greenhouse gas emissions for all scenarios (system boundaries), with the ethanol production from wheat using the Zörbig process as an example. Similar representations of both Schwedt process variants – also for wheat – are provided in the appendix (7.2).

Results

- The selection of the reference for the heating value of the respective by-products resulting from VERBIO ethanol production significantly influences the greenhouse gas balance of the main product. All results are better than in the basic scenario.
- In all cases, the basic value of greenhouse gas reduction potential specified in the BioNachV ordinance was maintained for wheat-based ethanol: in all examined scenarios, regardless of the heating value reference used, the greenhouse gas emissions resulting from the production of VERBIO ethanol from wheat were lower than those of the fossil equivalent, i. e. normal petrol.

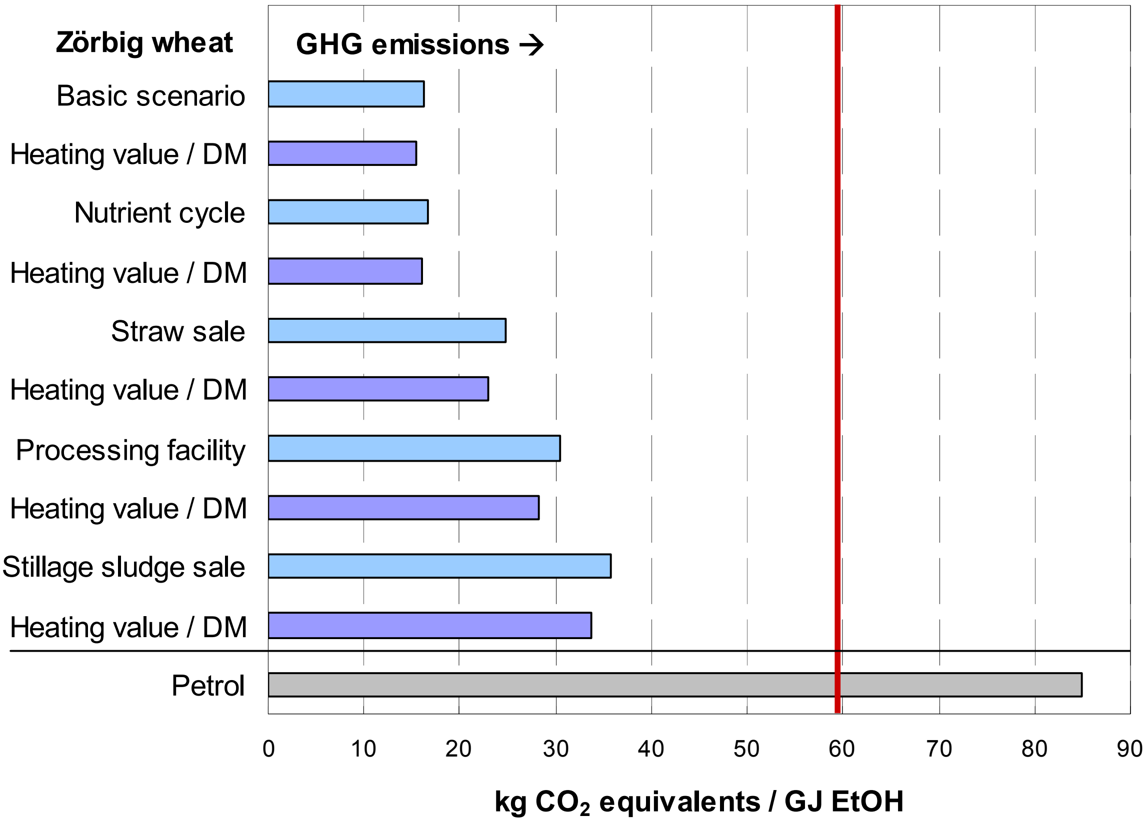


Fig. 4-3 Greenhouse gas emissions of ethanol production from wheat using the Zörbig MBE process. Comparison of the allocation of by-products using the heating value for wet mass and dry mass for different system boundaries

Example (2nd bar from the top)

If the by-products are allocated using the dry mass heating value instead of the wet mass heating value, the basic scenario of production of ethanol from wheat using the Zörbig MBE process results in total greenhouse gas emissions of approx. 15 kg CO_2 equivalents per GJ of liquid fuel. This is equivalent to a balance improvement of approx. 4 % compared to the basic scenario.

Conclusion

The lower heating value of the by-products is a central parameter for calculating greenhouse gas emissions in line with the BioNachV ordinance. The inexact definition of this parameter clearly leads to variable results. Despite this fact, all results determined when varying this parameter – independent of the system boundaries chosen – were significantly below the basic value specified in the BioNachV ordinance, i. e. the greenhouse gas balances for VERBIO ethanol are much better than those of conventional petrol.

5 Summary and conclusions

The examination shows that ethanol from all examined VERBIO processes reaches or even greatly exceeds the greenhouse gas reduction potential of 30 % compared to petrol, as specified in the German Biomass Sustainability Ordinance (BioNachV). For example, using the basic scenario based on the VERBIO AG business model, greenhouse gas reduction potentials between 40 % (Schwedt DDGS rye) and 80 % (Zörbig wheat) were determined. Even when disadvantageous values are used, as was the case in several sensitivity analyses, or when the framework conditions are changed, the basic value of 30 % valid till 2010 is always achieved. With the exception of two cases, the basic value almost always fell below the 40 % stipulated as of 2010. The major sub-results are:

- Compared to rye, ethanol production from wheat leads to lower greenhouse gas emissions because a relatively low specific quantity of nitrogen fertilizers is estimated for wheat cultivation (as per the BioNachV ordinance).
- Plant concepts with biogas production (Zörbig and Schwedt biogas) yield significantly better results than those with DDGS production (Schwedt DDGS), because the provision of energy for drying the stillage sludge to DDGS causes high emissions.
- The comparison of the two plants with biogas production (energy production in Zörbig compared to preparation and feeding into the gas network in Schwedt) shows clear advantages for the Zörbig concept. Among other reasons, this is due to the fact that the process steam required is produced from biomass (straw) whereas all the process steam in Schwedt is provided via fossil fuels.
- In particular, grain cultivation (mainly due to the use of fertilizer) and processing (mainly due to energy provision) have a major influence on greenhouse gas emissions in the production chain of VERBIO ethanol.
- Compared to the default values specified in the BioNachV ordinance, the values for VERBIO ethanol are very good, since the greenhouse gases emitted both during cultivation (due to straw sales and returning of digestate) and those emitted during generation of the process steam (with default values based on the use of lignite) are significantly smaller.
- Using the latitude resulting from the BioNachV ordinance's specifications leads to results that are very different to those of the basic scenario, but VERBIO ethanol still achieves the basic value of 30 % in all these cases.

From the point of view of the plant operator, it is necessary for legal and investment security to provide more exactitude in the BioNachV draft, since it does neither define exact system boundaries for greenhouse gas balances nor mention explicitly the reference of the heating value to the wet mass. The draft should also be enhanced to include additional raw materials such as rye or triticale as well as ethanol production processes with biogas production. However, this will now only be possible within the scope of a European Guideline because the EU commission rejected the German BioNachV ordinance on 13/03/2008 with reference to the Renewable Energy Sources Directive currently under development [CEC 2008].

6 Literature and abbreviations

Literature

[BioNachV 2007] German Federal Government: Entwurf einer Verordnung über Anforderungen an eine nachhaltige Erzeugung von Biomasse zur Verwendung als Biokraftstoff (Biomasse-Nachhaltigkeitsverordnung – BioNachV) (Draft of an ordinance on the requirements for sustainable production of biomass for use as biofuel (biomass sustainability ordinance – BioNachV)). Berlin, 05/12/2007

[CEC 2008] Commission of the European Communities: Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources) COM(2008) 19 final. Brussels, 23/01/2008

[Fehrenbach et al. 2007] Fehrenbach, H., Giegrich, J., Gärtner, S.O., Reinhardt, G.A. & Rettenmaier, N.: Greenhouse gas balances for the German biofuels quota legislation – Methodological guidance and default values. Institut für Energie- und Umweltforschung (IFEU). Heidelberg, 2007

[IFEU 2008] Institut für Energie- und Umweltforschung: IFEU-internal calculations and database queries. Heidelberg, 2008

[IPCC 1996] Intergovernmental Panel on Climate Change: Revised 1996 IPCC guidelines for national greenhouse gas inventories. Geneva, 1996

[Kaltschmitt & Reinhardt 1997] Kaltschmitt, M. & Reinhardt, G.A. (Hrsg.): Nachwachsende Energieträger. Grundlagen, Verfahren, ökologische Bilanzierung. (Renewable sources of energy - fundamentals, procedures, ecological balancing). Vieweg, Braunschweig / Wiesbaden, 1997.

[Münch 2008] Münch, J.: Nachhaltig nutzbarer Getreidestrohanteil in Deutschland. (Sustainably usable grain straw proportions in Germany) Position paper of Institut für Energie- und Umweltforschung (IFEU). Heidelberg, 2008

[VERBIO 2007/08] Lüdtke, O.: Personal messages. VERBIO Vereinigte BioEnergie AG. Leipzig, 2007/08

Abbreviations

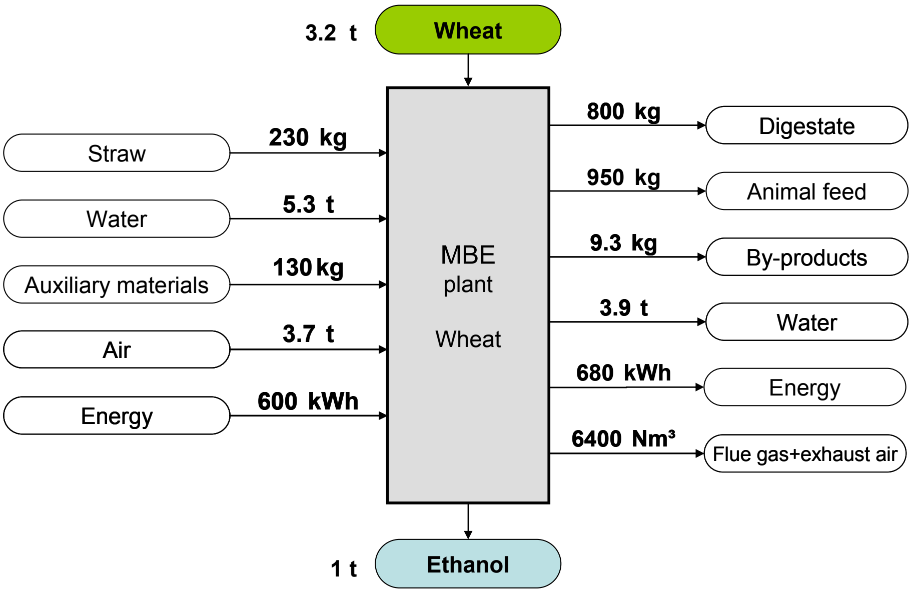
CHP plant	Combined heat and power plant
BioNachV	German Biomass Sustainability Ordinance (draft)
CH_4	Methane
CO_2	Carbon dioxide
DDGS	Distiller's Dried Grains with Solubles
EtOH	Ethanol
GJ	Gigajoule, 10^9 joules
CHP	Combined heat and power generation
MBE	Mitteldeutsche BioEnergie GmbH & Co. KG, Zörbig
N_2O	Nitrous oxide, laughing gas
NBE	Nordbrandenburger BioEnergie GmbH & Co. KG, Schwedt
Otto-KS	Petrol
RME	Rapeseed methyl ester, rapeseed biodiesel
GHG	Greenhouse gas(es)

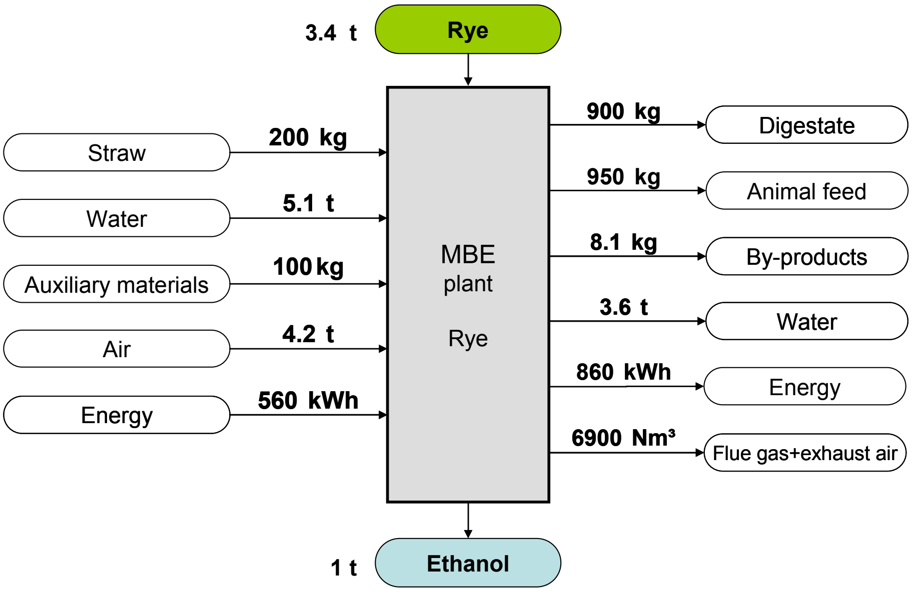
7 Appendices

7.1 VERBIO process: inputs and outputs

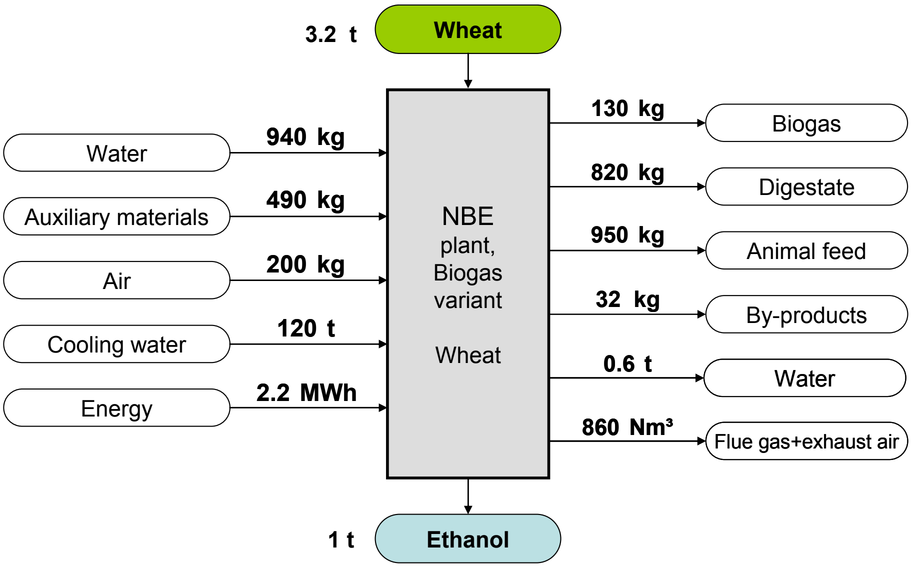
The following illustration of the flow of materials either sums up in part the inputs and outputs for each process or denotes them differently. Detailed information about the processes can be found in the following.

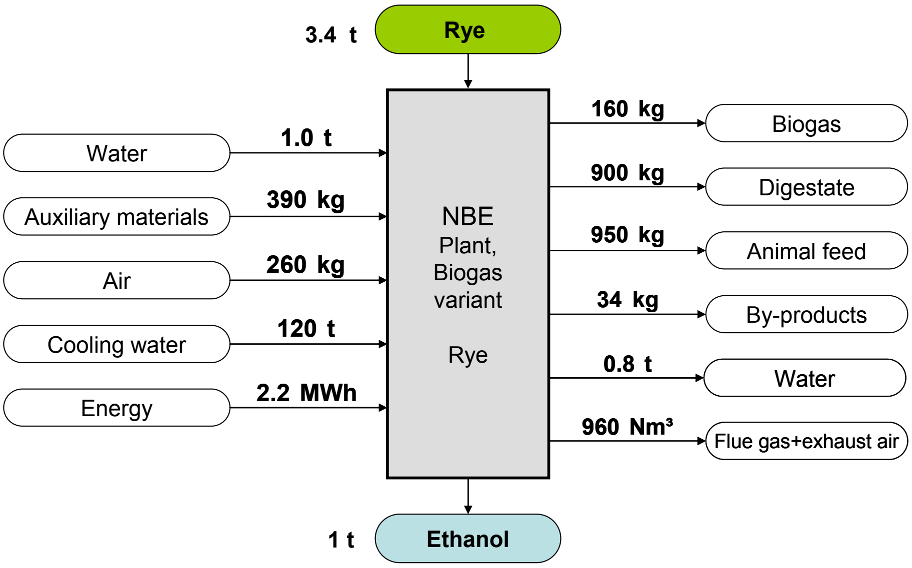
Zörbig (MBE)



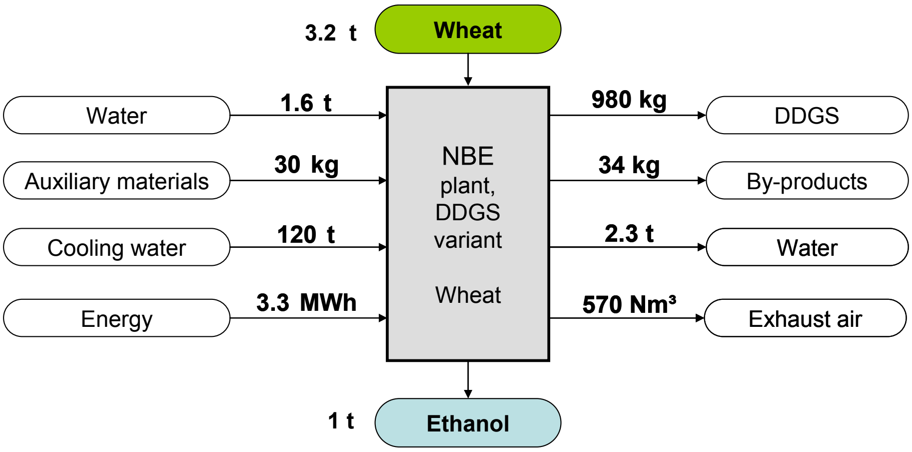


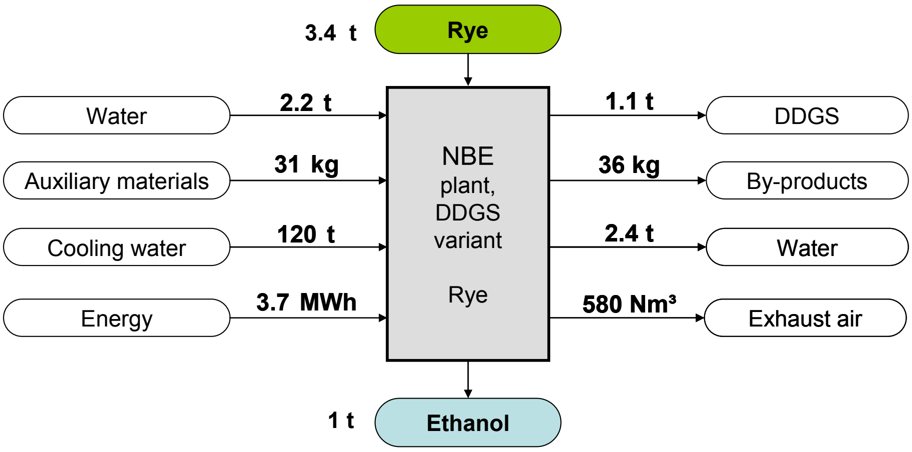
Schwedt Biogas (NBE)





Schwedt DDGS (NBE)





Inputs

- Auxiliary materials: enzymes, sulphuric acid, flocculants, and animal feed
- Energy: electricity, steam, and natural gas

Outputs

- Digestates: foul sirup and digestate
- Animal feed: draff
- By-products: ash, cereal residues, and fusel oils
- Water: H_2O vapour and waste water

7.2 Results: alternatives to the basic scenario (NBE)

Variation of the system boundaries: emissions from the individual processes

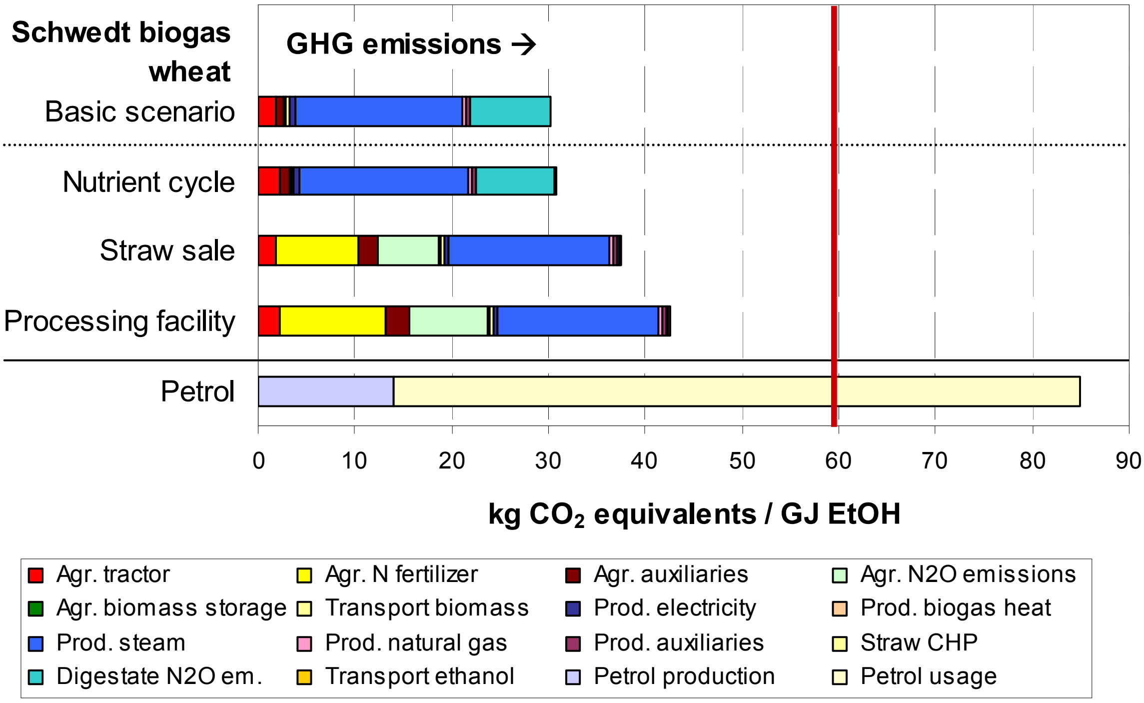


Fig. 7-1 Greenhouse gas emissions of ethanol production from wheat using the Schwedt NBE biogas process. Comparison of the results for different system boundaries in line with the BioNachV ordinance. Red line: BioNachV basic value

Example (4th bar from the top)

If neither the straw accrued from grain harvesting nor the digestate is sold, i. e. they remain in the system, the production of ethanol from wheat using the Schwedt NBE biogas process produces greenhouse gas emissions of approx. 42 kg CO_2 equivalents per GJ of liquid fuel.

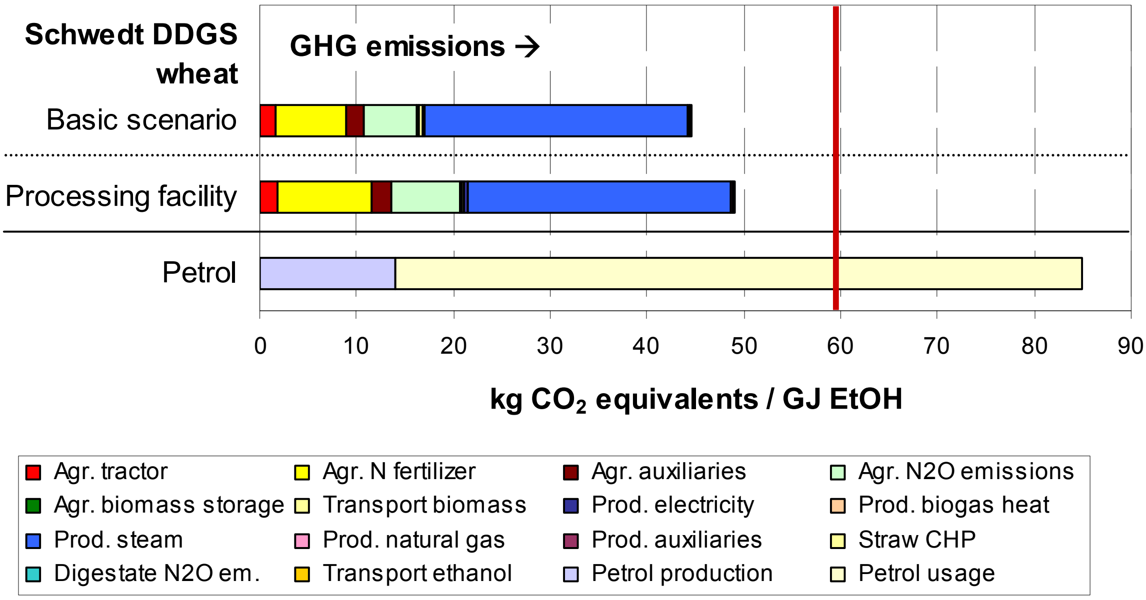


Fig. 7-2 Greenhouse gas emissions of ethanol production from wheat using the Schwedt NBE DDGS process. Comparison of the results for different system boundaries in line with the BioNachV ordinance

Example (2nd bar from the top)

If neither the straw accrued from grain harvesting nor the digestate is sold, i. e. they remain in the system, the production of ethanol from wheat using the Schwedt NBE biogas process produces greenhouse gas emissions of approx. 49 kg CO_2 equivalents per GJ of liquid fuel.

Variation of the system boundaries: individual greenhouse gas emissions

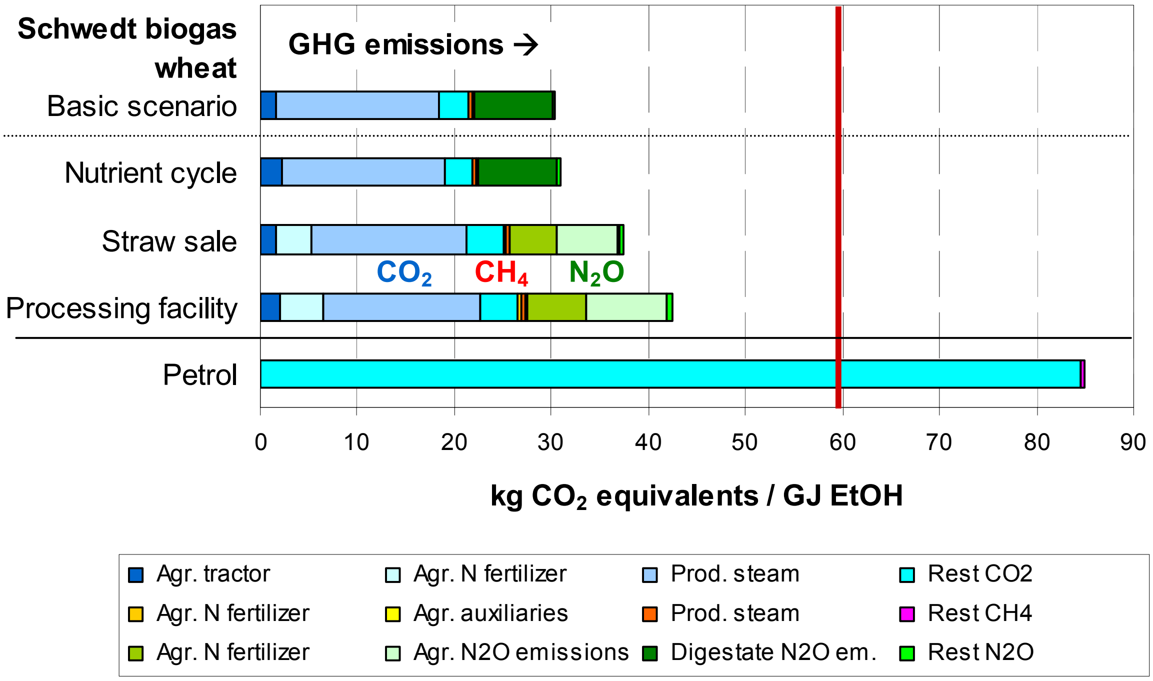


Fig. 7-3 Emissions of individual greenhouse gases from single process steps of ethanol production using the Schwedt NBE Biogas process: CO_2 (blue bar section), CH_4 (yellow-red), N_2O (green). Comparison of different system boundaries in line with the BioNachV ordinance

Example (4th bar from the top)

If neither the straw accrued from grain harvesting nor the digestate is sold, i. e. they remain in the system, the production of ethanol from wheat using the Schwedt NBE biogas process produces greenhouse gas emissions of approx. 42 kg CO_2 equivalents per GJ of liquid fuel, with approx. 27 kg CO_2 equivalents as CO_2 and approx. 15 kg CO_2 equivalents as N_2O.

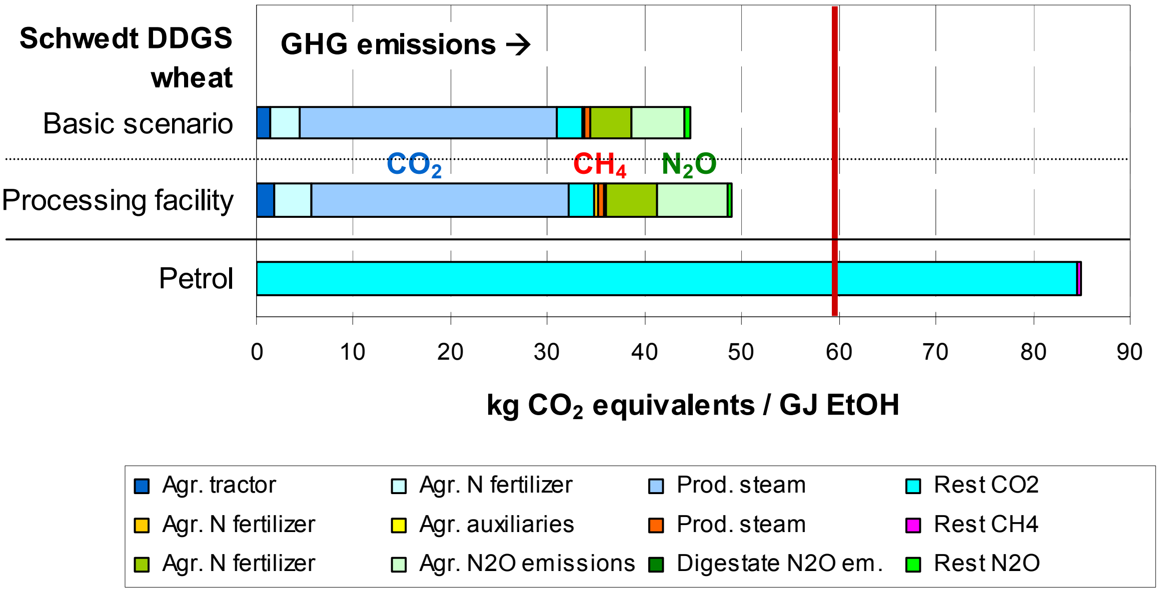


Fig. 7-4 Emissions of individual greenhouse gases from single process steps of ethanol production using the Schwedt NBE DDGS process: CO_2 (blue bar section), CH_4 (yellow-red), N_2O (green). Comparison of the basic scenario and an alternative system boundary in line with the BioNachV ordinance

Example (2nd bar from the top)

If neither the straw accrued from grain harvesting nor the digestate is sold, i. e. they remain in the system, the production of ethanol from wheat using the Schwedt NBE biogas process produces greenhouse gas emissions of approx. 49 kg CO_2 equivalents per GJ, with approx. 35 kg CO_2 equivalents as CO_2 and approx. 13 kg CO_2 equivalents as N_2O.

Variation of the heating value reference

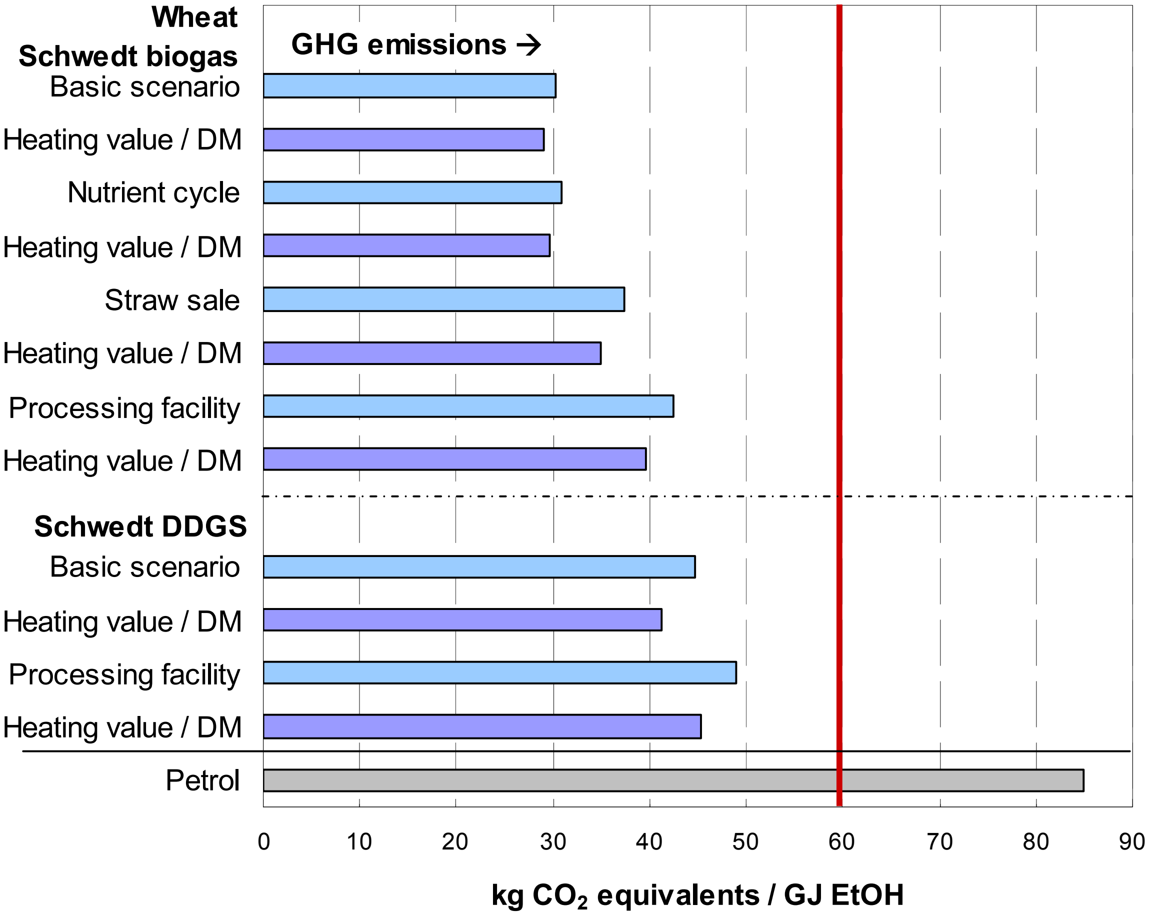


Fig. 7-5 Greenhouse gas emissions of ethanol production from wheat using the Schwedt MBE process variants. Comparison of the allocation of by-products using the heating value for wet mass and dry mass for different system boundaries

Example (2nd bar from the top)

If the by-products are allocated using the dry mass heating value instead of the wet mass heating value, the basic scenario of production of ethanol from wheat using the Zörbig MBE process results in total greenhouse gas emissions of approx. 29 kg CO_2 equivalents per GJ of liquid fuel. This is equivalent to a balance improvement of approx. 4 % compared to the 1st bar.