Cost and Life-Cycle Analysis of Biofuels

Long version

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- Long version -

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1 Background and objective

In the past, different pathways in view to generate fuel from biomass were developed or put into practice in order to reduce both the dependency of the current traffic sector of fossil resources and the greenhouse gases. Thus, the established biofuels as plant oil, biodiesel from vegetable and animal oils and fats (especially rape seeds) or ethanol from cereals make an essential contribution at the market. Moreover, it is expected in the future to increase the generation and use of synthetical biofuels (BTL ans SNG) and ethanol from lignocellulose as well as biomethane.

The current available studies as results of the vast investigation and development works show considerable bandwidths of the potentials, environment impacts and costs of biofuels and are therefore controversally discussed. This makes an objective assessment difficult, consequently influences the continuous further development of target-aimed biofuel pathways.

Against this background, the essential methodologies on the biofuel provision are consecutively compared in a synopsis taking into account selected criteria. The biofuel pathways considered in this study with the relevant feedstocks as well as biofuel and by-products can be taken from Table 1.

Table 1: Considered provision pathways

Provision pathway	Biomass input	Conversion technology	**main fuel products**, other revenues
	biomass	→ conversion →	biofuel
rape oil	rapeseed	cleaning/milling, pressing, extraction, oil processing	**rape oil**, extraction groat
	rapeseed	cleaning/milling, pressing, oil processing	**rape oil**, press cake
biodiesel (RME)	rapeseed	rape oil provision (see above), catalytic transesterification using methanol	**RME**, press cake, raw glycerine
	rape oil	catalytic transesterification using methanol	**RME**, raw glycerine
biomethane	maize silage	silage pre-treatment, anaerobic fermentation, gas processing	**biomethane**, fermentation residues
BTL from lignocelluloses	wood chips (willow from SRC)	biomass pre-treatment, gasification, gas cleaning and conditioning, FT synthesis, product upgrading	**FT diesel**, **naphtha**, electricity
	straw slurry	biomass pre-treatment, gasification, gas cleaning and conditioning, FT synthesis, product upgrading	**FT diesel**, **naphtha,** electricity
ethanol from lignocelluloses	wheat straw	biomass pre-treatment, hydrolysis, fermentation, distillation, rectification	**ethanol**, electricity, fertiliser
ethanol from wheat	wheat grain	biomass pre-treatment, saccharide pulping, fermentation, distillation, rectification	**ethanol**, slop/DDGS
SNG	wood chips (willow from SCR)	biomass pre-treatment, gasification, conditioning	**SNG**, electricity, heat

RME-rapeseed methyl ester, DDGS-Dried distillers grains with solubles, SRC-short rotation coppice, SNG-Synthetic natural gas

The synopsis comprises potential, costs and environmental effects that are raised according to unitary basic conditions or for the pathways of respectively typical basic conditions. Thus, the present research shall contribute to the reduction of the bandwidth of these criteria and consequently, to an objectification of the discussion.

2 Methodology

Firstly, present researchs are evaluated according to the above-mentioned criteria. A verification based on this approach is made and if it is necessary, a reduction of the bandwith of this reference studies will occur, e.g. by saving evidently not representative values or updating initial values, such as e.g. the prices for the used raw materials (e.g. rapeseeds, wheat). The result is a justifiable limited range of literature values.

Additionally, own calculations are carried out by the Institute for Energy and Environment (IE) regarding the single criteria. Unlike the totality of the evaluated literature data, homogeneous general frameworks are taken as basis so that a direct comparability can be possible to the largest extent. Following assumptions are made for the corresponding conversion plant:

- 8.000 full load hours per year,
- typical plant rating systems, e.g. 10 GWh/a for an agricultural biogas plant, 100 GWh/a for a plant industrially operated with cereals[1].
- utilisation of obtained by-products, such as e.g. rapeseed press cake in the biodiesel production, utilizable current in the BTL production in energy-autarchic concepts.

Apart from the above-mentioned homogeneous basic conditions, the consideration of input quantities is also relevant. A typical magnitude should be respectively represented according to the application case. The following aspects are relevant for this consideration:

- different feedstocks, e.g. straw or woods for the BTL synthesis,
- different method concepts, e.g. utilisation of the useable energy obtained in the ethanol production from cereal as process energy (industrial) or for the electricity and heat input (agricultural), centralised and decentralised concept in the plant oil provision,

[1] These figures represent the heating value of the net fuel production per year of the relevant plant.

- feedstock price (in case the agricultural aspect is taken into consideration, the producer price should be generally estimated, if the industrial aspect is considered, the wholesale price is relevant)

These variants lead compulsorily to a certain bandwidth of the values according to the calculations. The determined value range is usually located inside the bandwidth of the reference literature as a consequence of the above-mentioned methodology leading to its restriction in a suitable way. In single cases, there are also divergences that will be more detailedly explained in the corresponding text passage.

3 Biofuel provision costs

The specific biofuel provision costs free production plant will be taken into account in the following. The provision costs referred to on litre of biofuel equivalent are those costs that would arise in order to provide the amount of biofuels containing the same energy quantity as one litre of the equivalent conventional biofuel (i.e. diesel and gasoline). The attribution or allocation as well as the used heating values are represented in the following table:

Table 2: Biofuels with allocated equivalent biofuels and heating values (according to /2/)

Biofuel			
biodiesel	32,65 MJ/l	bioethanol	21,17 MJ/l
rape oil	34,59 MJ/l	biomethane (SNG)	36,00 MJ/m³
BTL (FT diesel)	33,45 MJ/l		
Allocated equivalent fuel			
diesel	35,87 MJ/l	gasoline	32,45 MJ/l

The by-products (e.g. rapeseed press cake, raw glycerine, electricity, naphta) obtained in the different biofuel productions concepts are also taken into consideration when determining the provision costs according to the current market prices.

3.1 Data basis

Several relevant studies /6/, /12/ are evaluated, a part of the studies /6/ comprises the evaluation of further sources. In this part, data with very high or low assumed feedstock costs or conversion are not considered any more and the divergences resulting from the non-consideration of the by-products as well as the of the fuel distributioin are corrected. In this way, a reduced bandwidth taken into account in the present work can be determined.

Own calculations are performed by the IE for the considered biofuels. The obtained values are mutually comparable due to the above-mentioned homogeneous basic conditions. However, some input parameters can vary according to the applied method. Thus, for example, on the one hand, rapeseed oil or rapeseed can be imported in case of the feedstock provision for the biodiesel production. As for the biogas production the maize silage – liquid manure correlation is variable whereas logging residue or short-rotation wood can be used for the BTL method. On the other hand, the use of basically different method concepts is possible;

thus the plant oil provision can be exemplarily organised either in a centralised or decentralised way or the process energy supply can occur through the conventional energy net or via a CHP plant for the ethanol production. In the case of Bio-SNG, for example, data concerning the different plant technologies (e.g. gas cleaning methods) are available and are different with respect to the originated costs. The described variations were scientifically analysed, considered in the calculations and as a result in the bandwith of the calculated values of the IE.

3.2 Results, graph and discussion

Starting from the described data basis the fuel provision costs are represented in Fig. 1. The bandwidth marked in grey reproduces the assessed literature values; the value range calculated by the IE is represented in blue.

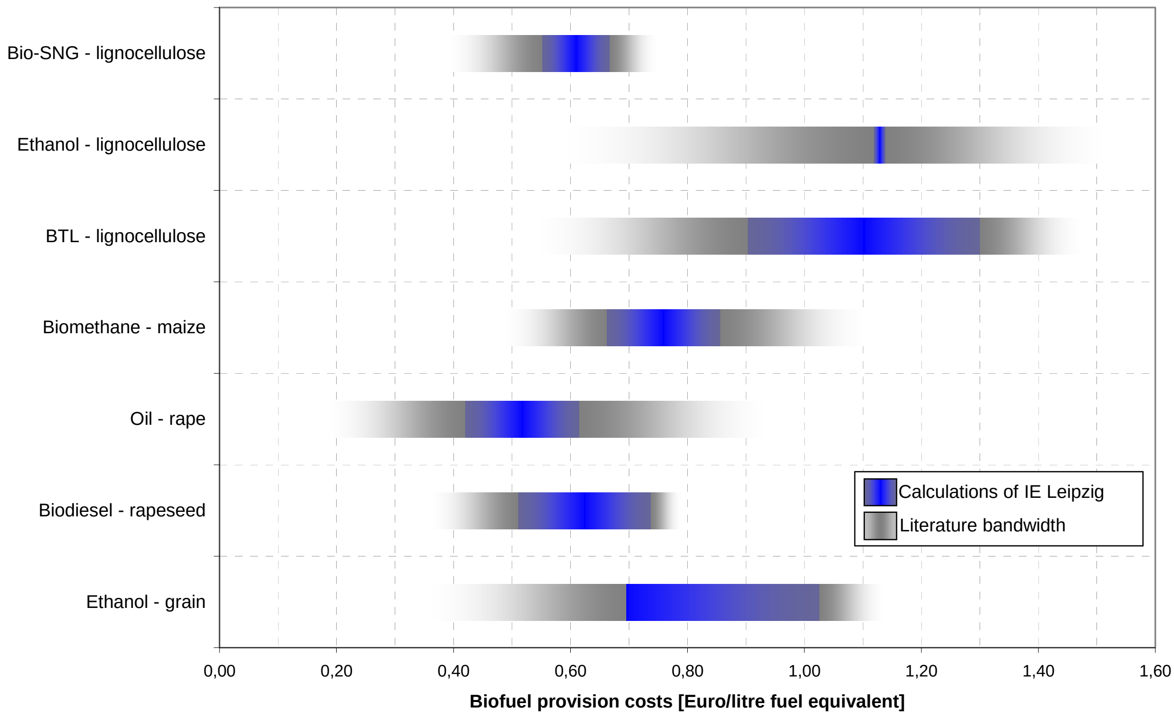

Fig. 1: Fuel provision costs free biofuel production plant

According to the results, it can be determined that biofuels of the second generation (i.e. synthetical biofuels such as BTL and Bio-SNG as well as bioethanol from lignocellulose) show on average notably higher costs than biofuels of the first generation (i.e plant oil and biodiesel as well as bioethanol from wheat). A big bandwidth of the calculations should be determined for the BTL method. This is based on the fact that the new and very complex method with a great deal of technical variations that has not been completely demonstrated so far is however full of technical and economical uncertainties. As for the ethanol provision from lignocellulose and the Bio-SNG method few examined concepts and variants are available until now, that is why it is only possible in this case to have recourse to few protected data and thus a small bandwith is created as a result.

As a result of the assessment of the biofuel costs the average values of the calculated bandwiths are used as an orientation point.

4 Area-related biofuel yield

The area-related biofuel yield is the highest energy amount of biofuel that can be generated if the initial products obtainable on a hectare of area under cultivation can be converted via the respectively considered pathway. The by-product naphtha is also considered as fuel as a particularity of the BTL method, though the reasonability of this option has to be proven with regard to the material utilisation from technical-economical point of views. Further energetic utilisable by-products, such as electricity or heat, are not considered in this case and will be tackled only in chapter 5 regarding balancing.

4.1 Data basis

Various sources /4/, /5/, /8/ are used on order to determine the literature bandwidth, among others the BEE values provided by the UFOP /1/ (pure fuel yield).
The calculations of the IE are based on the average hectare yields of the initial products (rapeseed, grain or silo maize, cereal, cereal straw /9/ as well as wood from short-rotation coppices /11/) and the degrees of conversion of existing biofuel provision plants. The latter vary according to the context of the plant (agricultural or industrial utilisation), of the plant size and the used raw material (among others composition of the maize silage biogas substracts, wheat or triticale for the ethanol production.). The bandwidth of the IE values is obtained as a result therefrom.

4.2 Results, graph and discussion

The area-related yields of the considered biofuels derived from the described data basis are represented in Fig. 2. The bandwidth represented in grey reproduces the assessed literature values, whereas the value range calculated by IE is marked in blue.

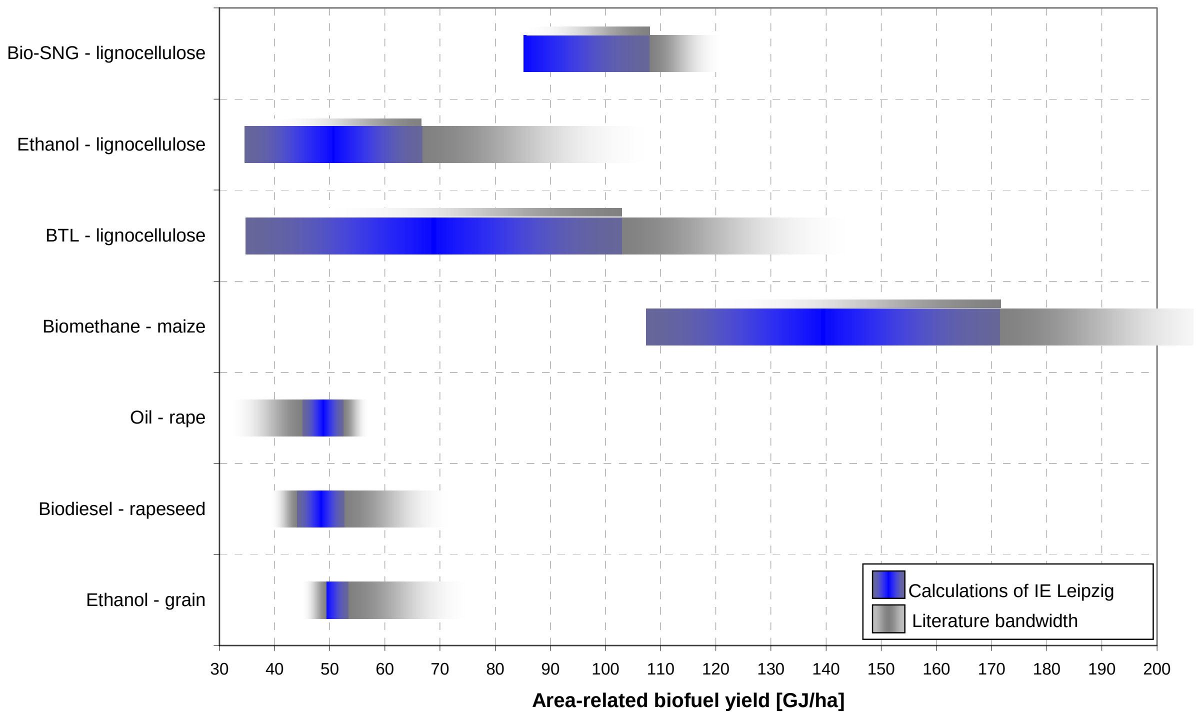

Fig. 2: Area-related biofuel yield

The values obtained by the IE can confirm and limit the considered literature values of the established fuels. It can be clearly seen that they are partially lower than the literature values as for the fuels of the second generation. The reason is that the hectare yields required for the calculation can considerably fluctuate according to the season and regional situation. Yield numbers that can be reached in long-term annual averages according to the literature indications are used for the calculation of the IE in order to obtain applicable values that are as universally valid as possible. Conversion plants with optimal location will exceed the obtained values due to higher local yields.

5 Area-related total final energy yield

The area-related final energy yield is the highest energy amount of the biofuel that can be generated if the initial products obtainable on a hectare of area under cultivation can be converted via the respectively considered pathway. The energetically utilizable by-products are taken into consideration, too. Materially utilizable by-products are additionally indicated.

5.1 Data basis

The total energy yield is composed of:

- the fuel yield determined in passage 4,
- the energetically utilisable by-products obtained during the fuel generation and
- the heat and electricity provided during the fuel generation.

The BEE values /1/ and /4/ for Bio-SNG, in this case under consideration of the by-products, are used as literature sources.

5.2 Results, graph and discussion

The bandwidth determined by the IE for the net biofuel yield (blue) is represented in Fig. 3, in the process of decoupable amounts of electric current (yellow) and heat amounts (red) as well as possibly when converting obtained utilisable by-products (green). The latter group is only exemplarily quantified through its heating value – due to the area-related efficiency comparison that occurs here – moreover it is mentioned in the diagram. The reasons for this methodology are explained in the following. The bandwidth of the assessed literature is marked in grey in the graph.

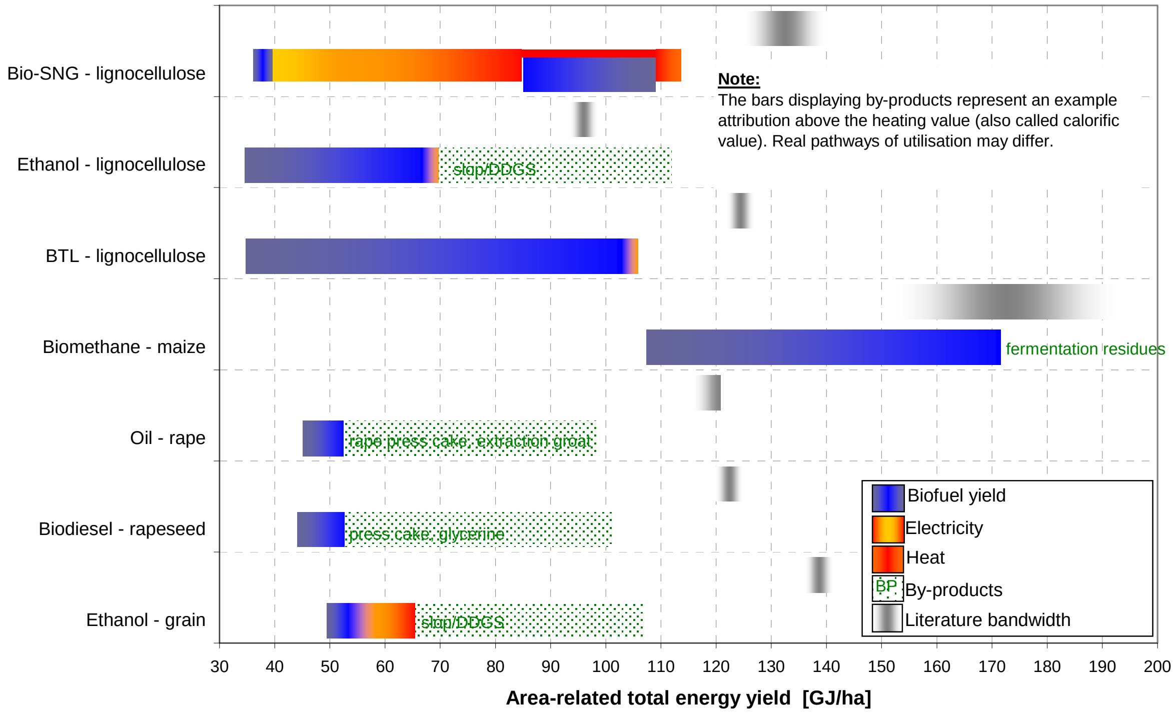

Fig. 3: Area-related total energy yield

The calculated values represent an interesting additional statement with regard to the area-related fuel yield since certain concepts are in part substantially coined by their by-products from economic point of view. Nevertheless, a comparison of various final energies such as heat, electricity and fuel should always be assessed critically. Therefore, from an exergetic point of view electric energy should be assessed at a considerably higher degree than decoupled heat energy. A simple addition as in Fig. 3 causes an overassessment of exergetically inferior energy forms.

However, according to the plant conditions, an elevated electricity and heat decoupling – to the detriment of the fuel yield in BTL and SNG plants - can be reasonable from the point of view of the fuel utilisation. That is why the energy yield was calculated both for the fuel generation and for the combined generation of heat and electricity. Consequently, a clearly lower provided fuel amount is obtained as a result for the combined provision of electricity, heat and fuel (in so-called polygeneration plants), the biomass input conversion rate increases simultaneously.

An allocation of an energy yield is still more difficult for the by-products obtained apart from electricity and heat. The reason for this is that the by-products can be used in different ways; some examples are compiled in Table 3:

Table 3: Possible ways of by-product utilisation

By-product	*Possible ways of utilisation*
rape extraction groat	combustion, forage
rape press cake	combustion, forage
slop	combustion, biogas production, fertiliser
glycerine	energy recovery, chemical industry
fermentation residues	fertiliser, post-combustion, energy recovery

Furthermore, the by-products can be allocated or credited in different manners. Apart from the purely energetic utilisation (quantifiable through the calorific values of the by-products) the revenues that occur due to an alternative use can be taken into consideration herein. Either the energetic (manufacture process of the alternative product) or the monetary approach (provision costs of the alternative product) is possible. Energy values for the by-products are obtained according to the assessment method used for the by-products that are significantly different from one another.

Therefore, it is necessary to get familiar with the used assessment methods with the aim to carry out a comparison of the determined IE data with help of the BEE reference (marked in grey in the diagram). These are not obtained from the available data. That is why, a reasonable target is the determination of homogeneous criteria regarding the energetic assessment of electric current, heat and obtained by-products so that further considerations can be made. By-products are exemplarily quantified in the diagram via their heating value (compare Table 4). It does not necessarily correspond to the really existing utilisation ways, therefore, e.g. glycerine is utilised rather as chemical base material than as fuel.

Table 4: Heating values used for the quantification of the by-products

by-product	*used heating value*
rape extraction groat	18,40 MJ/kg
rape press cake	20,25 MJ/kg
slop	19,00 MJ/kg
glycerine	18,00 MJ/kg
fermentation residues	hardly determined, strongly correlation to water content

6 Energy-related greenhouse gas reduction

The reduced greenhouse gas emissions are determined, expressed in CO_2-equivalents (basically carbon dioxide (CO_2) that is developed during the combustion of fossil fuels (as energy sources), moreover, among others, methane (CH_4) and laughing gas (N_20) that is taken into account via so-called equivalent factors) if compared to the equivalent fossil fuel (compare Table 2). The energy content of one litre of the equivalent fuel serves as reference point. The allocation occurs as in the case of the fuel provision costs. By-products are also considered herein.

6.1 Data basis

Calculations are carried out and indications are made by the IE in order to reduce the greenhouse gases when using biofuels. The methodology of the LCA (ecobalancing) is used then. Ecological impacts play a relevant role that can be ascribed to the provision of biogeneous energy sources. As for the combustion, it is to be considered that CO_2 emissions of the biogeneous energy sources are put to zero in contrast to the fossil equivalent fuel since this amount was bound from the atmosphere during the growth of the plant. However, CO_2 emissions derived from cultivation, care, processing or conversion are not considered here. The obtained bandwidths result from the different variants of the fuel use.
Different studies and lectures /3/, /6/, /7/, /8/ are used as reference literature.

6.2 Results, graph and discussion

The energy-related greenhouse gas reductions of the considered biofuels are represented in Fig. 4, based on the described data. The bandwidth marked in grey reproduces the assessed literature values; the value range calculated by the IE is represented in blue.

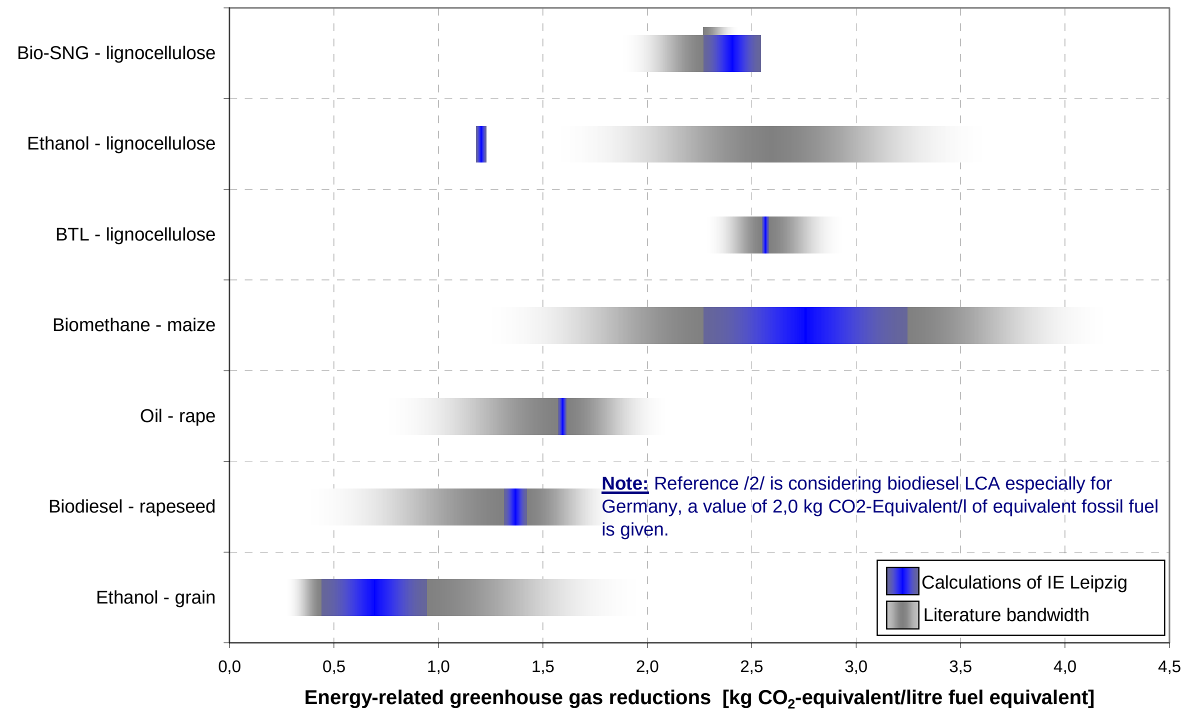

Fig. 4: Energy-related greenhouse gas reductions

The bandwidth of the reference literature can be practically reduced by values obtained by the IE for almost all considered biofuels. An exception is the ethanol provision from lignocellulose (straw). The reason for this divergence is to be found in the fact that the assessed literature concerning biofuels from residues allows that an eventual use of alternatives of these residues is not taken into account. Straw can be really used as fertiliser and for soil improvement. If, however, it is supplied to the fuel provision, additional expenditures are required for the compensation, e.g., the production of mineral fertilisers. These compensations measures were also considered in the IE calculations for ethanol from straw. That is why the calculated values are clearly below the numbers indicated in the considered studies. The described facts and circumstances do not exert any influence on the BTL fuel and Bio-SNG, since short-rotation wood can be taken into account barely here as biomass input, for which there is no corresponding agricultural relevant use.

7 Area-related greenhouse gas reduction

The reduced greenhouse gas emissions are determined here, expressed in CO_2 equivalents. A hectare of area under cultivation can be used as reference quantity for the relevant source material.

7.1 Data basis

The BEE data /1/ provided by the UFOP as well as further literature references /6/ are available.

The used IE numbers are obtained from the previously above-determined values as for the energy-related greenhouse gas reductions and the area-related biofuel yield.

The following consideration is applicable:

$$\frac{GHGR_{Litre}\left[\frac{kg_{CO_2}}{l_{FE}}\right]}{H_{U,FE}\left[\frac{GJ}{l_{FE}}\right]} \cdot HA\left[\frac{GJ}{ha}\right] = GHGR_{ha}\left[\frac{kg_{CO_2}}{ha}\right] \qquad (1)$$

$GHGR_{Litre}$	energy-related greenhouse gas savings
$H_{U,\,FE}$	heat or calorific value of the equivalent fuel
HA	area-related biofuel yield
$GHGR_{ha}$	area-related greenhouse gas reductions

The bandwidths of the previously determined input values are taken into consideration in the above-mentioned equation obtaining the bandwidth as a result for the area-related greenhouse gas reductions.

7.2 Results, graph and discussion

The area-related greenhouse gas reductions of the considered biofuels are represented in Fig. 5 based on the described data. The bandwidth marked in grey reproduces the assessed literature values; the value range calculated by the IE is represented in blue.

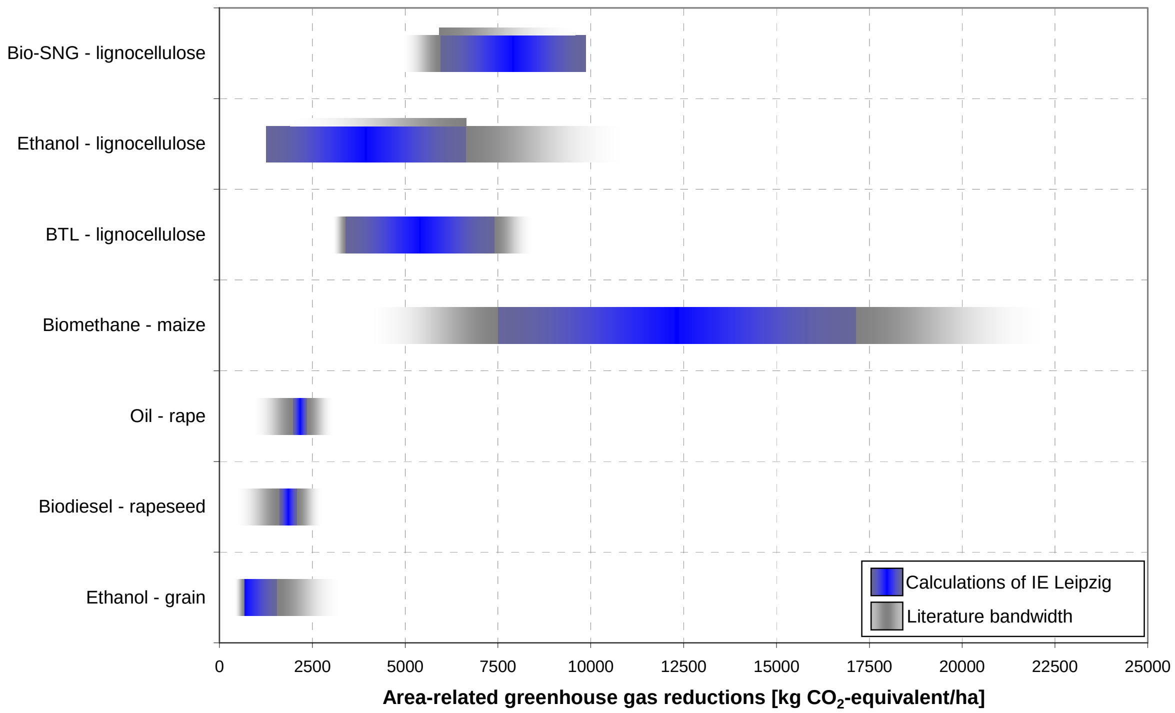

Fig. 5 : Area-related greenhouse gas reductions

The values determined by the IE can appropriately reduce the numbers indicated in the assessed literature for almost all considered biofuels. Certain divergences occur only with ethanol from lignocellulose and Bio-SNG. In this case, this should provide a reference to the backgrounds with regard to the energy-related greenhouse reductions and the fuel yield.

8 GHG avoidance costs

The GHG avoidance costs provide a comparison of the costs and the greenhouse gas emissions of the two different fuel provision pathways (here: plants used for the provision of biofuels or equivalent fossil fuels). Therefore, they can be interpreted as costs that have to be raised in order to avoid a unit of greenhouse gas emissions, measured in CO_2 equivalents.

8.1 Data basis

Literature values are provided by the above-mentioned source /6/, with an adapted bandwidth, completed by /8/ with respect to Bio-SNG-plants.

Own calculations are carried out by the IE, starting from the previously above-determined provision costs and greenhouse gas reductions. The GHG avoidance costs are calculated as follows, respectively for a considered biofuels:

$$\frac{BK\left[\frac{€}{l_{FE}}\right]-BK_{FE}\left[\frac{€}{l_{FE}}\right]}{GHGR_{Litre}\left[\frac{kg_{CO_2}}{l_{FE}}\right]}=VK\left[\frac{€}{kg_{CO_2}}\right] \qquad (2)$$

BK	provision costs biofuel
BK_{FE}	provision costs of the equivalent fuel
$GHGR_{Litre}$	area-related greenhouse gas saving
VK	CO_2 – avoidance costs

The range of the previously determined input values are taken into consideration in the above-mentioned equation obtaining the bandwidth for the GHG avoidance costs.

8.2 Results, graph and discussion

Starting from the above calculation the GHG avoidance costs for the considered biofuels are compiled in Fig. 6. The bandwidth marked in grey reproduces the assessed literature values; the value range calculated by the IE is represented in blue.

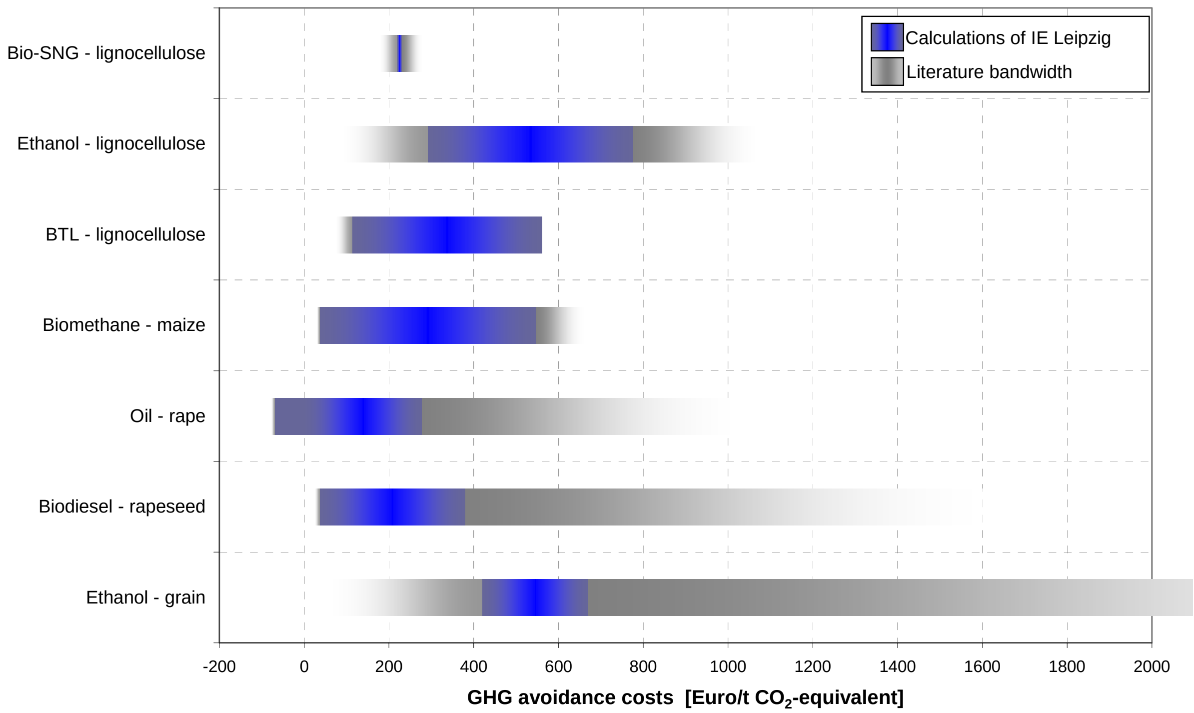

Fig. 6: GHG avoidance costs

The values obtained by the IE can sensibly reduce the bandwidth of the assessed literature. Bandwidths are almost identical for both BTL and biomethane; the values of the IE reproduce the lower cost range of the reference literature for the remaining fuels. Rape oil shows negative CO_2 avoidance costs when considering more favourable basic conditions (lower provision costs, high area-related greenhouse gas reductions). As a result, apart from greenhouse gas emissions this can additionally represent an economic advantage with regard to the provision of rape oil instead of fossil diesel.

The circumstance that the represented costs describe a sort of „snapshot" /6/ can be given as a cause for the enormous literature bandwidth (especially in case of ethanol from cereal). They are strongly dependent on the personal and transportation costs and fluctuating feedstock prices. The data of different moments and locations are based on the used studies; the calculation of the IE rests on assumptions specifically related to Germany made at the current date (2007).

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