Sustainable First and Second Generation Bioethanol for Europe

A sustainability assessment of first and second generation bioethanol in the context of the European Commission's REDII proposal

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1. Executive summary

A comprehensive sustainability assessment shows that first generation bioethanol is as advantageous as second generation bioethanol for a feasible climate strategy. The results clearly indicate that the systematic discrimination against first generation biofuels of the current Commission proposal is in no way founded on scientific evidence. It would be counterproductive to further lower the share of first generation fuels in the EU's energy mix.

The objective of this study was to compare the sustainability of bioethanol made from different feedstocks, most importantly comparing first generation (sugar, starch) fuels to second generation (lignocellulosic, waste-based) fuels. This was conducted against the background of the on-going deliberations regarding Europe's Renewable Energy Directive (RED) after 2020. The Commission's REDII proposal of November 2016 suggests an abolition of a dedicated transport target, a strong reduction of first generation fuels and their replacement by second generation fuels. Those measures are supposed to ensure that Europe fulfils its ambitious climate targets while not endangering food security.

Evaluation of sustainability – how to identify the most sustainable bioethanol?

A number of criteria were selected in order to evaluate the sustainability of first and second generation bioethanol. The criteria selection was based on the most current standards and certification systems of bio-based fuels and materials, including environmental, social and economic aspects. A dedicated focus was put on food security due to the continued accusation towards first generation biofuels that they cause harm to food security. After analysing the existing data (both quantitative and qualitative), the performance of the respective fuel option was assessed relative to the others to establish a ranking of the options, based on a traffic light system (green for high performance/low risks, yellow for medium performance/risks and red for moderate performance/considerable risks). Table 1 presents an overview of the results, which are explained in more detail in the presented text (see chapters 2 – 13).[1]

The results – what is the most sustainable bioethanol?

The analysis of twelve different sustainability criteria shows that all of the researched bioethanol feedstocks offer significant strengths as well as weaknesses for a feasible climate strategy:

- All feedstocks realise **significant reductions of greenhouse gas emissions**. While second generation fuels perform better in this regard, this effect is strongly relativised, when offset against the abatement costs. Reducing GHG emissions through second generation biofuels is expensive – and prevents much more efficient climate actions that could be implemented elsewhere.

- When it comes to the often-criticised negative impact on **food security** of first generation biofuels, the evidence points into a different direction. The competition for arable land is counterbalanced by the excellent land efficiency of first generation crops (especially sugar beet) and protein-rich co-products (especially wheat and corn). In this regard, the utilisation of short rotation coppice (SRC) for biofuels poses much stronger competition for arable land, since they use up much larger acreages of arable land and provide no protein-rich co-products.

- In the case of wheat, most of European ethanol production is based on grain of **non-food quality and on harvest surpluses**, not posing any competition at all, but offering additional outlets to farmers. In the opposite case of bad harvests and rising prices for agricultural

1 The ranking is based on the assumption that the use of agricultural residues is restricted to an amount that ensures continued soil quality, i.e. of only 50%.

crops, bioethanol production often does not pay off, which means that the crops are redirected towards food markets.

The results clearly indicate that the systematic discrimination against first generation biofuels of the current Commission proposal is in no way founded in scientific evidence. This has also been criticised by an independent assessment of the REDII proposal (Impact Assessment Institute 2017).

On the way to a climate-friendly Europe, biofuels made from any kind of feedstock offer advantages in terms of GHG emission reductions and should indiscriminately be part of a viable transitional strategy towards low-emission mobility, as long as they adhere to sustainability criteria.

Key results per feedstock

Sugar crops

The main strength of sugar beet and sugar cane is their very high land efficiency. No other biomass can produce more bioethanol per ha. High GHG reductions and especially the lowest GHG abatement costs are additional strong points. The infrastructure and logistics are well developed, co-products are used as animal feed. The main disadvantages are the impacts on biodiversity, water, air and soil due to intensive agriculture – but the impacts are limited to small areas because of the very high land efficiency.

Starch crops

The main strength of starch crops are the protein-rich co-products, which are valuable animal feed. The land efficiency is lower than for sugar crops, but higher than for wood. The GHG reductions are assumed to be lower than for the other options, but this is only partly true and is rooted to a large part in the specific LCA standards applied in the RED. The infrastructure and logistics are well developed. The main disadvantages are the impacts on biodiversity, water, air and soil due to intensive agriculture, which is partly counterbalanced by high land efficiency.

Virgin Wood and SRC

The main strength of wood as a fuel feedstock is the low competition with arable land and consequently the absence of direct or indirect land use change risks (LUC / iLUC). For Short Rotation Coppice (SRC) this is only true if they are not cultivated on arable land. The infrastructure and logistics are well developed for wood, but less for SRC. The GHG reduction is on the same level as for sugar crops, but the GHG abatement costs are much higher. The main disadvantages are the very low land efficiency and the lack of co-products for the feed market.

Waste and residues

The main strengths of waste and residues as fuel feedstocks are the very high GHG reductions – partly because of the specific LCA standards applied in the RED – and the lowest impacts on biodiversity, water, air and soil. The main disadvantages are the high GHG abatement costs, barely developed infrastructure and logistics, low traceability and most importantly, the limited availability.

Combine first and second generation

The highest bioethanol yield per hectare results from a combination of first and second generation biomass co-utilised, such as first generation wheat plus second generation wheat straw. The advantage of first generation sugar and starch crops is that they carry the potential of second generation in them by providing their own lignocellulosic co-products, without occupying additional areas and at the same time provide protein rich feed.

Criteria	Sugar		Starch		Virgin Wood		Waste wood		Agricultural Residues	Organic waste
	Sugar beet	Sugar cane	Wheat	Maize	Forest	SRC	Forest residues	Post-consumer wood		
GHG footprint	yellow	yellow	red	red	yellow	yellow	green	green	green	green
Level of subsidies needed / GHG abatement costs	green	green	yellow	yellow	red	red	red	red	red	red
Land use / land efficiency	green	green	yellow	yellow	red	red	red	green	yellow	green
Food security, negative impact on	green	green	green	green	green	yellow	green	green	green	green
Protein-rich co-products	yellow	red	green	green	red	red	red	red	yellow	red
Employment, rural development, livelihood of farmers and foresters	green	green	green	green	yellow	green	yellow	yellow	green	yellow
LUC / iLUC	yellow	yellow	yellow	yellow	green	yellow	green	green	green	green
Logistics/Infrastructure/ Availability	green	green	green	green	green	yellow	yellow	yellow	yellow	yellow
Traceability	green	green	green	green	green	green	green	yellow	green	yellow
Social impacts (land rights, human rights, education..)	green	green	green	green	green	green	green	green	green	green
Biodiversity and marginal land, potential impacts	red	red	red	red	red	red	yellow	green	green	green
Impact on water, air and soil quality	yellow	yellow	yellow	yellow	yellow	yellow	green	green	green	green

Table 1: Overview of ranking results
Note: green = high performance / low risk;
yellow = medium performance / medium risk;
red = low performance / high risk

2. Greenhouse gas (GHG) footprint

EU legislation contains a set of mandatory targets to ensure that biofuels such as bioethanol provide GHG emission reductions at a sufficient level. These are laid down in the 2009/28/EC Renewable Energy Directive (RED) and the 2009/30/EC Fuel Quality Directive (FQD). These targets stipulate that biofuels need to reduce greenhouse gas emissions by at least 35% compared to fossil fuels from 2011 on. From 2017 on, greenhouse gases will have to be reduced by 50%, and from 2018 onwards by 60% (only for new installations). In its recent REDII proposal (EC 2016), the Commission suggested a GHG reduction by 70% for advanced biofuels from 2020 onwards.

Life cycle GHG emissions of bioethanol vary widely, depending on land use changes, choice of feedstock, agricultural practices, refining and conversion processes. The EU directives mentioned above also set out the rules for calculating the greenhouse impact of bioethanol (see box below) and list typical as well as default values for GHG emission savings of different fuels.

Bioethanol used in Europe is obtained from different raw materials, mainly wheat, maize and further grains, sugar beet and sugar cane from Brazil. Figure 1 summarizes the typical GHG emission savings for different pathways (feedstock and process fuel) to liquid biofuels (petrol, methanol, ethanol). Reductions are referred in comparison to a default emission value of 94 g CO_2 eq./MJ of the fossil fuel comparator (REDII proposal). The GHG emission savings include only emissions from direct land use change, not those from ILUC.

According to the typical values from the REDII proposal, using corn and other cereals as feedstocks for the production of ethanol lead to GHG emission reductions ranging between 47-69%. The emissions depend very much on the source of energy required for its processing (e.g. natural gas, forest residues). For instance, ethanol produced from corn by using natural gas as process fuel in a combined heat and power plant (CHP) is assumed to have a 48% lower footprint compared to the default emissions of fossil-based ethanol, thus, not meeting the EU goals for 2018. On the other hand, ethanol from corn, using forest residues as fuel for the processing in a conventional boiler, meets the EU goals with a saving of 69%.

Higher savings (58-79%) are reported for the production of bioethanol from sugar cane and sugar beet, considering, for the latter, different kinds of power supply (biogas, natural gas, lignite) during its processing. It needs to be stressed that this assessment depends on theoretically derived values, which can deviate significantly from real data. Actually, real data shows that grain-based ethanol performs better than assumed. Although there is no feedstock-specific data for the EU available, the UK biofuel statistics provide a good insight on real GHG savings of various biofuel pathways. According to data for 2016/17, grain-based ethanol saved on average 57 %, while sugar-based ethanol only reached 59% GHG savings.[2]

The use of second generation feedstocks (waste and farmed wood and agricultural residues) to produce liquid biofuels (petrol, methanol and ethanol) results in higher GHG savings for all pathways, in the range between 77-89% (due to the proposal of the Commission, advanced biofuels must have a GHG reduction by a least of 70% from 2020).[3] In particular producing ethanol from wheat straw saves 85% of GHG emissions

2 Cf. DfT (2017), Renewable Transport Fuel Obligation statistics: period 9 2016/17, URL: https://www.gov.uk/government/statistics/biofuel-statistics-year-9-2016-to-2017-report-4

3 The review of GHG emission reduction values as calculated in the RED revealed that there is no operational plant producing ethanol from wood, only from agricultural residues. In personal communication, a Commission's JRC employee confirmed that no plants are known producing ethanol from wood.

compared to a petrochemical pathway. One can expect considerable reductions in the same order of magnitude when other agricultural residues or organic waste is used as a feedstock for bioethanol taken into account that the RTFO statistics show 85% GHG savings on average for food-waste based ethanol.

LCA standards for biofuels

It needs to be stressed that the GHG emission reduction values as given by the RED are very dependent on the calculation and allocation rules used. And the RED standards are only partly based on science, while the other part is strongly influenced by political objectives.

So, one of the main reasons for the excellent values of fuels made from waste and residues is the fact that no burden of emission is assigned to their production, but only from the point in time when they occur onwards, so to collection, transportation and processing. This means for instance for agricultural residues that no burden of emission is assigned to crop cultivation (no allocation between main and co-product). In common scientific procedure, instead an economic or energetic allocation is applied if the co-product has a monetary or energetic value, which applies in most cases.

The effect of the different methods can be demonstrated with the example of wheat: The wheat kernel accounts for about 70% of the total energy content of the harvested wheat crop, while the straw accounts for about 30%. Applying energetic allocation, bioethanol from wheat kernel (first generation) would show 30% lower GHG emissions compared to the RED standard – and second generation bioethanol from wheat straw would show correspondingly higher GHG emissions. This means that if energetic allocation is applied, there is almost no difference between first and second generation bioethanol from wheat kernel resp. straw in terms of GHG emissions.

These approaches are politically determined, but questionable from a purely scientific point of view, especially if it concerns parts of plants that have a function, a market and a value.
For fuels made from wood, it is assumed that all process energy used is produced by incinerating wood residues and/or lignin, resulting in much lower process emissions than for first generation fuels (whose process pathways are shorter and less energy intensive).

Furthermore, protein-rich co-products of the biofuel production are not accounted for as substitutes for imported protein, but only for their energy content. This means that the real value of the co-product is underestimated. In the US, protein substitution is the preferred accounting method resulting in high reduction values for biodiesel for example.

In this regard, the climate advantage of second generation fuels is somewhat of a self-fulfilling prophecy.

Nevertheless, this report only refers to the RED standards, as they are the official benchmark values for Europe.

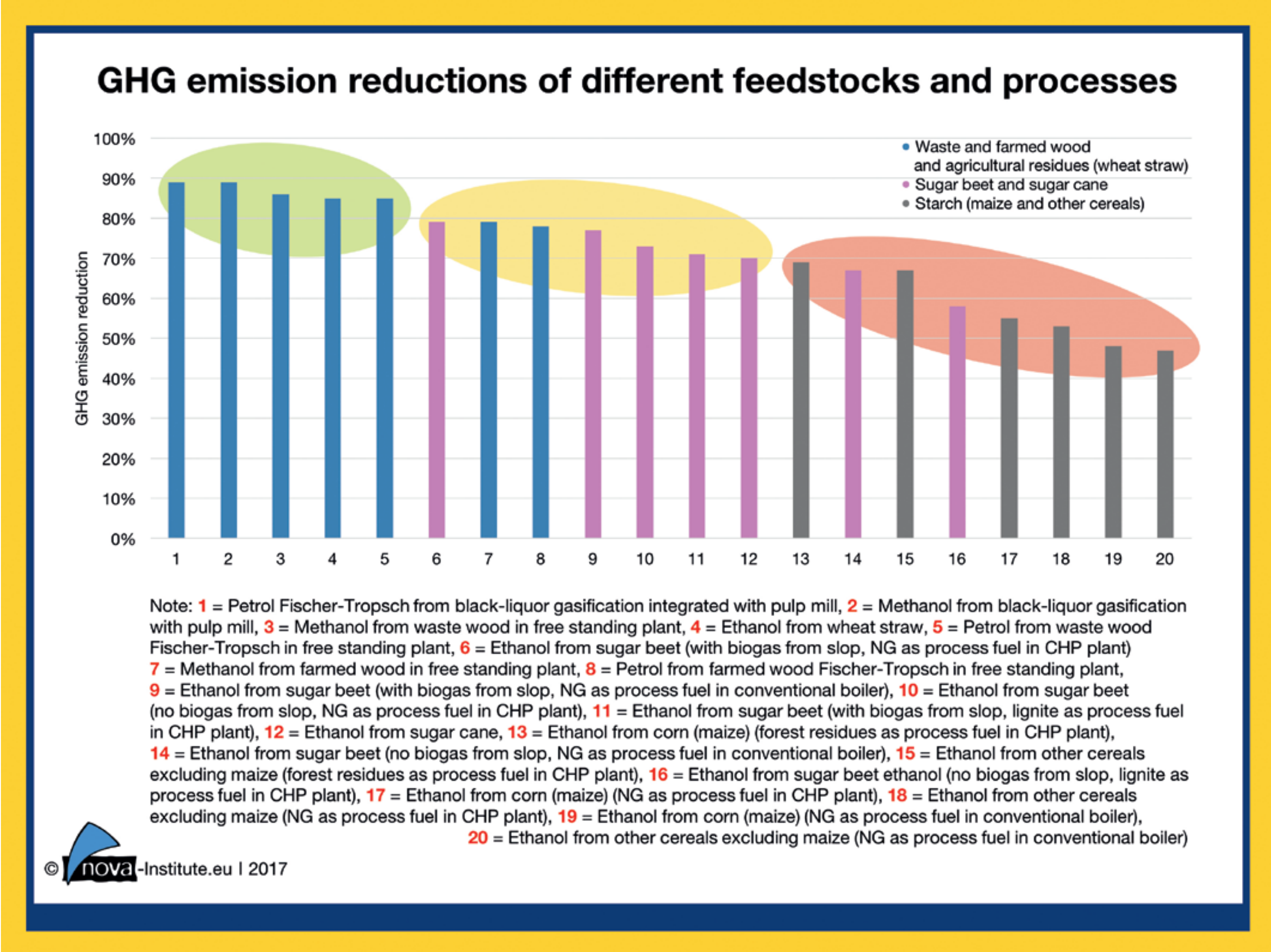

Figure 1: Typical GHG emission reduction according to RED methodology (2016) for the production of biofuels

3. GHG abatement costs / level of subsidies needed per GHG emission reduction

This criterion compares the amount of (public and private) investment necessary to reach a certain level of GHG emission reductions for conventional and advanced biofuels. While there are no confirmed numbers on the exact subsidies that will be necessary to establish second generation biofuels in Europe, several factors can be taken into account to derive an informed estimation:

There are only very few installations producing advanced biofuels yet, making up for approximately 1% of biofuel supply in the EU.[4] Building them will require significant investment.

Recent studies on the competitiveness of conventional vs. advanced biofuels have come to the conclusion that of all advanced biofuels, only biomethane and Synthetic Natural Gas (bio-SNG) will be able to compete with conventional biofuels in the long term (Millinger et al. 2016 & 2017). High feedstock prices and process costs will make lignocellulosic liquid biofuels economically unfeasible, if not supported by significant subsidies.

If the support structure for advanced biofuels will be implemented in a similar fashion as it has been done for the first generation of biofuels, there will be penalties for fuel producers for not fulfilling the advanced biofuels quota. Production costs for second generation ethanol are currently about twice as high as for first generation ethanol (Figure 2). This implies that, in order to provide the same level of support for both first and second generation biofuels, these fines need to increase for second generation biofuels by the same percentage as the increased production costs, i.e. by about +135%. The increased cost will be carried on to the consumer or to all citizens (e.g. through tax exemptions), thus constituting higher costs to society as a whole.

The chapter on GHG emission reduction has shown that while lignocellulosic biofuels can achieve higher emission reductions than first generation biofuels, the difference is only in an order of magnitude between 5-20% for most processes. For these moderate levels of GHG emission reductions, price support levels would have to more than double, given the difference in production costs as shown above.

The different GHG emission savings of sugar and starch feedstocks are the reason why sugar is ranked higher than starch for this criterion: At current cost structures, biofuels from sugar crops require the least subsidies for a reasonable amount of emission reductions (and are therefore ranked the highest). Starch crops also require fewer subsidies than second generation fuels, but achieve less emission reductions than sugar crops. They have therefore been ranked with a medium value.

The relatively small additional emission savings that advanced biofuels can achieve will cause significant costs to consumers and society as a whole. Put in other words, advanced biofuels are a very expensive way to reduce GHG emissions. It is therefore doubtful whether the strong focus on advanced biofuels is a feasible strategy from a climate and economic perspective. Other measures could potentially achieve much higher emission savings for the same amount of financial resources (i.e. investments in first generation biofuels, building infrastructures/insulation, energy efficiency etc.) and it should be a political goal to implement those measures.

4 Calculation based on http://ec.europa.eu/eurostat/web/energy/data/shares, https://ec.europa.eu/energy/en/content/energy-modelling-interactive-graphs?type=scrollcombidy2d&themes=s_15_energy-demand-in-transport

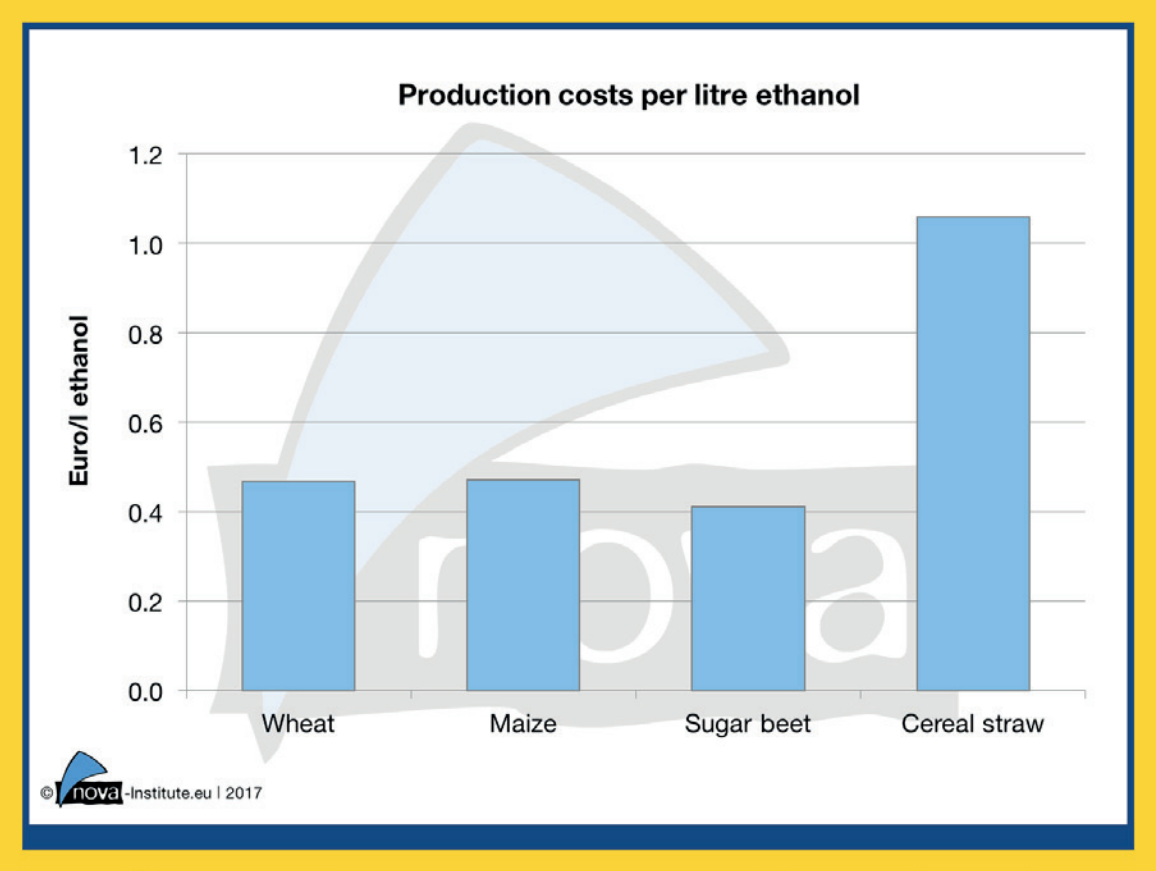

Figure 2: Comparison of production costs in Euro/l ethanol
Sources: Own calculations based on JRC 2017, Eurostat 2017, Euronext 2017

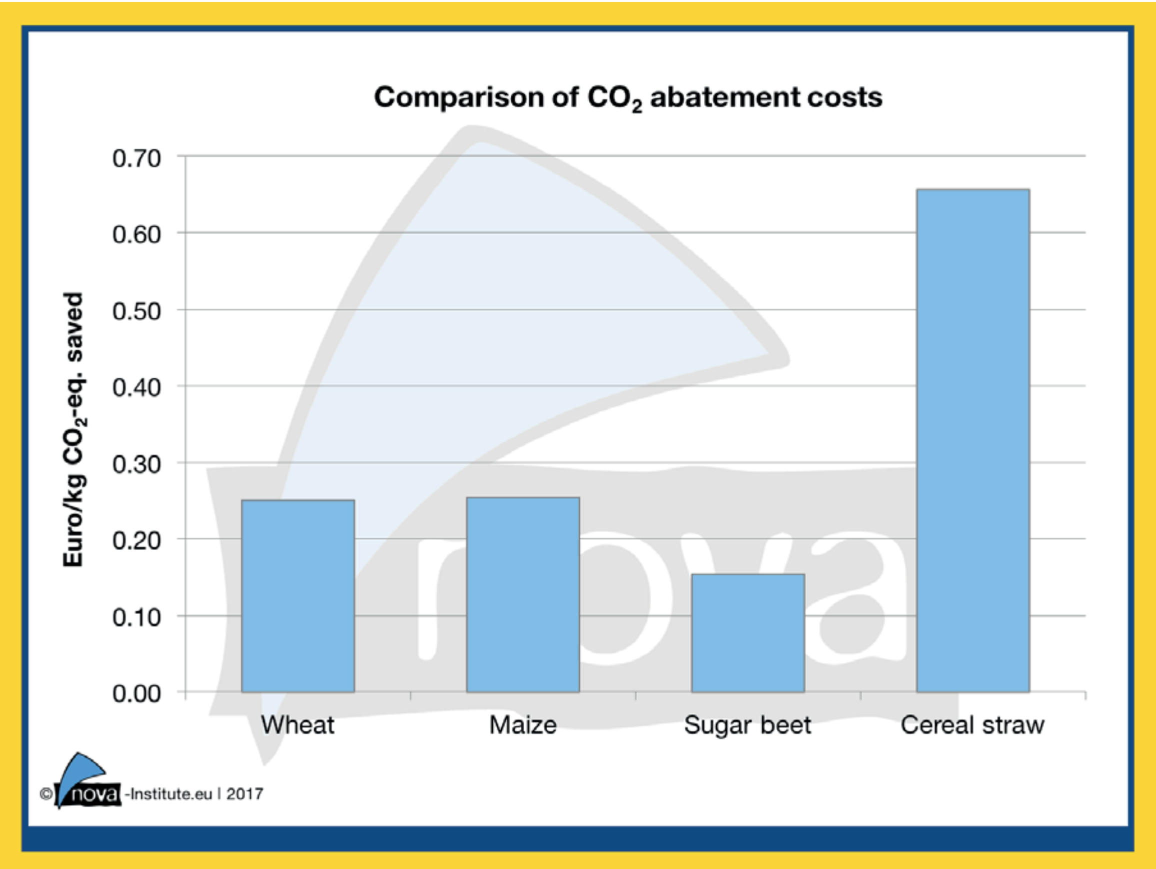

Figure 3: Comparison of CO_2 abatement costs for ethanol from wheat, maize, sugar beet and cereal straw
Sources: Own calculations based on JRC 2017, Eurostat 2017, Euronext 2017 and GHG emission savings as explained in chapter 2

4. Land use and conversion efficiency

4.1. Data on biomass yields

Figure 4 shows the biomass yields per hectare of the assessed annual crops (wheat, maize, sugar beet and sugar cane) and woody biomasses, including yields of the harvested product as well as primary harvest residues and processing residues. Primary harvest residues comprise leaves/straw in the case of annual crops and logging residues (branches, twigs) in the case of forest wood. For the assessment of primary residues from the agricultural crops, Residue-to-Product ratios (RPR) as reported in Ronzon and Piotrowski 2017 have been used.

Apart from the primary harvest residues, there are also processing residues in the case of sugar beet (pulp) and sugar cane (bagasse) which could potentially constitute second generation ethanol feedstocks. For details, see the notes below Figure 4.

For the determination of the yields of the annual crops (wheat, maize and sugar beet), 5-year averages (2012-2016) have been obtained from the Eurostat database on agricultural production. Due to the fact, that ethanol production from wheat and maize currently concentrates on specific regions of the European Union, we use crop yields from these regions, as they are more representative than average yields for the EU as a whole.

In the case of wheat, the main source for ethanol is currently North-West Europe (Germany, Belgium, the Netherlands, France, Sweden and Great Britain), so that we use average yields from these regions as the basis. In the case of maize, sourcing for ethanol concentrates much more in Eastern Europe (Poland, Czech Republic and Hungary) and parts of Spain and France. In the case of sugar beet, France is the main supplier (Goh et al. 2016).

Regarding forestry biomass, we have assumed that annual fellings equal annual increments (composed of about 90% stem wood and 10% residues). Since annual increments are varying greatly between species and climate conditions, we are comparing increments of an average of forest wood in Finland and Germany. Furthermore, we have included poplar wood from short rotation coppice (SRC), both from productive and marginal land.

Further to these biomasses, we are also considering organic waste. In this case, however, an area relationship cannot be established.

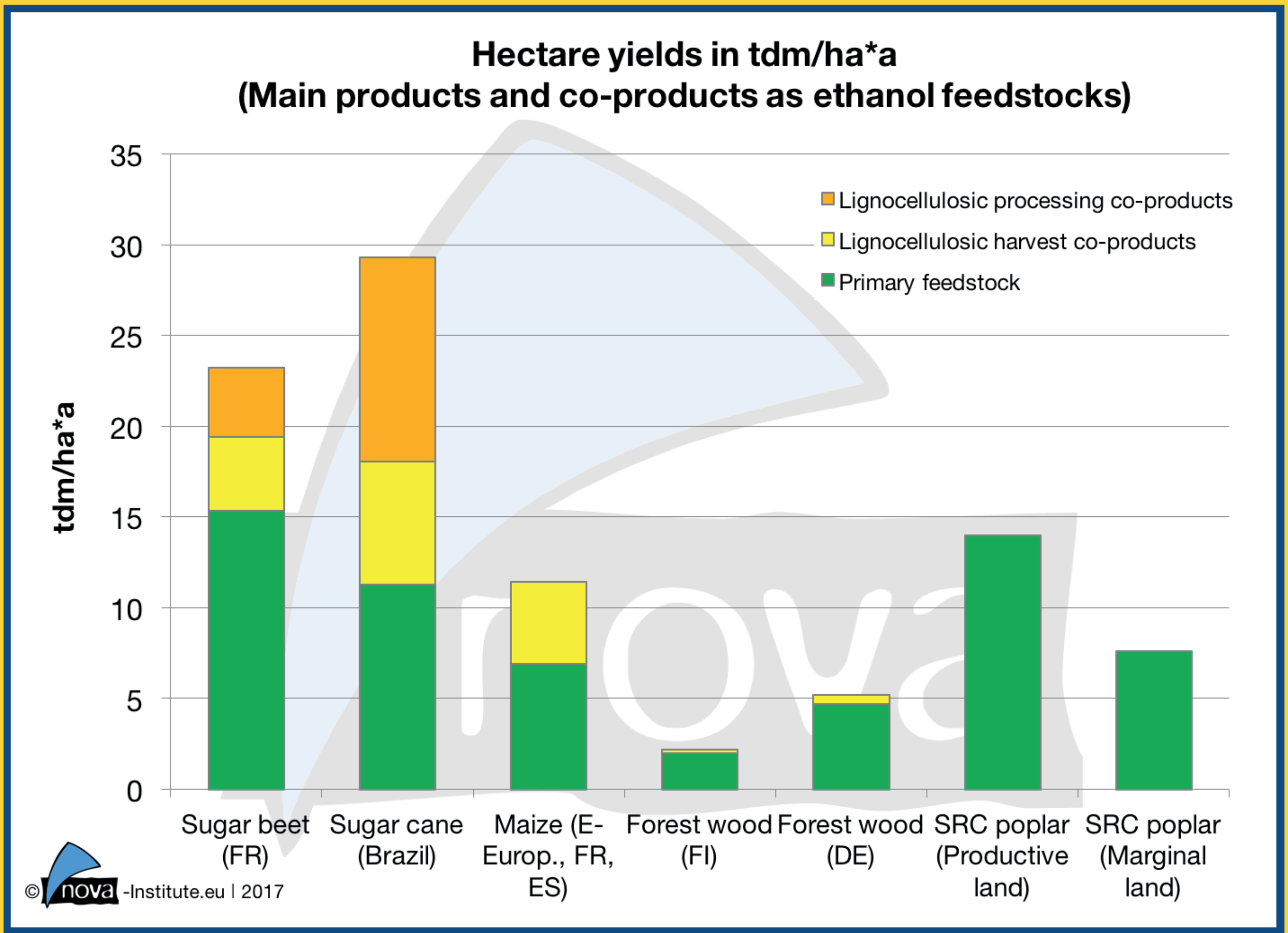

Figure 4: Hectare yields in tdm/ha*a
Note: Protein-rich co-products from sugar and starch crops that are not considered further as bioethanol feedstocks (DDGS and vinasse) are not taken into account here. See chapter 6 for information on these co-products.

Sources:

Sugar beet + leaves (FR): Average sugar beet yield in France, 2012-2016 (Eurostat 2017); Residue-to product ratio (RPR) calculated from the function RPR = 1.328*exp(-0.060*x) with x being the sugar beet yield (Ronzon and Piotrowski 2017); assumption of a sustainable extraction rate of 50% (Fischer et al. 2007)

Sugar beet pulp (FR): 1 tdm sugar beet yields about 0.2 tdm of pulp as the co-product from sugar production (KWS 2013)

Sugar cane + leaves (Brazil): Average sugar cane yield in Brazil, 2010-2014 (FAOSTAT 2017); Residue-to product ratio (RPR) constant at 0.60 (Bentsen et al. 2014); assumption of a sustainable extraction rate of 50% (Fischer et al. 2007)

Sugar cane bagasse (Brazil): 1 tdm sugar cane yields about 0.5 tdm of bagasse as the co-product from sugar production (Rezende et al. 2011)

Wheat + straw (NWE): Average wheat yield in Germany, Belgium, the Netherlands, France, Sweden and Great Britain, 2012-2016 (Eurostat 2017); Residue-to product ratio (RPR) calculated from the function RPR = 2.183*exp(-0.127*x) with x being the wheat grain yield (Ronzon and Piotrowski 2017); assumption of a sustainable extraction rate of 50% (Fischer et al. 2007)

Maize + straw (E-Europ, FR, ES): Average maize yield in Poland, Czech Republic, Hungary, France and Spain, 2012-2016 (Eurostat 2017); Residue-to product ratio (RPR) calculated from the function RPR = 2.656*exp(-0.103*x) with x being the maize grain yield (Ronzon and Piotrowski 2017); assumption of a sustainable extraction rate of 50% (Fischer et al. 2007)

Forest wood (FI): Annual increment of 4.60 m3/ha*a = 2.21 t/ha*a (State of Europe's Forests, 2005-2010); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

Forest wood (DE): Annual increment of 10.85 m3/ha*a = 5.21 t/ha*a (State of Europe's Forests, 2005-2010); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

SRC poplar (Productive land): 14 tdm/ha*a of short rotation coppice (SRC) poplar (Aust et al. 2014); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

SRC poplar (marginal land): 7.6 tdm/ha*a of short rotation coppice (SRC) poplar (Schweier and Becker 2013); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

SRC poplar (productive land): 10 tdm/ha*a of short rotation coppice (SRC) poplar (Konadu 2016); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

SRC poplar (marginal land): 8.5 tdm/ha*a of short rotation coppice (SRC) poplar (Konadu 2016); assumption of 90% stem wood and 10% residues in the total increment (Rademacher et al. 2001)

4.2. Conversion rates

In order to make transparent assumptions regarding the rates of conversion from biomass to ethanol, the following parameters are needed:

- Contents of carbohydrates (sucrose, starch, cellulose, hemicellulose) in the biomass
- Stoichiometric conversion rates of carbohydrates to ethanol
- Rate of actual extraction of these carbohydrates from the biomass, including losses due to the pre-treatment of lignocellulosic biomass
- Rate of actual hydrolysis and recovery from these extracted carbohydrates to C5 and C6 sugars (glucose and xylose)
- Rate of actual fermentation of these sugars to ethanol

Carbohydrate contents

Carbohydrate contents in the different types of biomass are shown in Figure 5, grouped according to whether the primary source of carbohydrates is sugar, starch or lignocellulose.

Sugar beet leaves contain apart from 30% structural carbohydrates (equal amounts of cellulose and hemicellulose) still 10% of soluble sugars (Aramrueang et al. 2017).

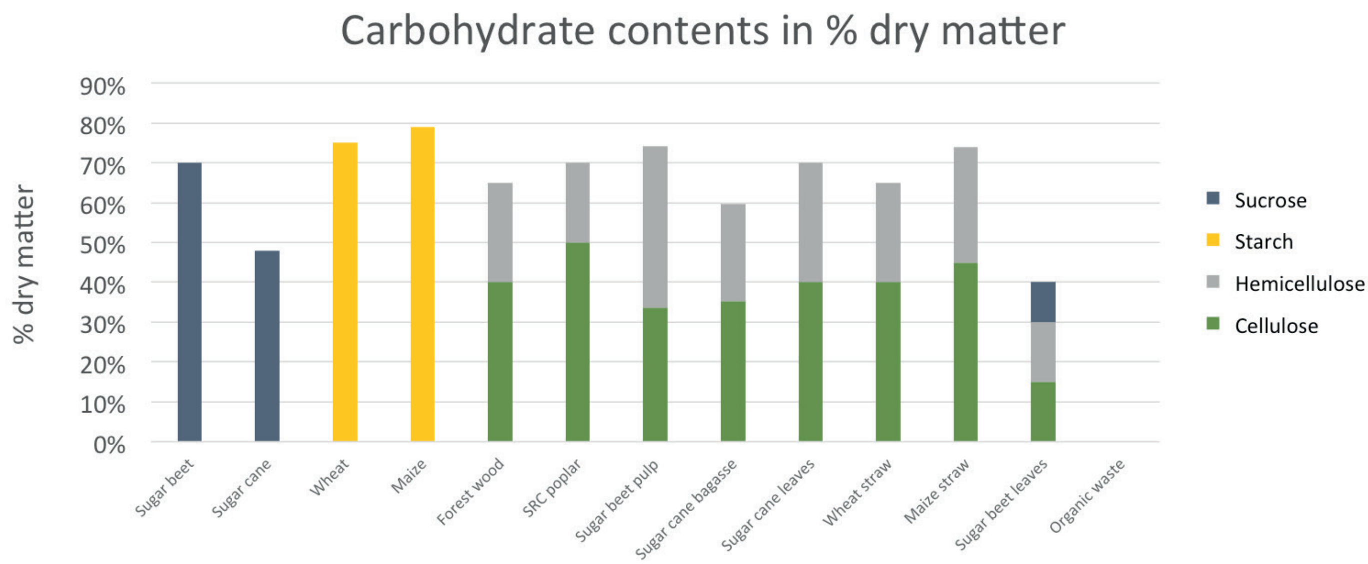

Figure 5: Carbohydrate contents in % dry matter
Sources: Piotrowski et al. 2015 (sugar beet, sugar cane, wheat, maize), Piotrowski and Carus 2012 (forest wood, SRC poplar), Rezende et al. 2012 (sugar cane bagasse), Aramrueang et al. 2017 (sugar beet leaves)

Stoichiometric conversion rates

In Iffland et al. 2015, the concept of the "Biomass Utilization Efficiency" "(BUE) has been introduced and a differentiation has been made between stoichiometric or theoretical efficiency (BUE_S) and the highest, currently reported efficiency (BUE_H). For this study, we first report the stoichiometric conversion efficiencies and derive the BUE_H by multiplying these rates with the efficiencies described below.

The stoichiometric efficiencies can be calculated by setting up the reaction equations from feedstock to ethanol:

Sucrose:	$C_{12}H_{22}O_{11}$ + 342	H_2O 18	→	4 C_2H_6O + 4*46	4 CO_2 4*44
	BUE_S = (4*46)/342 = **53.8%**				
Glucose:	$C_6H_{12}O_6$ 180		→	2 C_2H_6O + 2*46	2 CO_2 2*44
	BUE_S = (2*46)/180 = **51.1%**				
Starch:	$(C_6H_{10}O_5)n$ + 162*n	n H_2O 18*n	→	2*n C_2H_6O + 2*n*46	2*n CO_2 2*n*44
	BUE_S = (2*n*46)/(162*n) = **56.8%**				
Cellulose:	$(C_6H_{10}O_5)n$ + 162*n	n H_2O 18*n	→	2*n C_2H_6O + 2*n*46	2*n CO_2 2*n*44
	BUE_S = (2*n*46)/(162*n) = **56.8%**				
Hemicellulose:	3 $C_5H_{10}O_5$ → 3*150	5 C_2H_6O + 5*46		5 CO_2 5*44	
	BUE_S = (5*46)/3*150 = **51.1%**				

Rate of hydrolysis and recovery

While the extracted sucrose directly enters fermentation, starch, cellulose and hemicellulose need to be hydrolysed. In the case of starch, McAloon 2000 state that 100% of starch can be converted to glucose.

In the case of cellulose, a conversion rate of 61–67% of cellulose to glucose can be reached (Kamm et al. 2007; Yamada 2013; Pulidindi 2014). For the calculations we assume an efficiency of 65%. For the hydrolysis and recovery of sugars (mainly xylose) from hemicellulose, no comparable sources are available. The rate may even be higher than from cellulose due to the heterogeneous structure of hemicellulose with a low polymerization degree. Conservatively, we assume the same rate as for cellulose.

Rate of fermentation

According to Shapouri (2006), practical ethanol yield from sucrose is 86.6% of the theoretical yield. Since both starch and cellulose are composed of glucose strains, their fermentation efficiency is based on the fermentation efficiency of glucose. Ethanol can be produced anaerobically using e.g. glucose at high yields of 92.3% (Stryer 1975; Hama et al. 2014). Conservatively, we assume an ethanol yield of 90%.

Finally, Hahn-Hägerdal (2006) found the yield in g ethanol/g xylose to be between 0.3 and 0.49 for various microbes and hydrolysates, which means that between 59%-96% of the theoretical stoichiometric yield of 51.1% can be achieved. For our calculations, we assume an average fermentation efficiency of 78%.

4.3. Results

Table 2 summaries how the final BUE_H is calculated by assuming losses from the optimal BUE_S due to suboptimal carbohydrate extraction/pretreatment, hydrolysis and recovery as well as fermentation.

	BUE_S	Extraction/ pretreatment	Hydrolysis and recovery	Fermentation	**BUE_H**
Sucrose	**53.8%**	100%	100%	86.6%	**46.6%**
Starch	**56.8%**	100%	100%	90%	**51.1%**
Cellulose	**56.8%**	65%	90%	90%	**33.2%**
Hemicellulose	**51.1%**	65%	85%	78%	**25.9%**

Table 2: Assumptions for the conversion efficiencies from biomass to ethanol

Figure 6 to Figure 9 show the resulting ethanol yields in tonnes per tonne biomass as well as in tonnes per hectare. Figure 7 shows the ethanol yields per hectare separately for the main sources (e.g. sugar juice in the case of sugar beet) and the harvesting and processing residues while Figure 9 shows the theoretical yields if all parts of the harvested crop where used for ethanol production (e.g. not only the sugar juice but also sugar beet leaves and sugar beet pulp were used for ethanol). Figure 8 and Figure 10 show the results for calculations that include biogenic CO_2 which arises from the conversion process under the assumption that the CO_2 is converted (with additional renewable energy) into methanol, expressed in tonnes of ethanol equivalents.

In practice, such a maximum ethanol production from the whole crop on one site is rather unlikely since the processes for 1G and 2G ethanol are different and usually do not take place at the same facility. However, for a fair comparison between 1G and 2G feedstocks, it is justifiable to compare the whole extracted biomass from 1 hectare of forestry biomass also to the *whole* extracted biomass from 1 hectare of annual crops.

Taking into account a full utilisation for ethanol, sugar beet could yield more than 15 times more ethanol per hectare than forest wood from Finland. In fact, to fulfil half of the quota of 6.8% of low emission fuels from forest wood, 1.2 times the whole forest area of Finland would be needed. If based on the average annual increment across the EU-28, still 18% of the forest area of the EU-28 would be needed to reach that target.

Yields from wheat and maize are much less, but still on the same level as SRC poplar on arable land – and providing additional protein-rich co-products. In the following figures, it was assumed that the complete biomass except for protein-rich co-products is converted into bioethanol. The protein-rich co-products will always go to the feed market and are therefore accounted for separately in the chapter on protein-rich co-products (chapter 6).

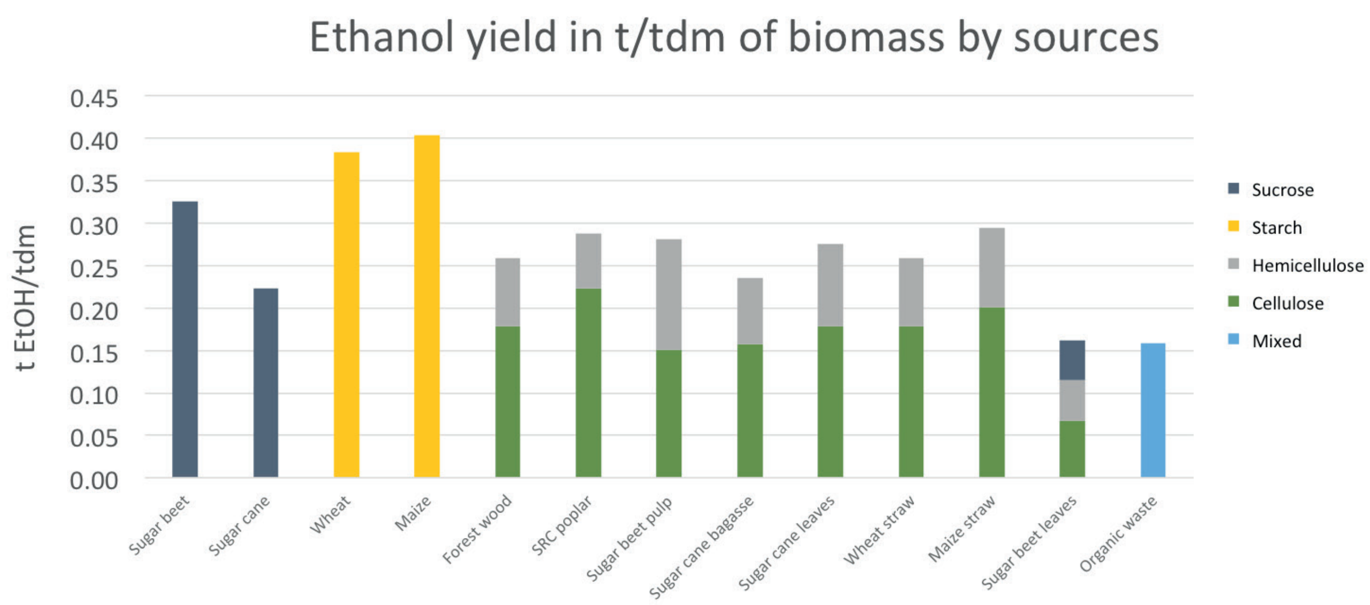

Figure 6: Ethanol yield in t/tdm of biomass by sources

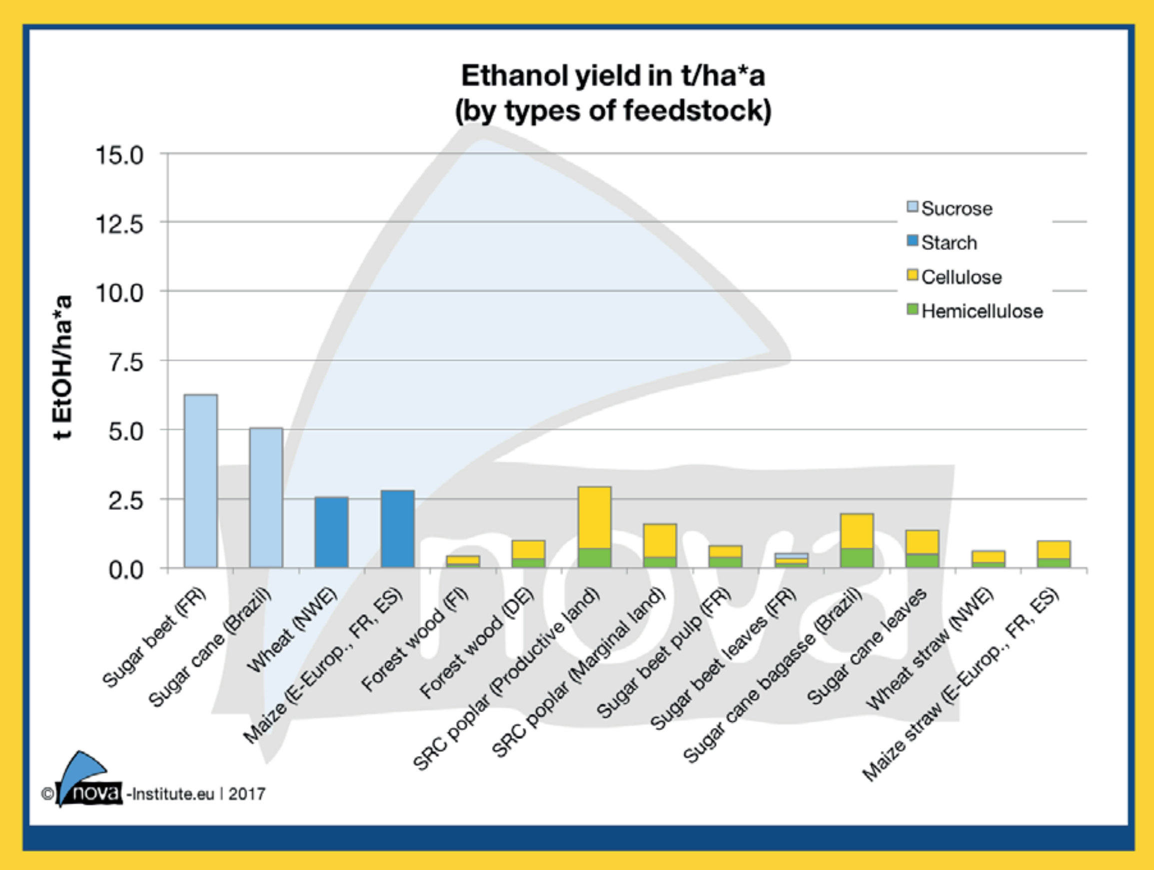

Figure 7: Ethanol yield in t/ha*a by biomass and sources

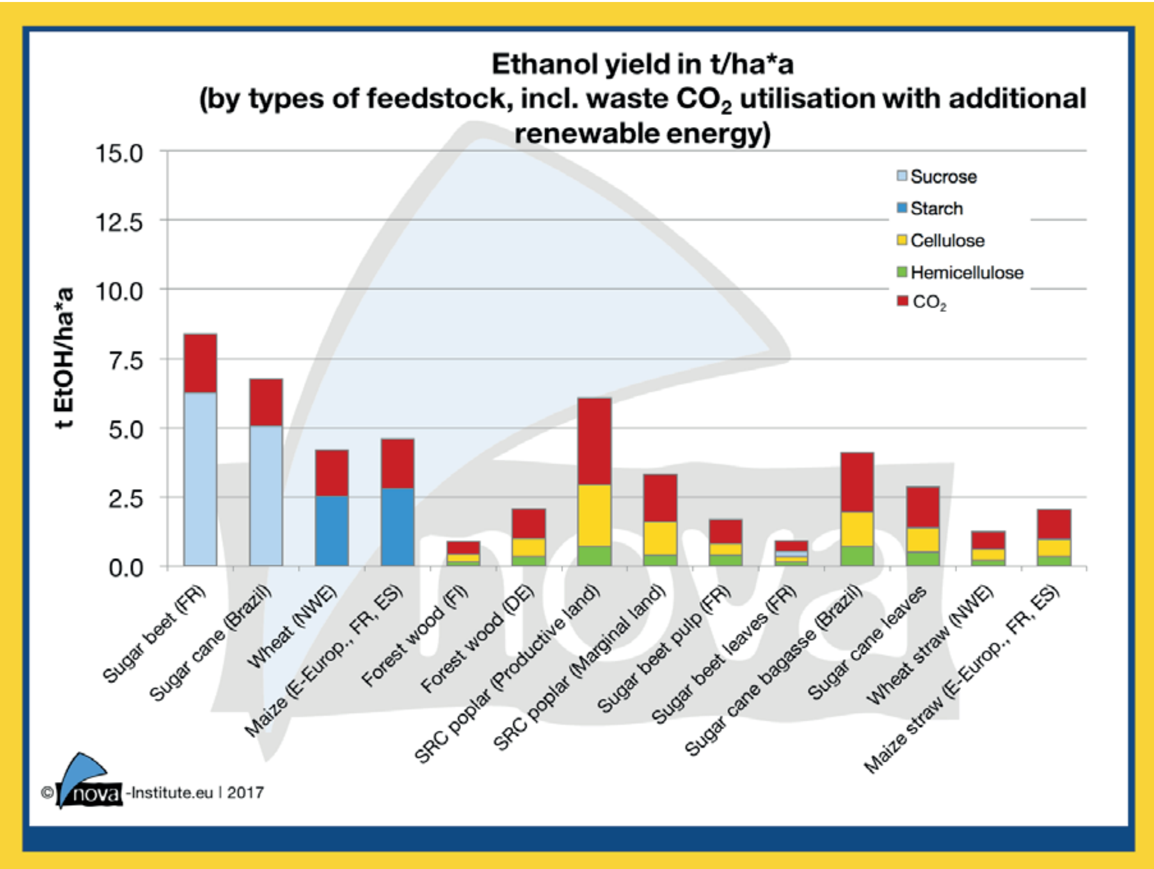

Figure 8: Ethanol yield in t/ha*a by biomass and sources, incl. biogenic CO_2 utilisation

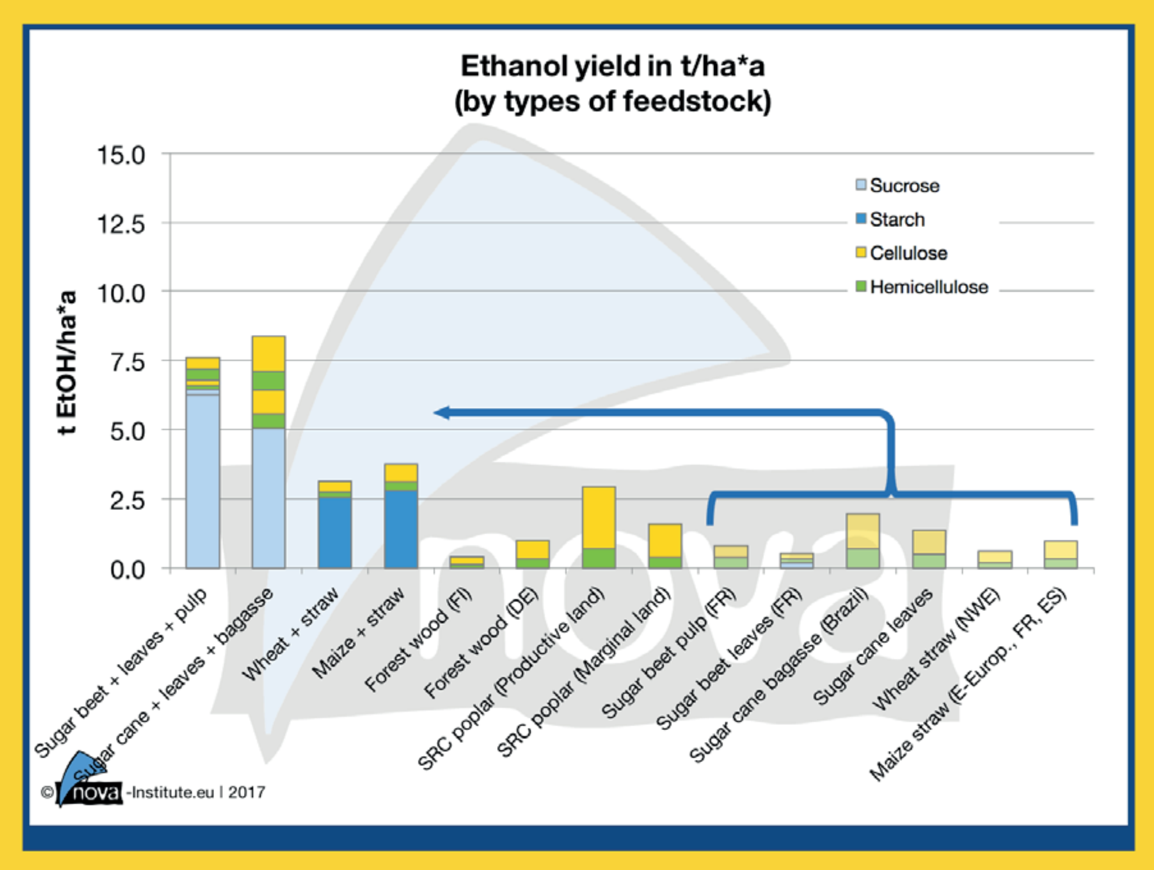

Figure 9: Ethanol yield in t/ha*a, by biomass and sources (assuming full utilisation of harvest and processing residues for ethanol)

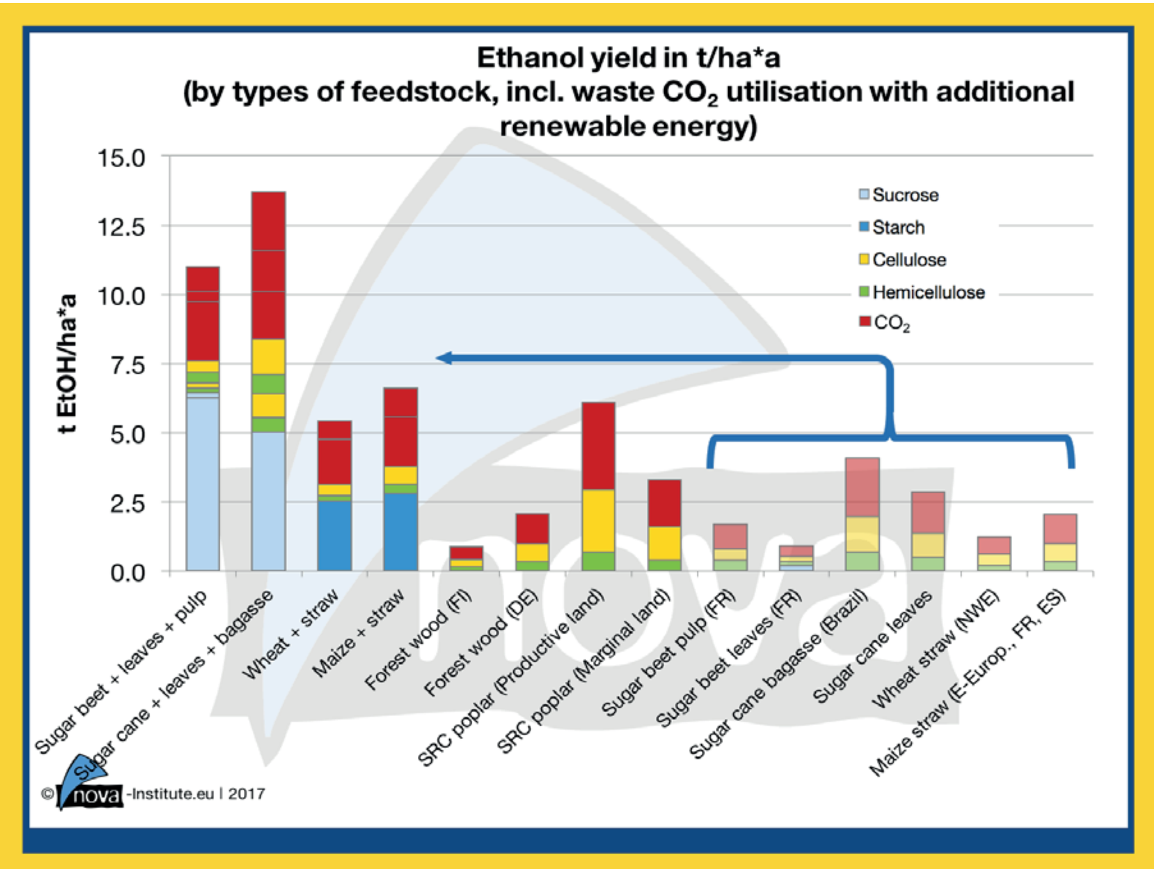

Figure 10: Ethanol yield in t/ha*a, by biomass and sources (assuming full utilisation of harvest and processing residues for ethanol and biogenic CO_2 utilisation)

5. Biofuels and food security

There is a widely-accepted allegation that biofuels consumed in Europe, which are produced from so-called "food crops" and which are also called "first generation biofuels", negatively influence global food security. This argument – and the resulting public pressure – has been the main reason for the last revision of the RED (iLUC Directive) with a cap of 7% for biofuels from food crops as well as for the further reduction to 3.8% by 2030 in the new Commission REDII proposal.

However, there is a significant lack of evidence to support this argument. On the contrary, there is growing evidence that the opposite may be the case and food crops grown for other purposes can also contribute to increased food security on a global level. The arguments both for and against food crops for biofuels can be structured into four categories, all of which will be further explained in the text below:

- Overall availability of food and feed on the planet
- Influence on food prices
- Contribution to protein supply for human and animal nutrition
- Emergency reserve

5.1. Availability of food and feed

First of all, it should be made clear that the competition between the different applications food/feed, energy and materials is not for specific crops. The competition is for land resources that can be used to grow any needed crop at a given moment. The chapter on land efficiency (see Chapter 4) shows impressively that in these terms, it is not a good idea to substitute fuels made from crops such as sugar or starch with fuels from lignocellulosic crops.

That means, with limited arable land, the most land-efficient crops should be used to produce first food and feed, and then ethanol and other industrial materials, and these are first generation sugar and starch crops. And they not only produce the highest amount of fermentable sugars per hectare, but in addition they also deliver proteins for the feed market (see extra criterion below). Also in many cases, cereals of non-food quality are used for bioethanol production which offers additional income to farmers, since without this option they would have to dump these products on world markets. This means that especially SRC score very badly on this criterion if they are grown on arable land, since they increase the competition for this valuable type of land, with less ethanol output and without protein-rich co-products. Forests do not pose a direct competition to food supply in terms of area needed as long as they are not grown on land which has been used for agriculture before. Also, organic waste used as a feedstock does not create competition for land.

Additional areas with food crops also provide a higher overall availability for sugar and starch (see below "emergency reserve", too). The overall supply of food and feed worldwide has been growing according to numbers published by FAO and USDA, although the demand for first generation biofuels has grown in parallel.

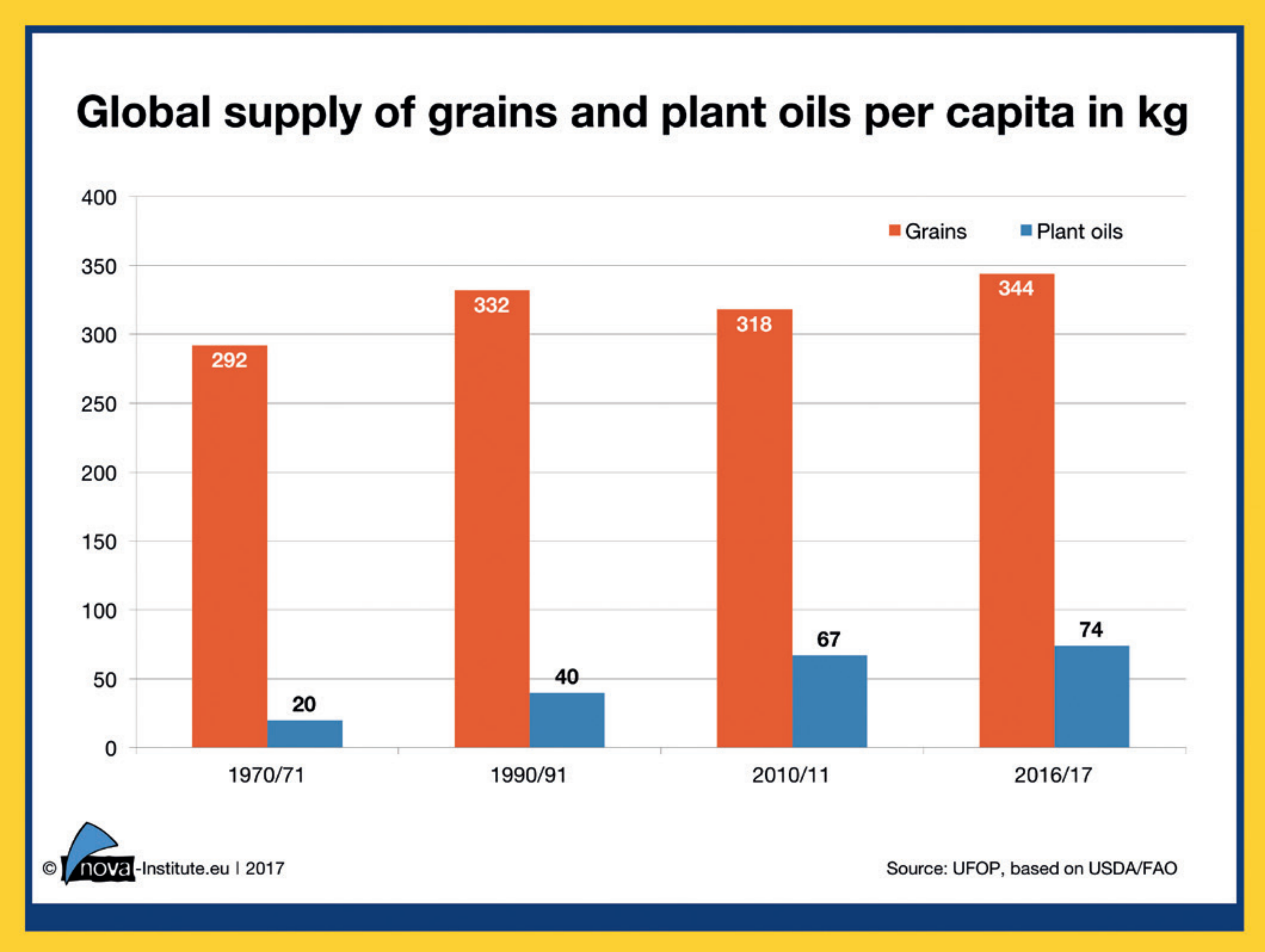

Figure 11: Supply of grains and plant oils, 2016/2017, estimated (source: UFOP 2017, based on USDA/FAO)

In terms of overall availability of food and feed, certain aspects such as wastage and meat consumption have a significantly bigger impact than biofuels consumption. According to Gustavsson et al. 2013, total losses of food from agricultural production up to the consumer amount to 30% of the potential production without any such losses. And meat production is extremely land consuming – producing animal-based protein needs 2.5 times (dairy) to 20 times (beef) as much land as it would to produce plant-based protein (Cassidy et al. 2013).

With regards to land competition and overall availability of food, first generation fuels score slightly better than second generation fuels. Especially SRC scores low due to competition for arable land at a bad efficiency ratio.

5.2. Influence on food prices

Since overall availability of food and feed does not seem to be the problem and is not negatively impacted by biofuels, it could then be – and often is – argued that subsidies for biofuels drive up food prices, making it inaccessible for the world's poor. It is true that the unbalanced distribution of wealth between the global North and South is one of the main reasons for the insecure access to food for many people. The World Food Programme (2013) lists the following six reasons as main drivers of hunger:

1. Poverty
2. Lack of investment in agriculture
3. Climate and weather
4. War and displacement
5. Unstable markets
6. Food wastage

Biofuels and bioenergy are noticeably absent from this list. The price argument was most often heard after the food crisis in 2008, when food prices spiked for about 15 months, and then shortly afterwards again in 2011:

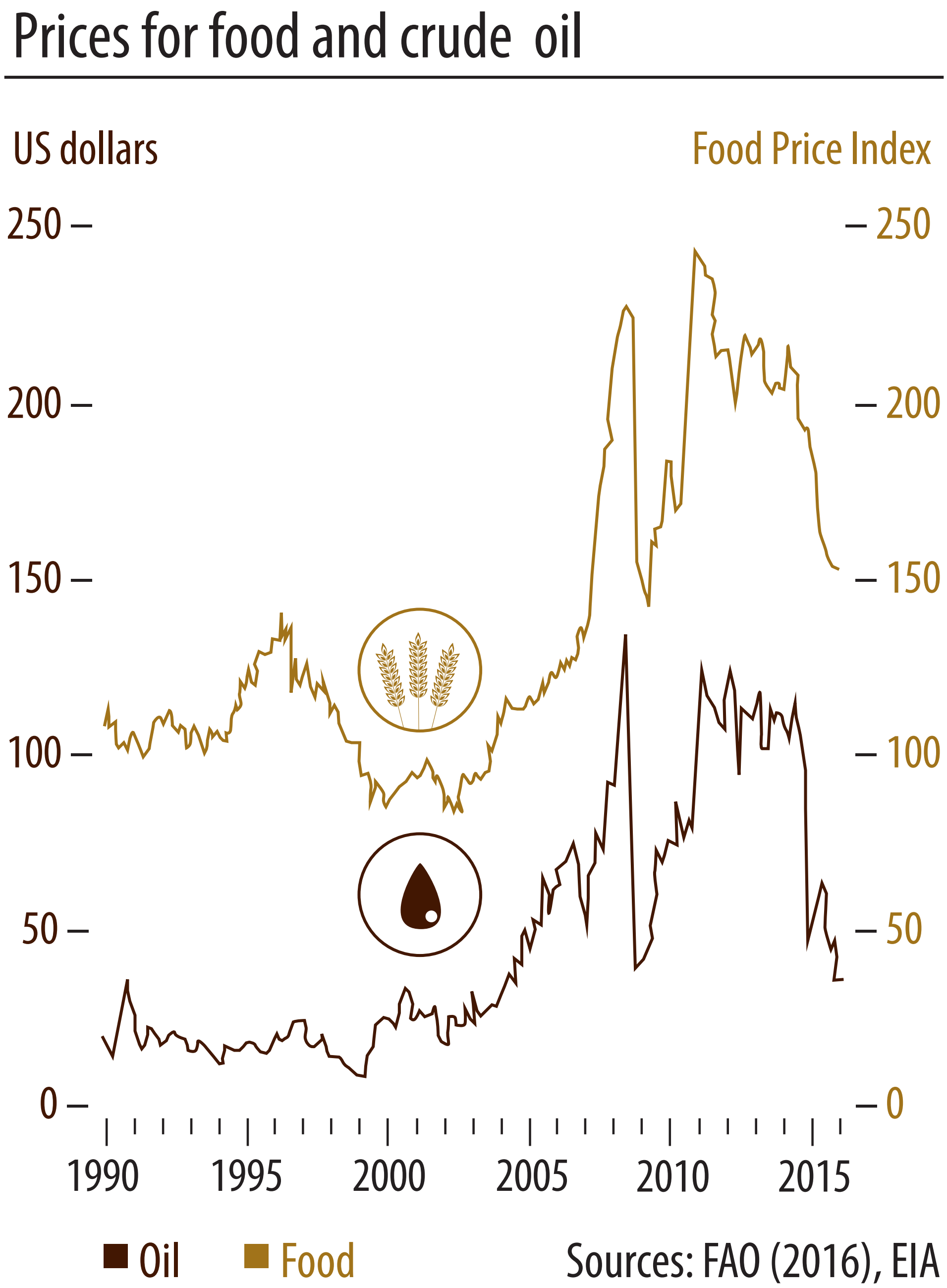

Figure 12: Prices for food and crude oil (http://www.globalagriculture.org/report-topics/food-speculation.html)

However, there is sound research that came to the conclusion that this peak in prices was – while related to a multitude of reasons – mostly caused by an extreme peak in speculation with commodity prices. As the UN Special Rapporteur on the Right to Food put it:

"The global food price crisis that occurred between 2007 and 2008 (...) had a number of causes. The initial causes related to market fundamentals, including the supply and demand for food commodities, transportation and storage costs, and an increase in the price of agricultural inputs. However, a significant portion of the increases in price and volatility of essential food commodities can only be explained by the emergence of a speculative bubble."[5]

Other papers draw similar conclusions.[6] It cannot be completely ruled out that the increased competition for land between biofuels and food production did influence the food price peak in 2008[7], but the reasons were definitely more complex and long-term trends (occurring at continued biofuels policy in Europe) seem to indicate that the influence of biofuels on these market prices are negligible. In more recent years, the development of prices both for wheat and for bioethanol has followed a declining tendency. Smaller increases in the price of bioethanol have not led to increases in wheat prices at all:

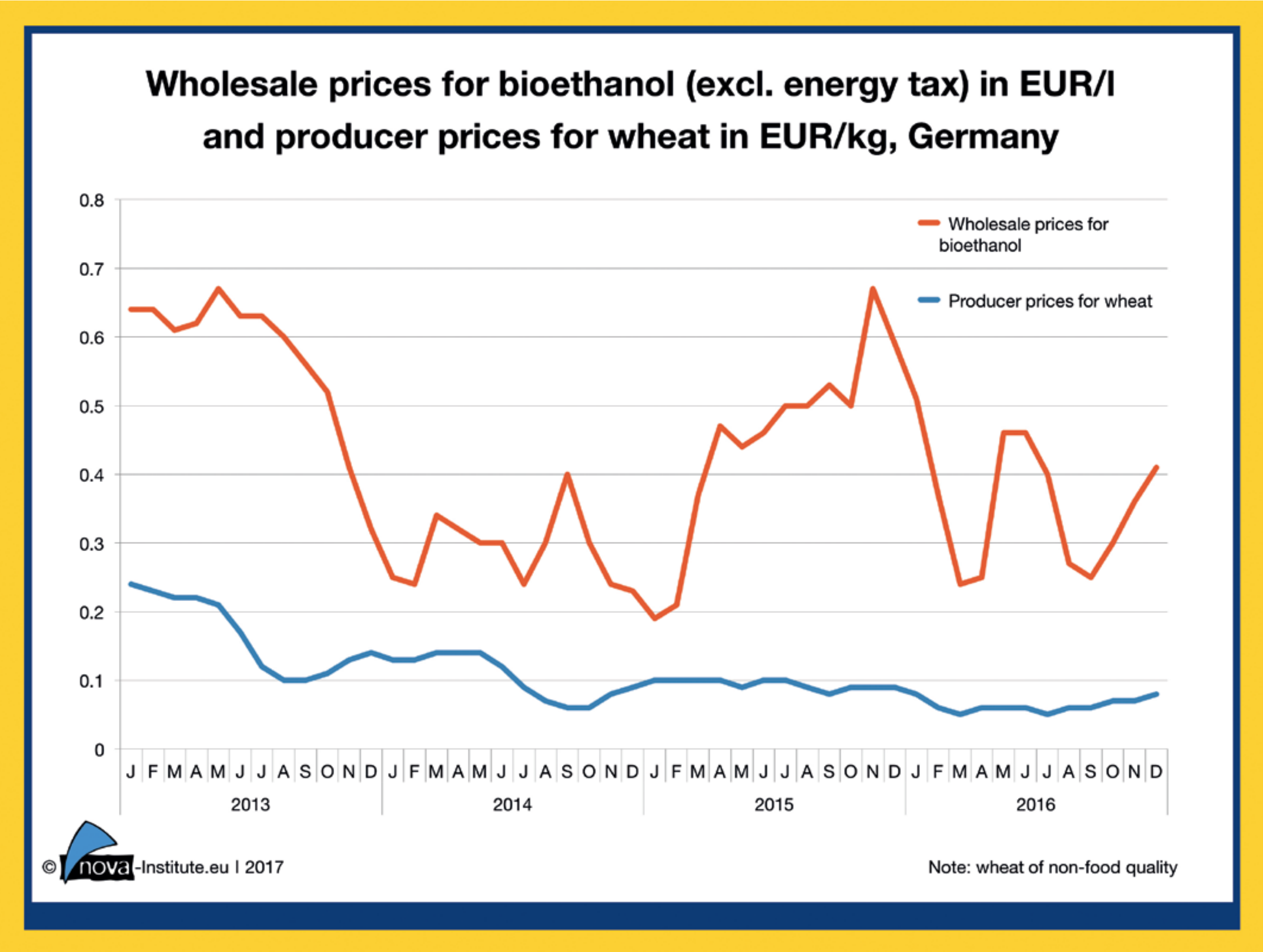

Figure 13: Wholesale prices of bioethanol and wheat (source: UFOP 2017 based on AMI/LK/MIO)

5 http://www.srfood.org/images/stories/pdf/otherdocuments/20102309_briefing_note_02_en_ok.pdf
6 E.g. http://www2.weed-online.org/uploads/weed_food_speculation.pdf
7 https://www.theguardian.com/global-development/2011/jan/23/food-speculation-banks-hunger-poverty

It can also be discussed whether the low prices for food crops are a good thing because it usually means that there is no incentive for investment in agriculture, which could lead to higher yields and increased food security. Extreme peaks such as in 2008 certainly cause volatility, but it does not necessarily make sense to condemn – steady – increases in market prices for food crops.

With the right policy in place, a controlled bioethanol demand can balance and stabilize the price development of sugar and starch, for example as an outlet for regional overproduction which the global market cannot cover. Unfortunately, the locality of agricultural markets is often ignored. For instance, only a small share of global grain production is internationally traded, as shown by Table 3. International trade concentrates mainly on corn and wheat, while e.g. rye is hardly traded at all. This means in consequence that price increases – if they happen at all – will mostly concern local or regional markets but cannot impact global price structures as is often alleged.

Country	Commodity	Attribute	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	Unit Description
World	Barley	Production	154.943	150.874	122.960	133.451	129.046	144.306	141.776	149.248	147.995	138.531	(1000 MT)
		Exports	19.998	17.140	15.916	20.394	19.630	22.856	29.016	30.768	27.800	24.014	(1000 MT)
		Export-qu	13%	11%	13%	15%	15%	16%	20%	21%	19%	17%	
	Corn	Production	800.197	826.406	837.282	891.588	872.994	994.693	1.019.415	968.807	1.068.793	1.036.898	(1000 MT)
		Exports	83.721	96.618	91.557	116.948	95.422	131.416	142.352	119.618	159.738	152.462	(1000 MT)
		Export-qu	10%	12%	11%	13%	11%	13%	14%	12%	15%	15%	
	Rye	Production	17.314	17.521	11.407	12.190	13.712	15.761	14.458	12.182	12.559	13.176	(1000 MT)
		Exports	225	293	362	490	462	420	413	353	294	336	(1000 MT)
		Export-qu	1%	2%	3%	4%	3%	3%	3%	3%	2%	3%	
	Wheat	Production	683.953	687.236	649.460	697.320	658.600	715.080	727.978	736.983	754.312	737.827	(1000 MT)
		Exports	144.121	136.764	133.038	157.643	138.069	165.875	164.173	172.867	181.637	178.424	(1000 MT)
		Export-qu	21%	20%	20%	23%	21%	23%	23%	23%	24%	24%	

Source: USDA (2017), https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery

Table 3: Grain production and export quotas, worldwide (source: USDA 2017)

There is no reported link between wood prices and food prices, either (even less so for waste and food prices, obviously). First and second generation fuels score evenly in this criterion, none of them having clear impact on food prices.

5.3. Contribution to protein supply for human and animal nutrition

In terms of valuable nutrition, protein supply is much more important to both human and animal welfare than the supply with carbohydrates. A lack of protein leads to a form of malnutrition called “protein-energy malnutrition (PEM)”[8], while a lack of carbohydrates can be made up for by digesting other energy sources. This means, carbohydrates are replaceable in human diet, while protein is not. The same applies to animal nutrition.

Bioethanol, however, are made from sugars, which are carbohydrates. When crops such as sugar beet or wheat are processed into bioethanol, there is a significant amount of protein-rich co-products which are fully utilized in feed applications (see separate section on co-products for details, Chapter 6). Since the supply of protein is so crucial for human and animal nutrition, the provision of said co-products is most valuable to food and feed security. This also applies even more to the production of biodiesel from rapeseed oil, but is not in the focus of this paper on bioethanol. If these crops were less cultivated in Europe due to a phasing out of first generation biofuels, there would be an increased need for importing protein-rich feed products from other regions, such as soy from Brazil. This would have huge impacts on land use, land use change and transport emissions. The need for increased and independent protein production in Europe is well acknowledged by policy makers which can be seen in the “European Soy Declaration”, signed in July 2017 by 14 Member States.[9]

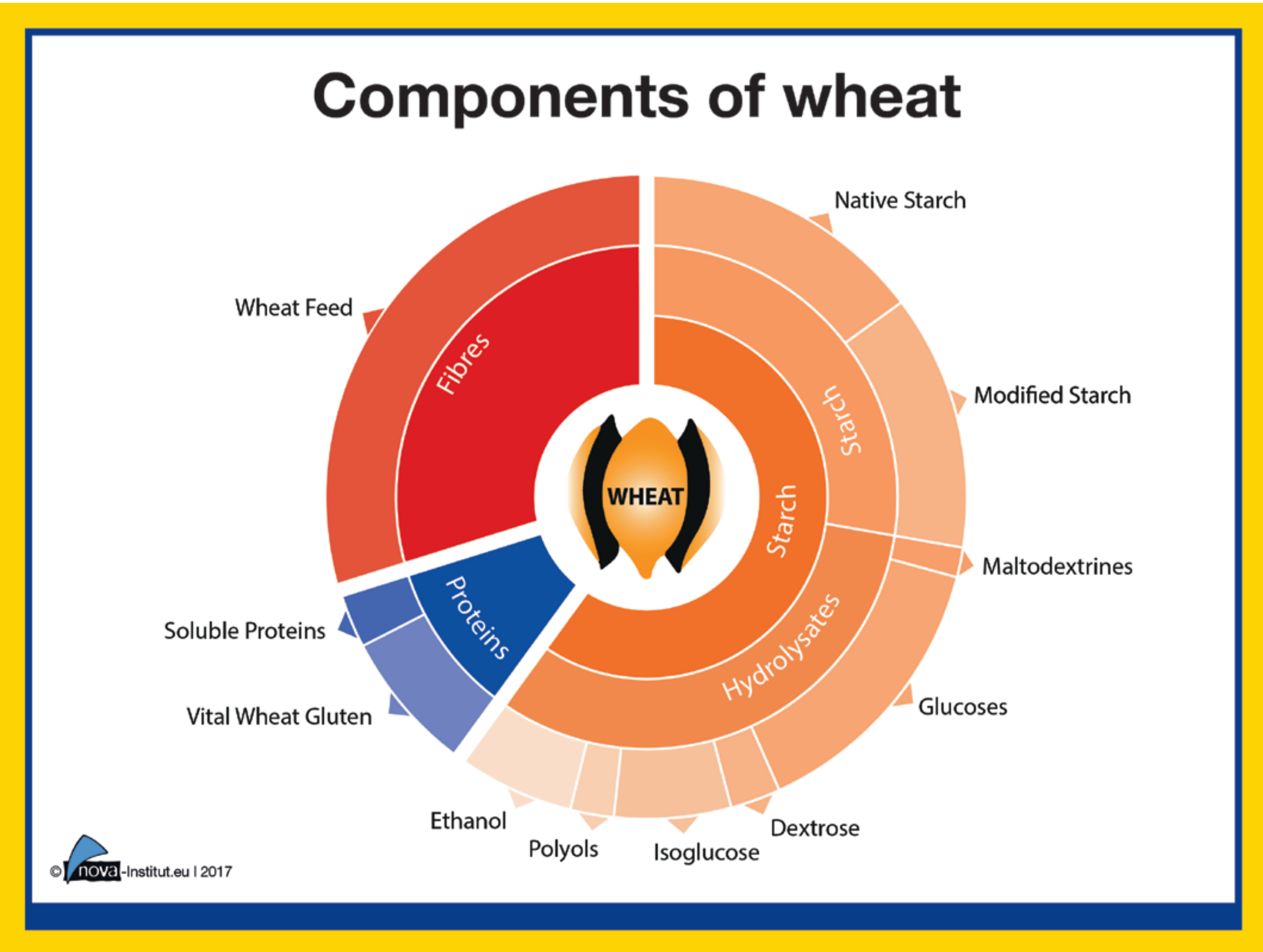

Figure 14: Co-product utilization from wheat (source: own drawing)

8 http://emedicine.medscape.com/article/1104623-overview
9 http://www.feednavigator.com/Regulation/More-countries-back-EU-soy-declaration

For the criterion "contribution to protein supply", first generation biofuels score significantly higher than second generation biofuels. Since wood- or waste-based biofuels do not worsen the situation on protein supply, however, the different types of biofuels have been ranked equally positively for the purpose of this analysis in the overall category "food security". For a European strategy that covers a multitude of strategic targets, however, the suggestion of MEP Sean Kelly should be taken seriously: He recently suggested to exempt biofuels from the conventional biofuels cap that adhere to strict sustainability criteria and provide protein for animal feed.[10]

5.4. Emergency reserve

In the case that humankind really faces a food crisis, food crops targeted to the bioethanol market can also serve as an emergency reserve for food and feed supply – second generation lignocellulose cannot be used as such.

Strictly speaking, food security is only achievable with additional food crops: In a food crisis, it is possible to re-direct sugar and starch to the food and feed market – taking it away from the bioethanol industry. Of course, for a transitional time, these feedstocks will not be available, exacerbating the food problem for a while. In the last decade, this has already happened several times in Brazil via a flexible bioethanol quota: If there is more demand for food and feed, the quota will be reduced to stabilize the markets. Or if there is higher supply than demand, the bioethanol quota can be expanded to stabilize the market prices for the producers. It might not even be necessary to implement legal measures to allow for such a change in feedstock utilisation, since market prices for feedstock are a strong driver for biofuel producers – in case of rising feedstock prices, they are often forced to produce less and the feedstock becomes available at the global market. Very strong fixed quotas, combined with the according incentive structures, however, can slow down this process. Flexible quotas are therefore still a preferable option from this point of view.

In a food crises, lignocellulosic crops such as short rotation coppice only give security to the industrial supply, but offer no emergency reserve for food supply. SRC cultivation takes land, which then cannot be used anymore for food and feed production, even in a food crisis. The lignocellulosic biomass will only feed the industry – but maintain the pressure on the food and feed markets. Also, a political focus on strictly waste-based fuels will not help to contribute to any emergency reserves.

With regard to the emergency reserve, first generation biofuels score slightly higher than second generation biofuels due to the time factor.

5.5 Conclusion

As stated in the beginning of the text, the evidence shows that first generation biofuels do not perform worse than second generation fuels made from lignocellulosic feedstocks or from waste with regard to endangering food security. On the contrary, they can even make positive contributions to enhancing food and feed security on a global level and act as emergency reserve too. This is counterbalanced by the fact that wood does not compete for agricultural land and that in times of crisis, if an emergency reserve cannot be activated quickly enough, the utilisation of wood for ethanol does not cause an immediate restriction to the access to food. Therefore sugar, starch and most lignocellulosic crops have been ranked the same in terms of food security. Only SRC has been ranked lower due to the land competition for arable land at a very low efficiency ratio. The concerns about food security are not well founded when it comes to bioethanol made from sugar or starch plants.

10 http://biofuels-news.com/display_news/12598/irish_mep_criticises_red_ii_biofuel_phase_out/

6. Protein-rich co-products and others

Due to the relevance of proteins in human and livestock diet (see chapter 5), this criterion especially assesses the prevalence of protein-rich co-products of the selected raw materials.

Depending on the feedstock and process, the production of one litre of ethanol can result in different amounts and different types of co-products, which can be used for different purposes. The most common uses are either animal feed, fertilizer, chemicals or energy. As shown by Figure 15, sugar beet and starch crops are the only feedstocks that provide relevant co-products in terms of animal feed. Since the protein content of starch crops is significantly higher than that of sugar beet, wheat and corn have been ranked as highest performing, while sugar beet was ranked as medium performing. While the vinasse – as one of the possible co-products of sugar cane utilisation – could theoretically be used for animal feed just like the vinasse from sugar beet is, literature is quite clear on the fact that in reality, the vinasse from sugar cane is used as fertilizer on the fields.

The availability of protein from European crops is of utmost importance in order to reduce the dependency of soy imports from South America. Less soy cultivation in Brazil, for example, is also helpful to avoid unwanted land use change effects (see chapter 8).

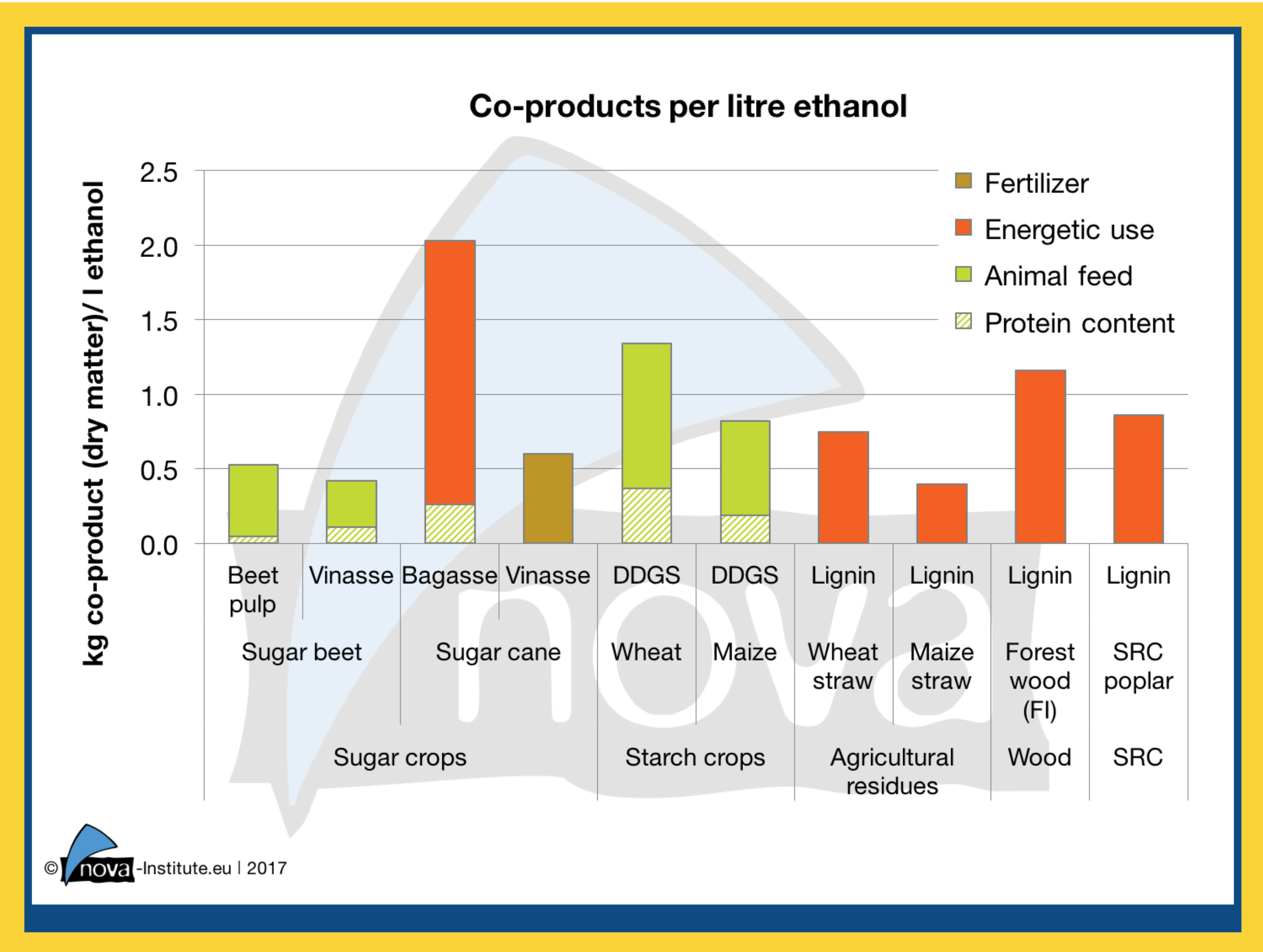

Figure 15: Co-products of different feedstocks and their usages (own calculations, based on Hansa Melasse 2017, Soccol et al. 2016, Costa et al. 2015, Heuzé et al. 2017, Heuzé et al. 2015 and Wirsenius 2000)

7. Employment, rural development, livelihood of farmers and forest workers

According to ePURE (based on a study by Urbanchuk 2012),

- "For every 100 million litres of domestically produced renewable ethanol, approximately 1,500 long-term jobs are created."

- "The renewable ethanol industry has generated and sustained 70,000 direct and indirect jobs in Europe during the recent economic crisis."

- "By 2020, based on current growth projections, employment in the European renewable ethanol sector could reach up to 205,000 jobs."

These results are confirmed by the WifOR institute (2013), which analysed the economic impact of the bioethanol activities of CropEnergies in Belgium and Germany. According to this study, the bioethanol plants in Wanze (Belgium) and Zeitz (Germany) secured more than 11,400 jobs. Taking into account the installed capacity of about 700 million litres of renewable ethanol on both locations, this corresponds to approx. 1,600 jobs per 100 million litres.

Data from Eurostat and FAOSTAT

- Calculations based on statistics (Eurostat, FAOSTAT) show that for the processing from raw material to bioethanol, both first and second generation processes create a similar number of jobs: 0.002-0.003 full time equivalents (FTE) per tonne ethanol.

- In crop production, however, agriculture creates more than ten times as much jobs as forestry does: 0.04 annual working units (AWU, approx. equivalent to FTE) per ha in agriculture; while the European average in forestry is 0.004 AWU/ha (e.g. 0.001 AWU/ha in Finland and 0.003 AWU/ha in Germany). For short rotation coppices, labour demand is about half of that for annual crops (0.02 AWU/ha).

- Given that ethanol in Europe is currently mainly produced from sugar and starch crops, this calculation results in about 70,000 FTE in agriculture plus 13,000 FTE in the manufacture of ethanol. Based on the assumption that almost all of the crops are actually produced in the EU[11], these employment figures match the ePURE figure of 70,000 direct and indirect jobs in Europe in 2010 quoted above quite well.

- Referring these numbers to one tonne of ethanol, it is quite clear that those crops requiring agricultural cultivation (or semi-agricultural cultivation as in the case of SRC) create more employment per tonne of ethanol than woody and waste biomass (see Figure 16).

11 Eurostat and: http://epure.org/media/1472/feedstocks-quantity.png

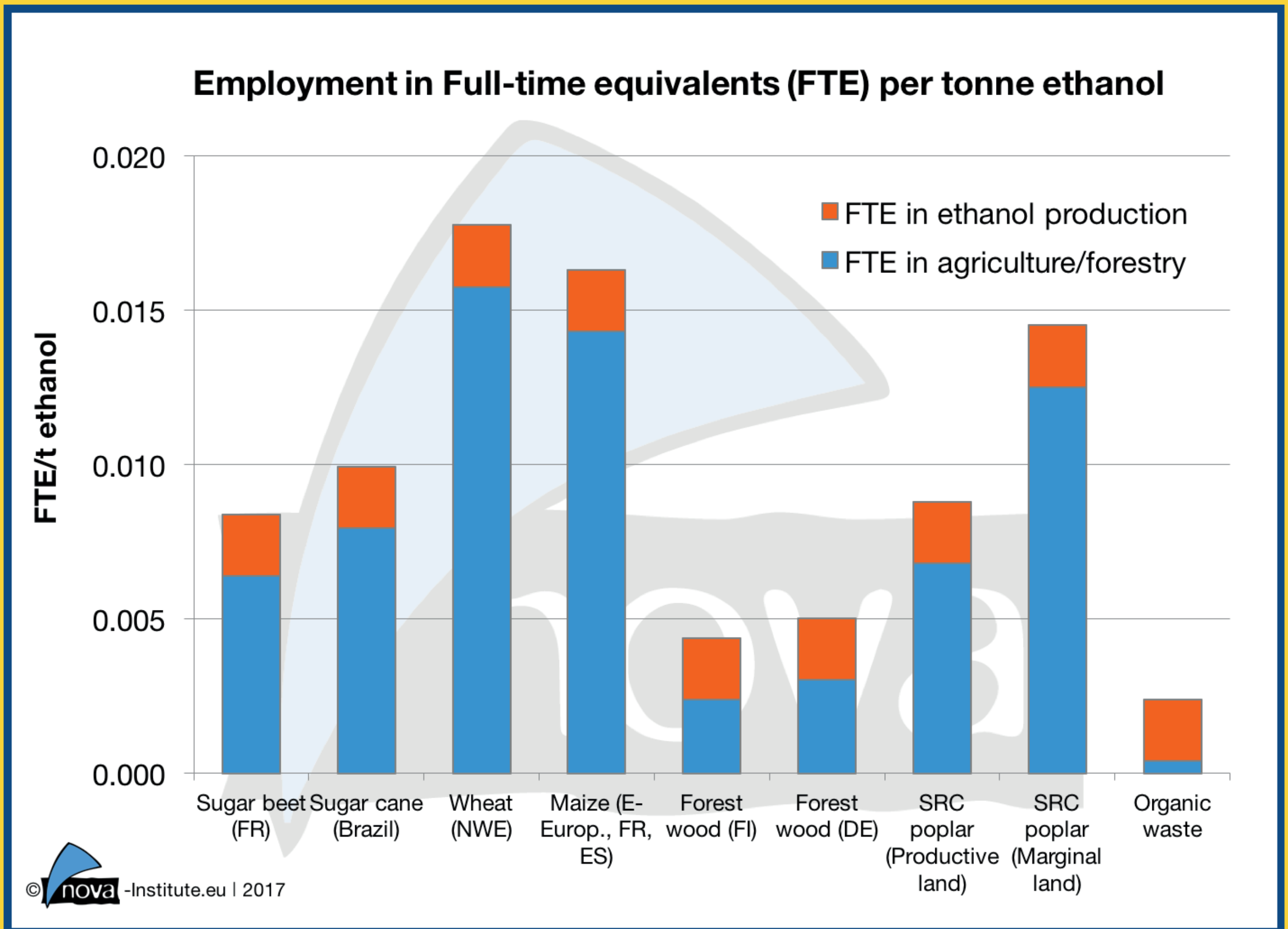

Figure 16: Employment generated by ethanol production, FTE/t Ethanol (sources: Eurostat, FAOSTAT)
Notes: FR = France, NWE = North-West Europe (Germany, Belgium, The Netherlands, France, Sweden, Great Britain), E.-Europ. = Czech Rep., Poland, Hungary, ES = Spain, FI = Finland, DE = Germany

European biofuels also help to reduce agricultural land losses, thereby contributing significantly to stabilising the livelihood of farmers, especially when markets for agricultural products are fluctuating strongly (Farm Europe 2016). Since ethanol facilities are mostly built in rural and structurally weak areas, their establishment can also contributes to the prosperity of the region since the revenue from additional direct jobs will increase purchasing power and benefit other sectors.

Biofuels from woody biomass would also support jobs in rural areas, however not to the same extent as biofuels from agricultural residues or SRC. Therefore, ethanol from forest wood has been ranked as medium performing. In addition to that, the utilisation of waste, would probably create only few jobs, mostly in urban areas, which is why these feedstocks were ranked as medium performing, too. However, if waste-based fuel options are considered as a complete substitute to 'job intensive' biofuels from crops, a 'red' ranking must be considered. All other feedstock options have been ranked 'green'.

8. Land use change (LUC/iLUC)

As discussed in the chapters on land utilisation (Chapter 4) and food security (Chapter 5), different crops that can be used for bioethanol production have different impact on the availability of arable land. They can have different impacts on land use change, too.

Land use change describes the impact of a change in the land management or use due to agricultural activities. It can result in a change of the land cover which may have an impact on “sources and sinks of greenhouse gases (GHGs), or other properties of the climate system” and may thus rise local or global climate relevant impacts (IPCC 2000). Land use change can be distinguished between direct and indirect effects. Direct land use change (dLUC) refers to the emissions due to a change in the land use of one particular land area while indirect land use change (iLUC) refers to a change in the production level of a certain agricultural or forestry product elsewhere (IPCC 2000). Or to make it even clearer: If biofuel production takes place on cropland which was previously

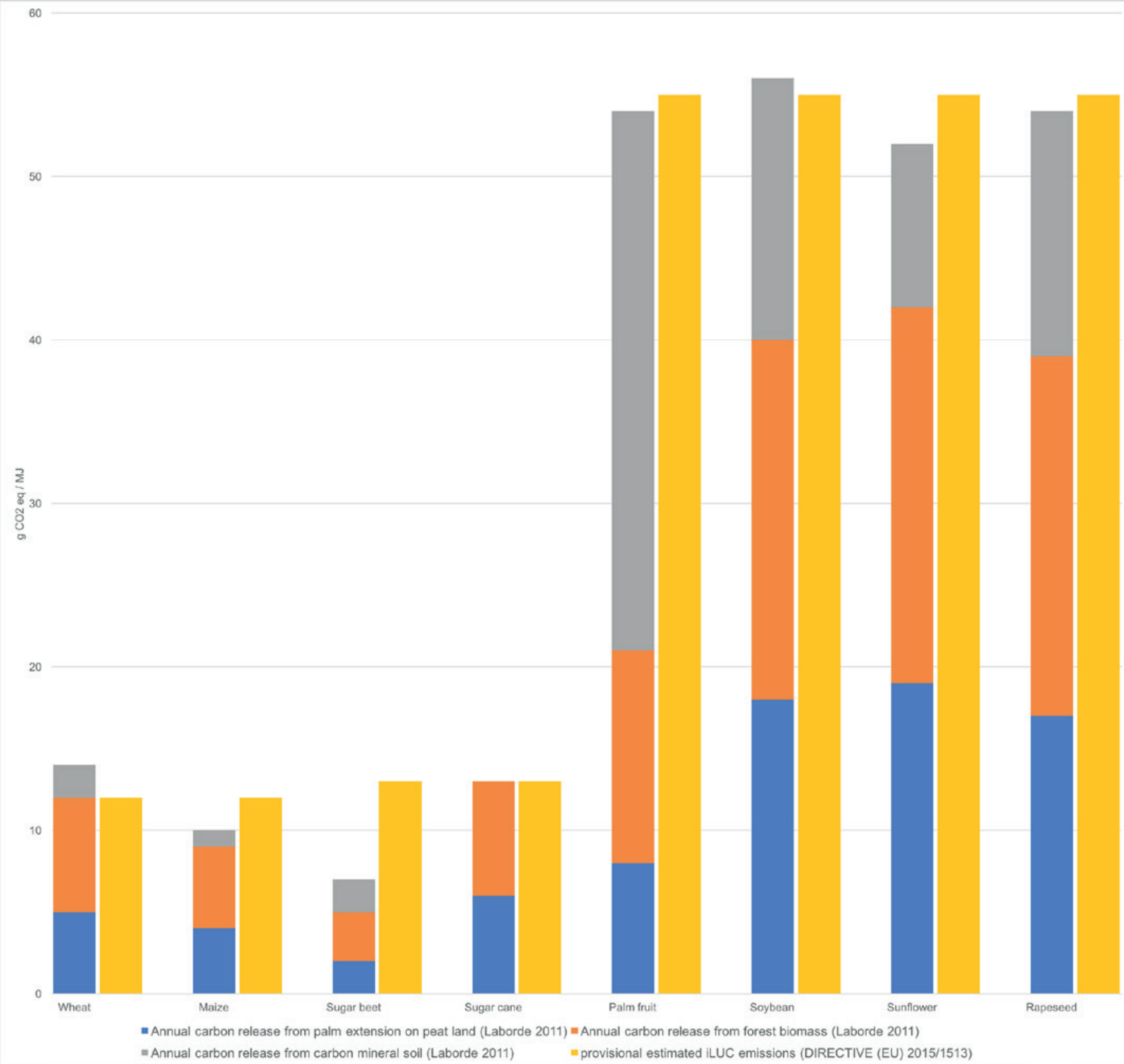

Figure 18: Estimated emissions due to land use change (own diagram based on EP 2015, Laborde 2011; all in g CO_2 eq /MJ)

used for other agriculture such as growing food or feed, this production may be displaced to previously non-cropland such as grasslands and forest. This effect is known as indirect land use change. The conversion of one land use or land type to another leads in most cases to a release of carbon dioxide.

The iLUC debate is highly controversial as (1) the specific cause-effect relation is difficult to define, (2) these indirect effects are hard to quantify and (3) there is no agreed method to assess these effects. A study by Laborde (2011) used a global trade model (MIRAGE (CGE)) to assess the market-driven effects on land use and calculated the related effects and provided the foundation for the incorporation of LUC in legislation. The “iLUC Directive” (2015/1513) provides estimates for indirect land use change emissions from biofuels. These values were politically determined, based on the values that Laborde (2011) provided. The following graph shows the two different calculations/determinations:
The results indicate that oil crops for biodiesel have a high LUC/iLUC risk while sugar and starch crops mainly for ethanol show low to medium risks. The GLOBIOM study (Valin et al. 2015) came to similar conclusions. Other biomass such as agricultural residues, forest biomass or organic waste do not have significant risks of land-use change related emissions, provided that sustainable extraction rates are guaranteed. In contrast, SRC on agricultural land shows a significant risk of LUC/iLUC due to the fact that agricultural land for the cultivation of food/feed crops is lost for several years or even permanently and may be made up for somewhere else. Since the ranking in the overview table refers to a mixture of SRC from agricultural and marginal land, it was ranked with medium risk.

9. Availability and infrastructure

In terms of existing infrastructure, first generation biofuels score higher, which is not surprising since they have already been established and do not need additional investment. Also in terms of potential / future availability and infrastructure there is reason for doubt whether second generation feedstocks – except for virgin forest biomass – will be available in relevant dimensions at a reasonable effort.

- SRC: Previous trials on short rotation coppice have mostly failed. According to AEBIOM statistical reports, total area in the EU-28 has stagnated at around 50,000 ha (AEBIOM 2013, 2015 and 2016), compared to about 25 million ha of wheat, which is to a large part due to lacking economic feasibility. The main reason for stagnation is that farmers do not like to plant perennial crops on their fields, because they prefer to stay flexible in their decision which crops to grow from year to year. If there is demand for wheat on the world market, they would like to grow wheat. Moreover, SRC bring less profit than food crops and the demand growth depends to a large extent on policy which can be fickle.

- Forest residues and agricultural residues are available in certain locations, but require huge effort in terms of transport in order to provide sufficient amounts of feedstock in order to cover the demand as outlined by the Commission proposal.

- For post-consumer wood and organic waste, the collection infrastructure is still not far advanced in many member states. Availability will be limited for the foreseeable future.

In addition to these constraints, availability of waste feedstocks for biofuels needs also to be considered in competition to other uses.

- The availability of wood and organic waste is impacted by competing uses from other sectors, especially the chemical and material industries. Often incentives in the biofuel markets just shift feedstocks from the chemical and material industries to the biofuel industry, without any positive effect on GHG reductions or employment. Some examples for this are forest residues, traditionally used for energy purposes or fibre boards in the wood industry, being directed towards co-firing in the energy sector. Or tall oil, a traditional feedstock of the pine chemical industry, being classified as "waste" and being redirected towards advanced biofuel production.

- It should be kept in mind that for many so-called 'wastes' and 'residues', there is considerable competition from other, higher value-adding industries than biofuels. From an efficiency point of view, it would be more favourable to allow the market to regulate the allocation of these limited feedstocks to the highest value applications. Furthermore, it is very questionable to build a long-term climate strategy on feedstocks that will be dependent on significant subsidies for an infinite time in order to counterbalance this competition.

It should be noted that a renewable energy system which is built to rely heavily on waste is also in partial contradiction to the European waste hierarchy and its goal to prevent waste generation in the first place. For anyone planning to invest in biofuels it can also be questionable whether it makes sense to rely on feedstocks whose availability is intended to be further and further reduced strategically.

10. Traceability of feedstocks

In order to ensure that biofuels truly achieve the GHG emission savings and other sustainability targets that they are accounted for, it is key that they are really made from the feedstock that they are claimed to be made from. Previous cases such as scandals around used cooking oil (UCO) have illustrated this point quite impressively.

Certification systems and mass balance systems contribute greatly to the traceability of feedstocks through the value chain. While some feedstocks are still excluded from the sustainability requirements in the new REDII proposal ("Biofuels, bioliquids and biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues", EC 2016, Article 26), all feedstocks are required to provide proof of their origin via mass balance certification. There is, however, often a lack of criteria that define waste which makes it easier to get away with false claims. Also, a weak implementation of mass balance certification can lead to wrongful declarations, if, for example, only points of collections are checked and not the primary "producer" of waste. This is especially problematic in the case of imported wastes, such as used oil and fats, since the checking of waste origin in Asia for example has proven to be complex and elaborate, if possible at all.

It should be noted that as long as an incentive system exists which makes it worthwhile to sell falsely declared waste, it is very probably that certain energies will find ways to circumvent any kind of certification and checks.

In our ranking system, these issues mostly apply to post-consumer wood as well as organic waste. Therefore, the risk of false claims of feedstock is higher. These gaps can contribute to artificial generation of "waste", which is in conflict with the European waste hierarchy.

11. Social impacts: land rights, human rights, education, etc.

The potential social impacts of biofuel production cannot be evaluated for a whole group of feedstocks, since the concrete risks and impacts depend very much on location and specific cultivation practice. It has been suggested by several reports that sugar cane from Brazil is more at risk to have negative impacts on social aspects than feedstocks grown in Europe (see several reports on child labour and forced labour on sugar cane plantations in Brazil from the early 2000s[12]). Also land grabbing is still a problem in many developing and emerging nations.

However, ethanol used in the European biofuel quota needs to be sustainability certified; the most common sustainability scheme for sugar cane (Bonsucro) was rated relatively high in terms of social aspects by WWF[13]. More recent reports by the ILO seem to confirm the fact that sugar companies in Brazil have made considerable efforts to improve workers' conditions, especially in the abolition of child labour.[14]

A slight minus is the absence of social criteria from the mandatory sustainability criteria imposed by the RED; only some of the voluntary certification systems have implemented social criteria. It should be noted that for those certification systems working only with European feedstocks such additional social criteria are not really necessary since they are covered through legislation. And since the certification schemes that do include social criteria (ISCC, RSB, Bonsucro) represent the overwhelmingly largest share of the global market, the lack of social criteria from the RED is not seen as a major problem. In conclusion, all feedstocks were ranked equally high.

12 https://ethicalsugar.files.wordpress.com/2014/02/ethical-suagr-sugarcane-and-child-labour.pdf; https://www.theguardian.com/world/2007/mar/09/brazil.renewableenergy, http://grist.org/article/slave-ethanol/
13 http://awsassets.panda.org/downloads/wwf_searching_for_sustainability_2013_2.pdf
14 www.ilo.org/ipecinfo/product/download.do?type=document&id=5713

12. Biodiversity and marginal land

12.1. Key questions

For the comparison of different bioethanol options, the leading questions are:

- Do first and second generation crops show a systematically different impact on biodiversity?
- Are first and second generation crops of systematically different suitability for growing on marginal land and how is this related to biodiversity?

The main problem for an assessment is the lack of a quantifiable measurement system for biodiversity. Moreover, it is hardly possible to make general statements on the impacts on biodiversity, because this depends mainly on the local environment: Which local natural environment is or would be the alternative to agriculture or forestry?

"Biofuels have the potential to affect all of the major drivers of biodiversity loss identified in Global Biodiversity Outlook 3 (SCBD 2010): habitat loss and degradation; climate change; excessive nutrient load and other forms of pollution; over-exploitation and unsustainable use; and invasive alien species. … The impact of biofuel production on biodiversity will depend on the feedstock used, management practices, land-use changes and energy processes (UNEP/GRID Arendal 2011)." (Webb & Coates 2012)

"As with all land transformation activities, effects on biodiversity and ecosystem services of producing feedstocks for biofuel are highly variable and context specific. … Biodiversity resources are unevenly distributed across the globe. As a consequence of the asymmetrical geographic distribution of species, any consideration of the impacts of biofuels on biodiversity is likely to be biome, site and context specific. Land transformation is the most serious threat to biodiversity, and the rapid expansion of biofuels crops, most especially sugarcane and palm oil in the tropics, is currently the most serious of these concerns. Thus effects of biofuel feedstock production on biodiversity and ecosystem services are context specific, and location-specific management of biofuel feedstock production systems should be implemented to maintain biodiversity and ecosystem services." (Joly et al. 2016)

The expansion of biofuels crops has been either based on direct or indirect displacement of natural ecosystems or on the use of degraded or marginal lands. The former results in direct habitat loss, whereas the later results in usual agricultural impacts (e.g., soil and biotic contamination and water eutrophication).

"However, the expansion of biofuel crops may result in direct or indirect environmental impacts (e.g., alterations in habitat quality, pollution, and bioinvasions), besides conflicts between different sectors of society. Such impacts are mostly related to land use change (LUC) and/or agriculture intensification and should be rather considered as of primary not secondary concern." (Verdade et al. 2015)

Most important for the biodiversity is the *"conservation of priority biodiversity areas"* (Joly et al. 2016), meaning not to convert biodiversity hotspots into agricultural land for biofuel production. This is especially a problem in tropical regions. The RED states that biofuel crops must not be grown from land with "recognized high biodiversity value" in or after January 2008.

Including iLUC effects on biodiversity makes the discussion even more complex:

"Indirect land-use change (iLUC) remains a key unresolved biodiversity-related issue with biofuels. Biofuel production requires large areas of land normally dedicated to agricultural production. Land dedicated to agricultural production may then be displaced to other areas to keep up with demand for food and feed (Khanna and Crago 2011; Nuffield Council

on Bioethics 2011; UNEP/GRID Arendal 2011). Indirect land-use change (iLUC) occurs when biofuel feedstock production displaces previously productive land (e.g., agricultural land for food production) to other areas, causing deforestation or conversion of natural habitat and potentially negative impacts on carbon stocks and biodiversity (Dehue et al. 2011; Cornelissen et al. 2009). …The complexities of iLUC make the assessment of iLUC impacts on biodiversity extremely challenging, and have impeded the development of safeguards that might limit the impacts." (Webb & Coates 2012)

For a detailed assessment, there is still a lot of scientific work needed:

"However, in both cases long-term biodiversity monitoring programs should be established in order to help the decision making process concerning the conflict between the expansion of biofuels crops and the conservation of biodiversity." (Verdade et al. 2015)

Joly et al. 2016 recommend:

"Agroecological zoning principles and enforcement is of paramount importance to impede the conversion of ecologically significant and sensitive areas for biodiversity and ecosystem services protection into producing feedstocks for biofuel. Good governance and strong institutions are the most critical determinants of sustainable land use, especially in terms of biodiversity."

All these consideration and recommendations do not touch our key question: "Do first and second generation crops show a systematically different impact on biodiversity?". There is no scientific study covering this question directly. One report give at least some hints:

"… shows that the most negative short-term impacts from biofuels on biodiversity come from conversion of undisturbed natural vegetation. Beneficial impacts on biodiversity were only expected from conversion of cropland or grassland to grass feedstocks or woody feedstocks for biofuels. Neutral impacts were recorded on set-aside, marginal and abandoned land for only grass or woody feedstocks (UNEP/GRID Arendal 2011)." (Webb & Coates 2012)

From the existing literature, we can derive the following trends:

- Most scientists expect a bigger impact on biodiversity in agriculture compared to forestry and short rotation coppice (SRC) per hectare (also different kind of agricultural systems, harvesting methods and the use of co-products could lead to different size of impacts).
- However, also a planted forest can strongly decrease the biodiversity compared to a natural forest (also here the kind of forest system, harvesting methods and handling of dead wood could lead to different dimensions of impacts).[15]
- Short rotation coppice can show a lower biodiversity than a forest, but a higher compared to agriculture: *"… in some circumstances biofuels crops can result on an increase in biodiversity compared to other agricultural crops."* (Verdade et al. 2015)
- The discussions normally are based on impacts per hectare, not taking into account the different land use efficiencies (see Chapter 4).
- There is no final answer or methodology to the question how to compare the total impact on biodiversity of a small intensive agriculture area with a larger area of SRC or an even larger forest area.[16]

15 "For example, the Finnish Environmental Agency modelled the carbon impact of increased forest biomass use and found that using more wood for bioenergy is leading to decreasing carbon stocks in the Finnish forests (Liski et al. 2011). … Furthermore, dead wood provides habitat for a great diversity of species important for forest ecosystem function, and a large proportion of fallen and standing dead wood should be left for wildlife (Jonsson et al. 2005)." (Webb & Coates 2012)

12.2. Marginal land

All kinds of agricultural crops, SRC and forest show lower yields on marginal land. This is especially true for first generation food crops. But also for alternative second generation crops, there is no answer to the question whether they can be produced commercially on marginal land. This year, a European Horizon2020 research project (Marginal lands for growing industrial crops – MAGIC, project ID 727698) started to investigate this question.

Concerning biodiversity, also marginal land can be unique biotopes with specific crops and animals.

"In the United States, many such marginal lands have been enrolled in the Conservation Reserve Program (CRP), providing important habitat for grassland species. The demand for corn ethanol has changed agricultural commodity economics dramatically, already contributing to loss of CRP lands as contracts expire and lands are returned to agricultural production."[17]
"Not least of the issues is the lack of consensus on definitions of this kind of land. For example, should secondary forest be included as "degraded" lands? Some "degraded" lands support high conservation value species and the livelihoods of local communities. What may be considered marginal or degraded in one country may constitute a primary source of livelihoods in others, especially for the rural poor." (Webb & Coates 2012)

So, the use of marginal land cannot be evaluated in general as a plus for biodiversity.

12.3. Conclusion

Based on an extensive desk research and expert interviews, it was not possible to apply different rankings on biodiversity to first or second generation biomass for bioethanol made from fresh biomass from agriculture or forestry. First generation crops can have more impact per hectare because of intensive agricultural practices utilising chemical plant protection and fertilizers, while second generation biomass has an impact on much larger areas because of lower bioethanol yield per hectare.
More important for biodiversity are the specific local conditions and the management practice, and to avoid biodiversity hot spots by establishing good governance and strong institutions.
Using side and waste streams for second generation biofuels is another matter. Post-consumer wood and organic waste have no impact on biodiversity, also using agricultural residues has a low impact, as long as enough biomass is left on the field to maintain soil quality. Using forest residues is another matter still, because dead wood has high impacts on the biodiversity of mushrooms, insects and other small animals. For these reasons, all virgin materials have been ranked as posing high risks, while being well-aware of the fact that local practices in agriculture and forestry can differ significantly. Forest residues show medium risk and all waste materials low risk.

16 "Biodiversity can also be better protected through sustainable agriculture, reducing agricultural inputs and restoring degraded lands (UNEP 2009b). Enhancement in the efficiency of yields and production of biofuels, rather than expanding onto more land to meet energy demands, has also been suggested (Savage et al. 2011; Fairley 2011)." (Webb & Coates 2012)
17 https://www.ncbi.nlm.nih.gov/pubmed/21774415

13. Impact on water, air and soil quality

13.1. Water Quality & Consumption

Official default values for the impact of bioethanol production on water quality (expressed in e.g. freshwater eutrophication) could not be found. Though the German Umweltbundesamt (Environmental Agency, UBA) provides data sets on water pollution, it is not clear whether these could be used for official calculations regarding the preferability of different bioethanol path-ways. Given this lack of data, only a preliminary comparison between different bioethanol routes will be provided. It is solely based on fertilizer consumption, as run-off and leaching of fertilizer into water bodies considerably contributes to water pollution. Under a fertilizer consumption perspective, bioethanol produced from agricultural crops has a high impact, while wood-based ethanol has a medium impact (Smethurst 2010) and waste-based routes have a low impact. The latter is based on the assumption that residues and wastes have no share of fertilizer consumption during crop cultivation.

In addition to water quality, water consumption is another issue for bioethanol production. As for water quality, data on water consumption are scarce. Though the UBA provides, in a 2009 publication (Fehrenbach et al. 2009), some standard values for water consumption, this only covers first generation bioethanol production. Moreover, despite recognizing the importance of water consumption, the European Commission's Joint Research Center (JRC) does not include such consumption in their 2014 WTW study on future automotive fuels (Edwards et al. 2014).

A further challenge related to water consumption is the absence of an official default value for the fossil alternatives, which would allow for the calculation of saving potentials. In fact, the data on water consumption for fossil fuels such as gasoline varies quite a lot – see e.g. Wu et al. (2009) for ranges on water consumption.

13.2. Air Quality

Official default values on air quality for bioethanol production are scarce. Though a 2009 UBA report (Fehrenbach et al. 2009) provides some data regarding air pollutants (e.g. SO2, NO2, PM), it only covers first generation bioethanol. Due to this fact, the ranking of pathways is not possible. This is especially true since factors such as the impact related to the production of process utilities (e.g. enzymes) can swap the ranking between routes – see e.g. Liptow (2014).

13.3. Soil Quality

Assessing soil quality is a complex issue by its many physical, chemical, and biological processes and their interactions in time, space, and intensity. So far there is no established method to directly measure the rate of soil processes. The best soil quality indicators are those that integrate several properties and processes, including fungi and microbiological activities.

Among the different possible indicators, it is widely accepted that organic matter (carbon storage) plays an important role in maintaining healthy soils (EC 2015). Land use change, cultivation practices and different feedstocks have differing impacts on soil. For instance, the impact of sugar cane on soil is generally less than that of maize and other cereals (FAO 2008).

However, growing perennials such as short-rotation coppice (SRC) or switchgrass (second generation feedstocks) instead of annual crops (first generations feedstocks) can improve soil quality by increasing soil cover and organic carbon levels. In general, unmanaged forest and grasslands allocate a large fraction of their biomass production below ground and their soils are relatively undisturbed (Paustian et al. 2016). Accordingly, native ecosystems usually support much higher soil carbon stocks than their agricultural counterparts.

However, managed forests can have an even worse impact on soil quality than agriculture (Kolarek 2017), depending on the specific harvesting and processing methods. In good agricultural practice, it is usual to leave enough agricultural residues on the ground in order to ensure that soil quality is maintained. If, in contrast, the full amount of biomass is removed in SRC cultivation or forestry, this can have a stronger negative impact than good agricultural practice.

Nitrogen turnover is another indicator for soil quality as the bioavailability of nitrogen is one of the keys for plant growth (Schloter et al. 2003). Arable soils emit more N2O to the atmosphere than any other soils as microbial N2O production is rapidly stimulated by soil N inputs through fertilizers in all agro-ecosystems.

Research efforts and protocols to assess soil quality need to be established to better define the relationships between soil quality indicators and soil functions.

13.4. Conclusion

To conclude, data on water, air and soil quality are scarce allowing only for a preliminary ranking. Within these limitations, a tentative ranking has been attempted, ranking the agricultural systems and managed forest systems as posing medium risk (the impact of both are mainly dependent on specific practices such as harvesting and processing methods, and co-product handling) and all residues and wastes have been ranked best, because their impact on water and soil is low.

14. Conclusion

The analysis of twelve different sustainability criteria shows that all of the researched bioethanol feedstocks offer significant strengths as well as weaknesses for a feasible climate strategy:

- All feedstocks realise **significant reductions of greenhouse gas emissions**. While second generation fuels perform better in this regard, the performance of first generation fuels should not be ignored – especially considering the fact that a relevant part of the performance is determined by methodology choices that influence the outcome. Even based on this methodology, the GHG emission reductions of second generation fuels are strongly relativized, when offset against the abatement costs. Reducing GHG emissions through second generation biofuels is expensive – and prevents potentially more efficient climate actions that could be implemented elsewhere.

- Also with regard to the often-criticised negative impact on **food security** of first generation biofuels, the evidence points into a different direction. The competition for arable land is counterbalanced by the excellent land efficiency of first generation crops (especially sugar beet) and protein-rich co-products (especially wheat and corn). In this regard, the utilisation of short rotation coppice (SRC) for biofuels poses much stronger competition for arable land, since they use up much larger acreages of arable land and provide no protein-rich co-products.

- Several studies have come to the conclusions that the influence of biofuels on price peaks of food crops is much lower than assumed shortly after the food crisis in 2008. For a **sustainable food and feed strategy** in Europe, the protein-rich co-products of wheat processing are of utmost importance, reducing the dependence on soy imports from the Americas and preventing indirect land use changes.

- In the case of wheat, most of European ethanol production is based on grain of **non-food quality and on harvest surpluses**, not posing any competition at all, but offering additional outlets to farmers not forced any more to dump their production on world markets. In the opposite case of bad harvests and rising prices for agricultural crops, bioethanol production often does not pay off, which means that the crops are redirected towards food markets.

- While the use of forest biomass does not compete for arable land, their extensive utilisation can also have significant impacts on **biodiversity and soil quality**. Furthermore, biofuels made from lignocellulosic feedstocks create less **employment** than biofuels from agricultural crops, making the latter valuable for **rural development** in many rural areas of the EU.

- A European bioenergy strategy which focuses on **biogenic waste** is in partial contradiction to a waste strategy that targets the long-term prevention of such wastes, poses challenges in terms of availability and cost structures and can also lead to significant market distortions, since many of the so-called “wastes” have alternative applications and often have existing markets. These aspects counterbalance the obvious advantages with regard to land use and environmental issues to a certain extent.

The results clearly indicate that the systematic discrimination against first generation biofuels of the current Commission proposal is in no way founded on scientific evidence. This has also been criticised by an independent assessment of the REDII proposal (Impact Assessment Institute 2017).

On the way to a climate-friendly Europe, biofuels made from any kind of feedstock offer advantages in terms of GHG emission reductions and should indiscriminately be part of a viable transitional strategy, as long as they adhere to sustainability criteria.

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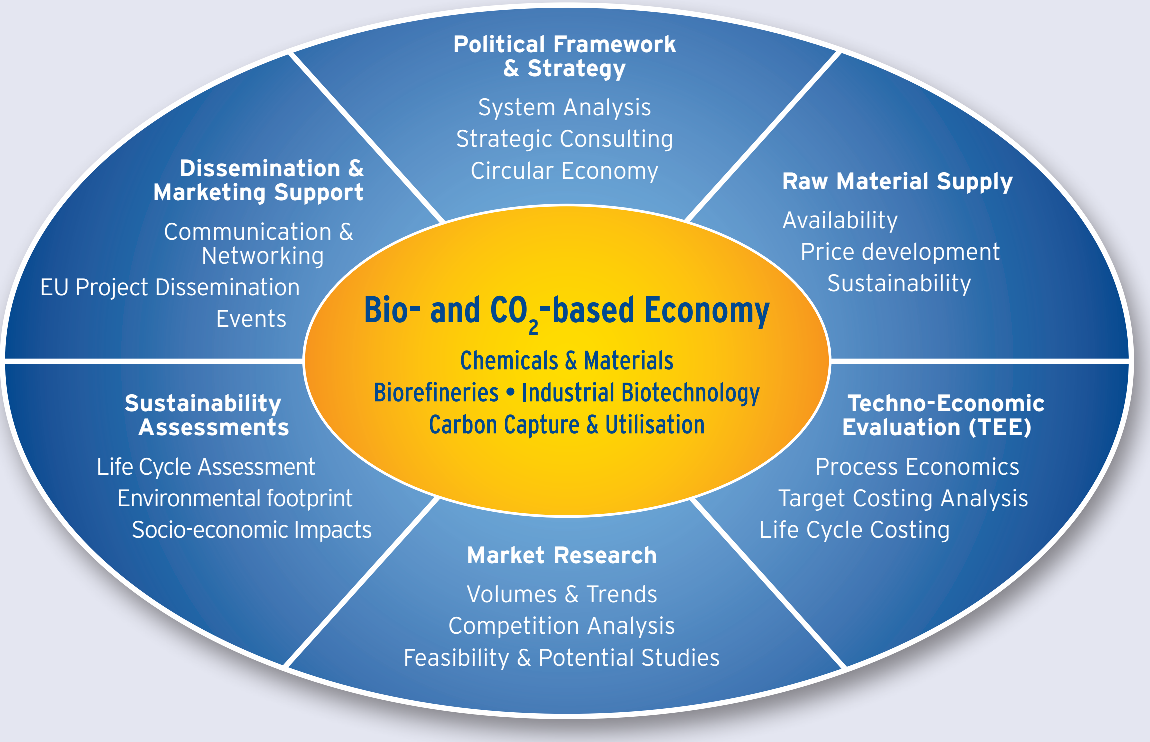

nova-Institute

nova-Institut GmbH was founded as a private and independent institute in 1994. It is located in the Chemical Park Knapsack in Huerth, which lies at the heart of the chemical industry around Cologne (Germany).

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