Sugar as Feedstock for the Chemical Industry

What is the most sustainable option?

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January 2019

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Imprint

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Publisher

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nova-Institut GmbH
Chemiepark Knapsack
Industriestraße 300
50354 Hürth, Germany

Layout
Esther Strunck

Edition
2018-07

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This study has been carried out on behalf of Südzucker AG.

1. Executive Summary

A comprehensive sustainability assessment shows that first generation sugars are as advantageous as second generation sugars for a feasible and sustainable resource strategy of Europe's bio-based chemical industry. The results clearly indicate that the negative image of first generation feedstocks portrayed in the public discussion and the concerns of certain stakeholders are in no way founded on scientific evidence.

This study was carried out in the context of shifting sugar markets as well as continuing discussions about feedstock sustainability for bio-based products and chemicals. On the one hand, the sugar quota has been abolished in 2017, making it possible to produce more sugar than ever, especially due to continuously increasing yields. In contrast to that, sugar demand in the EU from the food industry's side is expected to decrease. This means that availability of sugar is expected to increase significantly in the European market over the next few years. For the year 2017/18 already, EU sugar production increased by about 4 million tonnes while exports increased by 2 million tonnes, making the European Union a net exporter of sugar for the first time in more than a decade. With the reduction of the demand for sugar in food products, however, it may become difficult to direct the excess EU sugar production towards export markets. On the other hand, bio-based chemistry is developing more and more in Europe, which could constitute an important demand factor for sugar, since domestic sugars offer an attractive raw materials base for fermentation-based processes. However, concerns remain regarding the sustainability impacts of using so-called "food crops" (or first generation feedstocks) for anything other than food or feed applications. Instead, it is often suggested to replace these raw materials by second generation sugars from non-edible feedstocks. Cellulose and hemicellulose from lignocellulosic materials from forests, short-rotation coppice or agricultural waste, as well as biowaste can be transformed to fermentable sugars.

The study aimed at evaluating whether the concerns about first generation sugars and the claims about the superiority of second generation sugars are confirmed by evidence and has found that they are not.

Evaluation of sustainability – how to identify the most sustainable fermentable sugar?

A number of criteria were selected in order to evaluate the sustainability of fermentable sugars from first and second generation feedstocks. 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 products made from first generation feedstocks that they cause harm to food security. After analysing the existing data (both quantitative and qualitative), the performance of the respective feedstock option was assessed relative to the others to establish a ranking of the options, based on a traffic light system. Table 1: Overview of ranking results. presents an overview of the results, which are explained in more detail in this brochure. The calculations are based on the long version of a study on bioethanol nova-Institute has carried out in September 2017, "Sustainable First and Second Generation Bioethanol for Europe" (Dammer et al. 2017). More detailed background information and calculations from this study are available at www. bio-based.eu/ecology.

The results – what is the most sustainable fermentable sugar?

The analysis of twelve different sustainability criteria shows that all of the researched feedstock and sugar options offer significant advantages as well as disadvantages in terms of sustainability:

- All feedstocks realize significant reductions of greenhouse gas emissions. While second generation sugars perform better in this regard, this effect is strongly relativised, when offset against the abatement costs. Reducing GHG emissions through second generation sugars is expensive – and may prevent more efficient climate actions that could be implemented elsewhere.
- When it comes to the often-criticised negative impact on food security of products made from first generation sugars, 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 maize). In this regard, the utilisation of short rotation coppice (SRC) such as willow or poplar for fermentable sugars poses much stronger competition for arable land, since they use up much larger acreages, very often for long periods, and do not provide protein-rich co-products.

The results clearly indicate that the negative image of first generation feedstocks portrayed in the public discussion and the concerns of certain stakeholders are in no way founded on scientific evidence.

1.1 A short overview of 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 fermentable sugar per hectare. High greenhouse gas (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 savings are assumed to be lower than for the other analysed feedstock options when calculated with the official Life Cycle Assessment (LCA) methodology for biofuels, but this is only partly true and is rooted to a large part in the specific LCA standards applied in the Renewable Energy Directive (RED)[1]. 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 a high land efficiency.

Virgin Wood and SRC

The main strength of wood as a 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.

1 While the RED only applies to fuels and not to chemicals, it has established somewhat of a standard in the way that waste is accounted with zero burden of emission. This practice is therefore often also used for chemicals.

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 chemicals feedstocks are the very high GHG reductions – mostly if the specific LCA standards applied in the RED[2] are used for the calculation – 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.

Conclusion: Combine first and second generation

The highest fermentable sugar 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 by providing their own lignocellulosic co-products, without occupying additional areas and at the same time provide protein-rich feed.

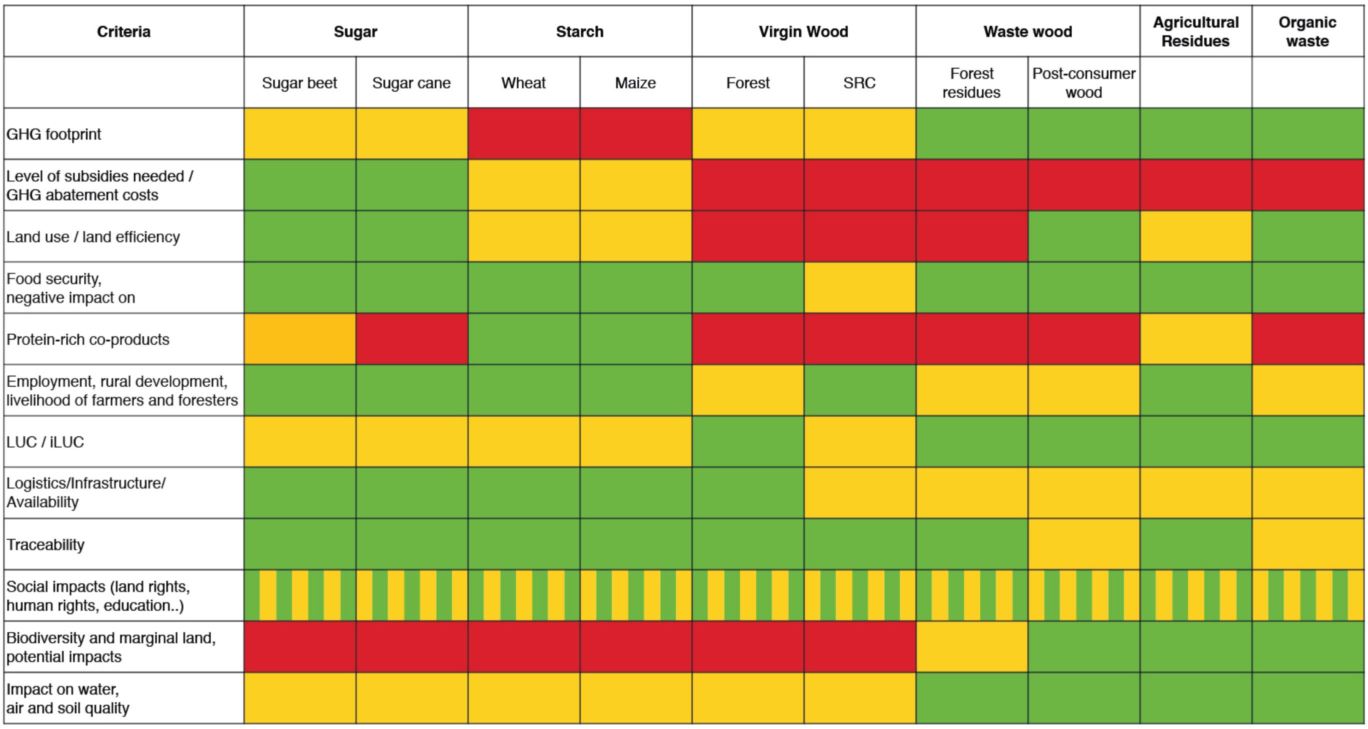

Table 1: Overview of ranking results.
Green = high performance / low risk, yellow = medium performance / medium risk, red = low performance / high risk

2 While the RED only applies to fuels and not to chemicals, it has established somewhat of a standard in the way that waste is accounted with zero burden of emission. This practice is therefore often also used for chemicals.

2. Results of the sustainability assessment

2.1. Greenhouse gas (GHG) emission reductions

One of the key questions regarding the overall sustainability of feedstock choice for the chemical industry is which kind of biomass will supply fermentable sugar at the lowest greenhouse gas emission balance: sugar beet, sugar cane, corn, wheat or lignocellulose? Is fresh biomass worse or better than agricultural residues or biowaste? Unfortunately, there are only few comprehensive studies on this subject.

The most data are available on the evaluation of the best raw material for bioethanol or other biofuels (e.g. Dammer et al. 2017). However, for these, LCA rules according to the Renewable Energy Directive (RED) are applied, although the RED standards are only partly based on science, while the other part is strongly influenced by political objectives, which in turn influences the results in a certain direction, as explained below. The comparison of GHG emission reductions from different feedstocks and processes based on the official calculations as included in the latest RED proposal (EC 2016) shows that overall, fuels from waste, farmed wood as well as agricultural residues perform the best; fuels from sugar beet and sugar cane show medium performance and grain-based fuels perform the relative lowest (Dammer et al. 2017):

"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%. … Higher savings (58-79%) are reported for the production of bioethanol from sugar cane and sugar beet, …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%. …In particular, producing ethanol from wheat straw saves 85% of GHG emissions compared to a petrochemical pathway." (Dammer et al. 2017)
However, the differences between GHG emission reductions are quite small in many cases, especially between wood-based and sugar-based fuels. And, as already mentioned, the results are heavily influenced by the calculation methods applied.

Life cycle assessments on GHG savings per tonne of bio-based chemicals for different feedstocks and chemicals came to similar results (see Figure 1: Greenhouse gas emission savings per tonne of bio-based chemicals for different bio-based feedstocks compared with their petrochemical counterparts (nova 2016, adapted from Hermann et al. 2007)). In one of the few existing more comprehensive studies, Hermann et al. 2007 found the highest GHG savings for sugar cane (both today and in the future) and for future lignocellulosics. In comparison, corn starch shows a lower GHG saving.

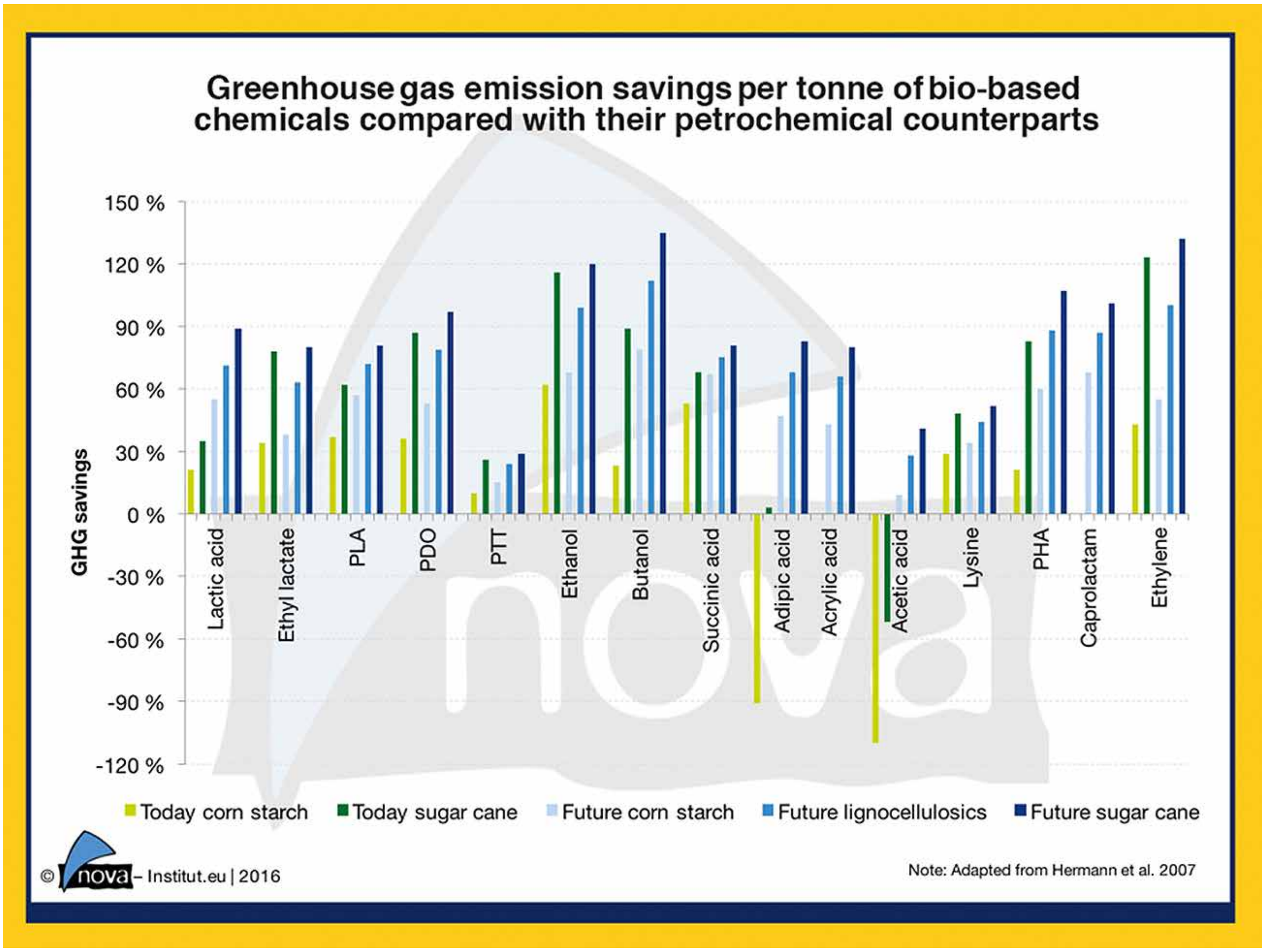

Figure 1: Greenhouse gas emission savings per tonne of bio-based chemicals for different bio-based feedstocks compared with their petrochemical counterparts (nova 2016, adapted from Hermann et al. 2007)

One of the main reasons for the excellent values of bioethanol made from waste and residues is the fact that (due to the RED standard) no emission is allocated to their production, only from the moment of collection, transportation and processing. This means for instance for agricultural residues that no 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.

In life cycle assessments for chemicals, for which the RED standard is not the first choice, and which will usually apply economic or energetic allocation[3], the GHG savings of chemicals made from waste and residues will be still good, but by far less favourable.

The effect of the different methods can be demonstrated with the example of wheat: The wheat grain accounts for about 70% of the total energy content of the harvested wheat crop, while the straw accounts for about 30%. Applying energetic allocation, sugars from wheat grain (first generation) would show 30% lower GHG emissions compared to the RED standard – and second generation sugars 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

3 The ISO 14040:2006 “Environmental management – Life cycle assessment – Principles and framework” favours system expansion over substitution and partition (which means for example economic or energetic allocation). To compare different feedstocks and pathways to fuels, chemicals or fermentable sugars, system expansion cannot be applied and in almost all cases partition is used.

generation sugars from wheat grain resp. straw in terms of GHG emissions.

Furthermore, it is crucial how the protein-rich co-products of the chemical production are accounted for: as substitutes for imported protein, or only for their energy content. Due to the RED standard, which only accounts for the energy content, the real value of the co-product is underestimated. In the US, protein substitution is the preferred accounting method resulting in higher reduction values for sugars from corn and wheat for example.

2.2 GHG abatement costs

The relatively small additional emission savings that materials from second generation feedstocks can achieve will cause significant costs to consumers and society as a whole. Put in other words, making materials from second generation feedstocks is a very expensive way to reduce GHG emissions. Figure 2 below shows a comparison of the costs of saved CO_2 equivalents for different bioethanol options. This product was chosen due to data availability.

It can be seen that focusing Europe's renewable chemicals branch solely on second generation sugars would be an expensive way to reduce GHG emissions and might prevent more efficient climate actions that could be implemented in the chemical industry (e.g. through more economical usage of first-generation feedstocks in combination with energy efficiency measures). **It is therefore doubtful whether the strong focus on second generation feedstocks for the bio-based economy is a feasible societal strategy from a climate and economic perspective.**

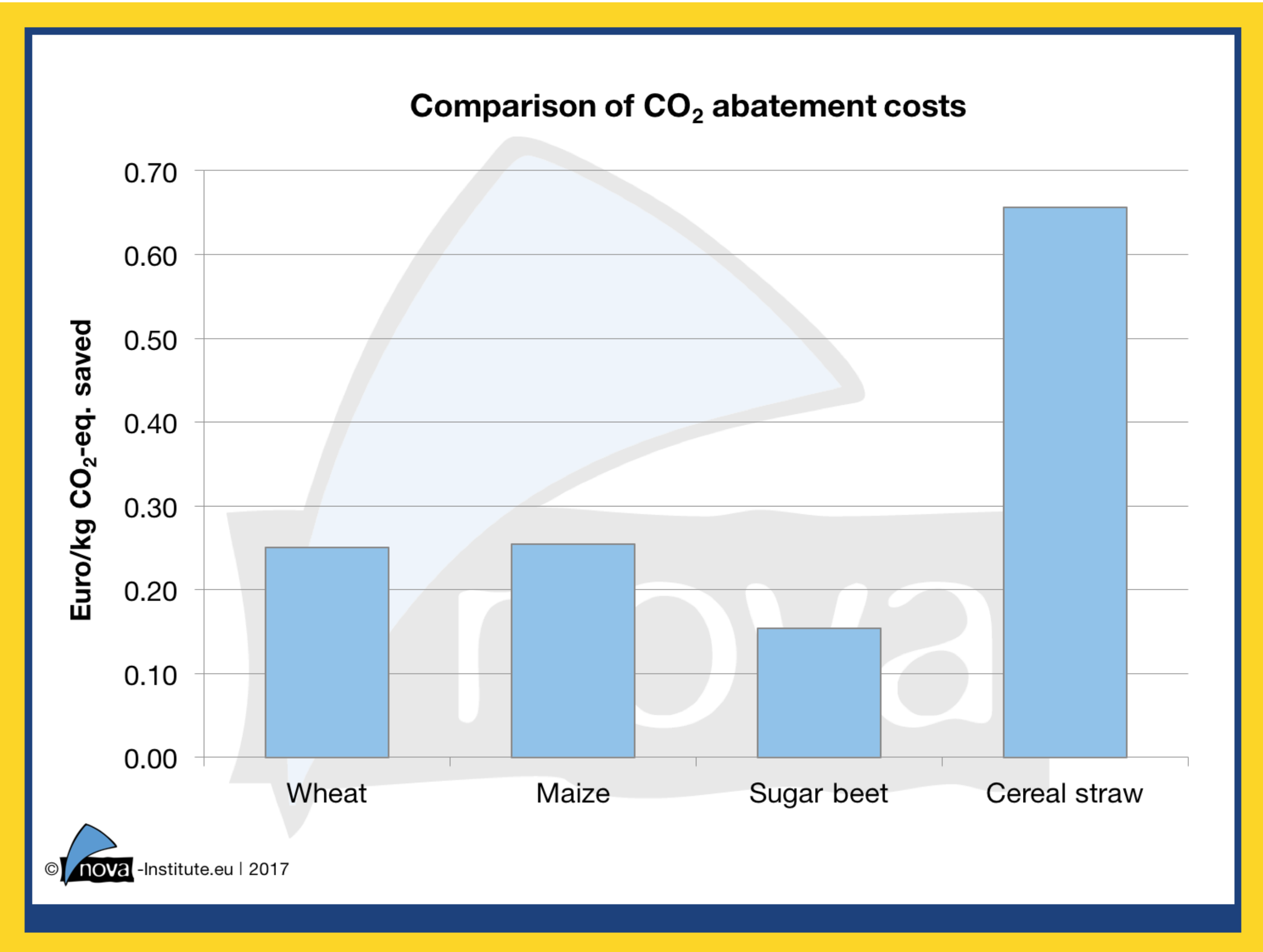

Figure 2: Comparison of CO_2 abatement costs for bioethanol from different feedstocks (source: own calculations, based on JRC 2017, Eurostat 2017, Euronext 2017 and GHG emission savings based on REDII proposal)

2.3 Land use and conversion efficiency

This criterion assesses how much fermentable sugar per hectare can be produced from different crops. This is a very important aspect, since it influences many other criteria (e.g. employment and rural development, food security, protein-rich co-products). The efficiencies were calculated by assessing hectare yields per crop, carbohydrate content and conversion efficiencies from carbohydrates to fermentable sugars (Table 2).

In the case of the lignocellulosic biomasses, pre-treatment (e.g. organosolv) leads to a loss of cellulose of about 3% (Buruiana et al. 2014 and Ragauskas et al. 2014) and hemicellulose loss of 3-5% (Kabir et al. 2015). For our calculations, we assume a maximum loss of 5% hemicellulose. In conclusion, the pre-treatment efficiency amounts to 97% for cellulose and 95% for hemicellulose.

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.

The results show that sugar beet and sugar cane perform by far the best in terms of land efficiency, producing more than five times as much fermentable sugar per hectare as the highly productive forest wood in Germany, and still more than twice as much as SRC cultivation on arable land (Figure 3).

	Extraction/ pretreatment	**Hydrolysis and recovery**	**Overall efficiency from carbohydrates to fermentable sugars**
Sucrose	100%	100%	100%
Starch	100%	100%	100%
Cellulose	97.0%	65.0%	63%
Hemicellulose	95.0%	65.0%	62%

Table 2: Assumptions for the conversion efficiencies from carbohydrates to fermentable sugars

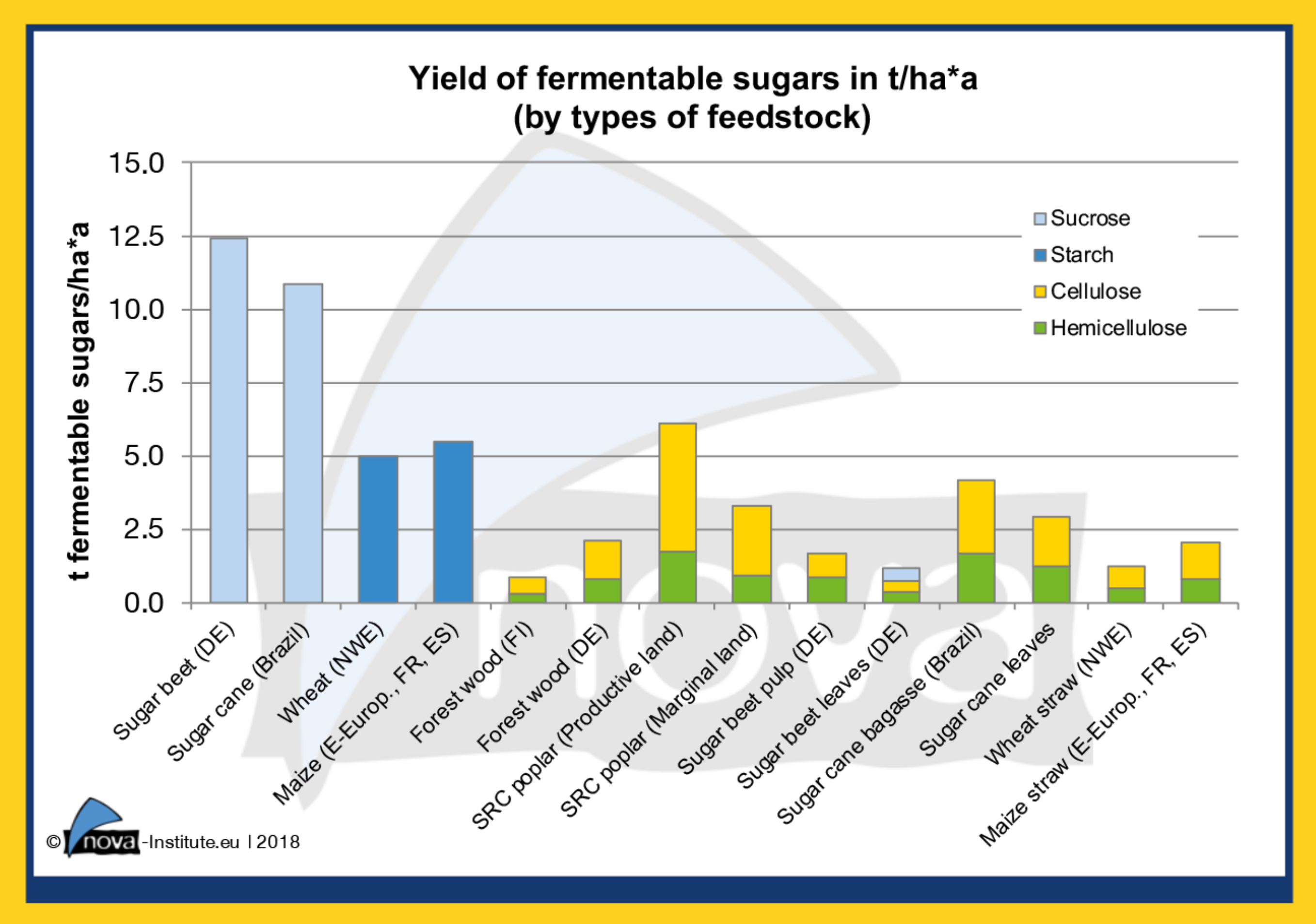

Figure 3: Fermentable sugar yield in t/ha*a by types of feedstock (source: own calculations, based on multiple sources. For details see long version.) Note: Protein-rich co-products such as DDGS and Vinasse are not considered for fermentable sugar production since they are considered feed in the section on co-products (p.16).

In addition to these results, it is interesting to see how much sugar can be produced from one hectare under the assumption that every part of a harvested crop is used for fermentable sugar production, including main products as well as most co-products (see Figure 4). Additional chemicals can even be produced if the biogenic CO_2 arising from the conversion process is further processed into methanol or other bio-based building blocks. For more details, see the long version at www.bio-based.eu/ecology.

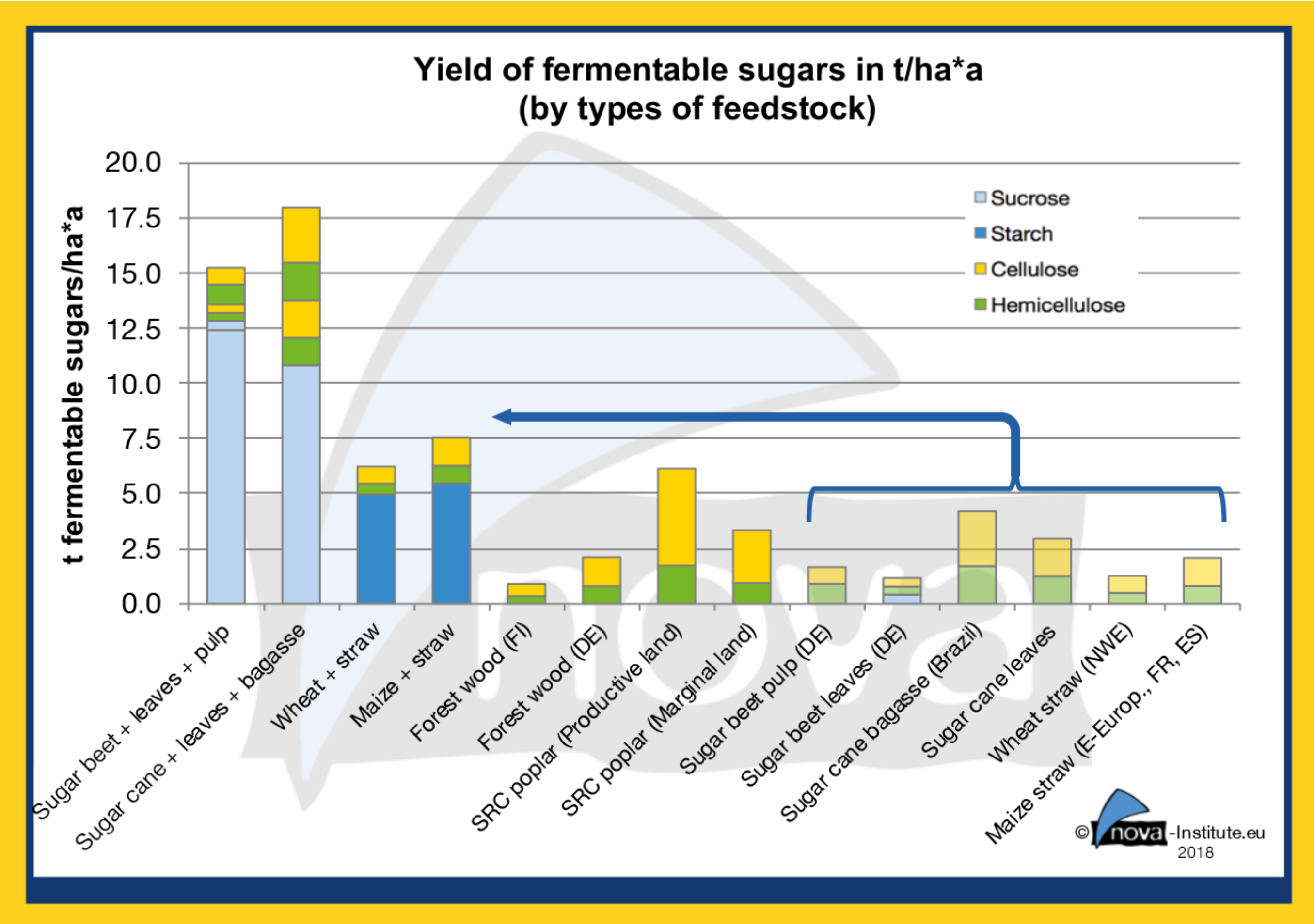

Figure 4: Fermentable sugar yield in t/ha*a for different types of feedstock assuming utilisation of main and co-products (source: own calculations, based on multiple sources. For details see long version.) Note: Protein-rich co-products such as DDGS and Vinasse are not considered for fermentable sugar production since they are considered feed in the section on co-products (p. 16).

In practice, such a maximum fermentable sugar production from the whole crop on one site is rather unlikely since the processes for 1G and 2G sugars 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 fermentable sugar, sugar beet could yield about 17 times more raw material per hectare than forest wood from Finland. Yields from wheat and maize are much less, but still 2 times higher than SRC poplar on marginal land.

2.4 Food security

There is a widely-accepted allegation that biofuels and bio-based materials consumed in Europe, which are produced from so-called “food crops”, negatively influence global food security. This assertion – and the resulting public pressure – has been the main reason for the last revision of the RED (iLUC Directive) as well as for the planned gradual reduction of biofuels from food crops to 3.8% by 2030 in the new Commission REDII proposal. Also, the bio-based chemicals sector is sometimes negatively impacted by this debate, which is mostly expressed through criticism by NGOs or scepticism from potential customers.

However, there is a significant lack of evidence to support the aforementioned claim. 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. This complex criterion has been split into four sub-criteria to allow for a more precise evaluation.

Availability of food and feed

Scarcity of resources is mainly caused by competition for land, not by the competition for specific crops. That is why from an availability point of view, the most land-efficient crops are preferable for producing a given product, be it food, feed, energy or materials. As shown by the calculations on land efficiency, first generation crops score significantly higher than second generation crops in this aspect. In many cases, cereals of non-food quality can be used for the production of bio-based chemicals and materials which offers additional income to farmers, since without this option they would have had 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. 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, waste used as a feedstock does not create any 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 (see Figure 5).

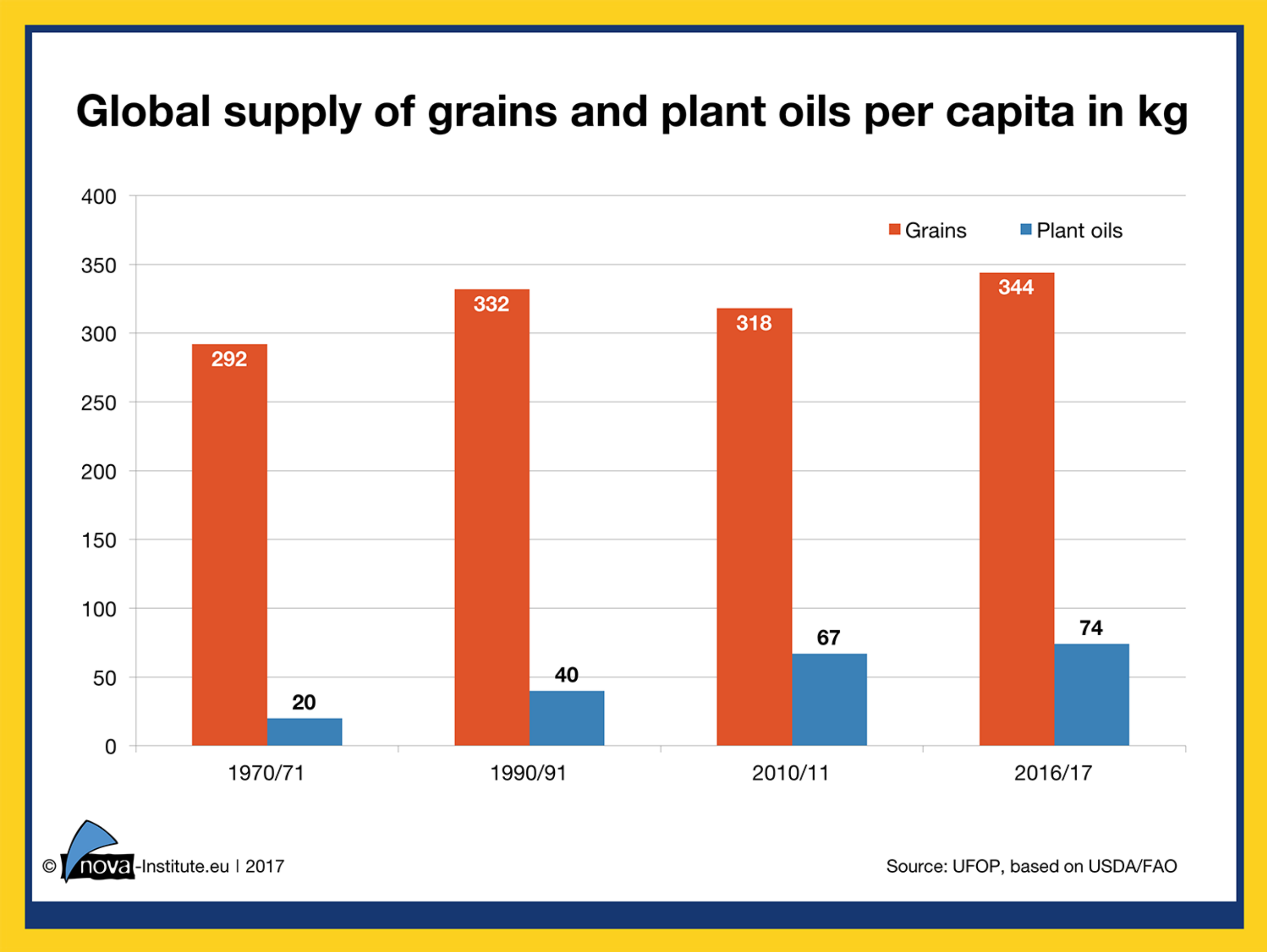

Figure 5: Supply of grains and plant oils 2016/2017, estimated (source: UFOP, based on USDA/FAO)

Influence on food prices

Several studies have come to the conclusion that the alleged influence of biofuels on the extreme increase of food prices during the crisis in 2008 was much weaker than originally assumed (for more details see the long version at www.bio-based.eu/ecology). There are no studies available checking this influence of bio-based chemicals. First and second generation feedstocks score equally in this matter, none of them having had a clear impact on food prices so far.

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)”[4], 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.

However, most bio-based chemicals are made from sugars, which are carbohydrates. When crops such as sugar beet or wheat are processed into chemicals, there is a significant amount of protein-rich co-products which are fully utilized in feed applications (see Figure 6 and Figure 7). 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. If these crops were

4 https://emedicine.medscape.com/article/1104623-overview

less cultivated in Europe due to a complete shunning of first generation biofuels and bio-based chemicals, 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[5]. Consequently, first generation feedstocks score significantly higher on this criterion than second generation sugars. Since wood- or waste-based sugars do not worsen the situation on protein supply, however, the different types of sugars have been ranked equally positively for the purpose of this analysis.

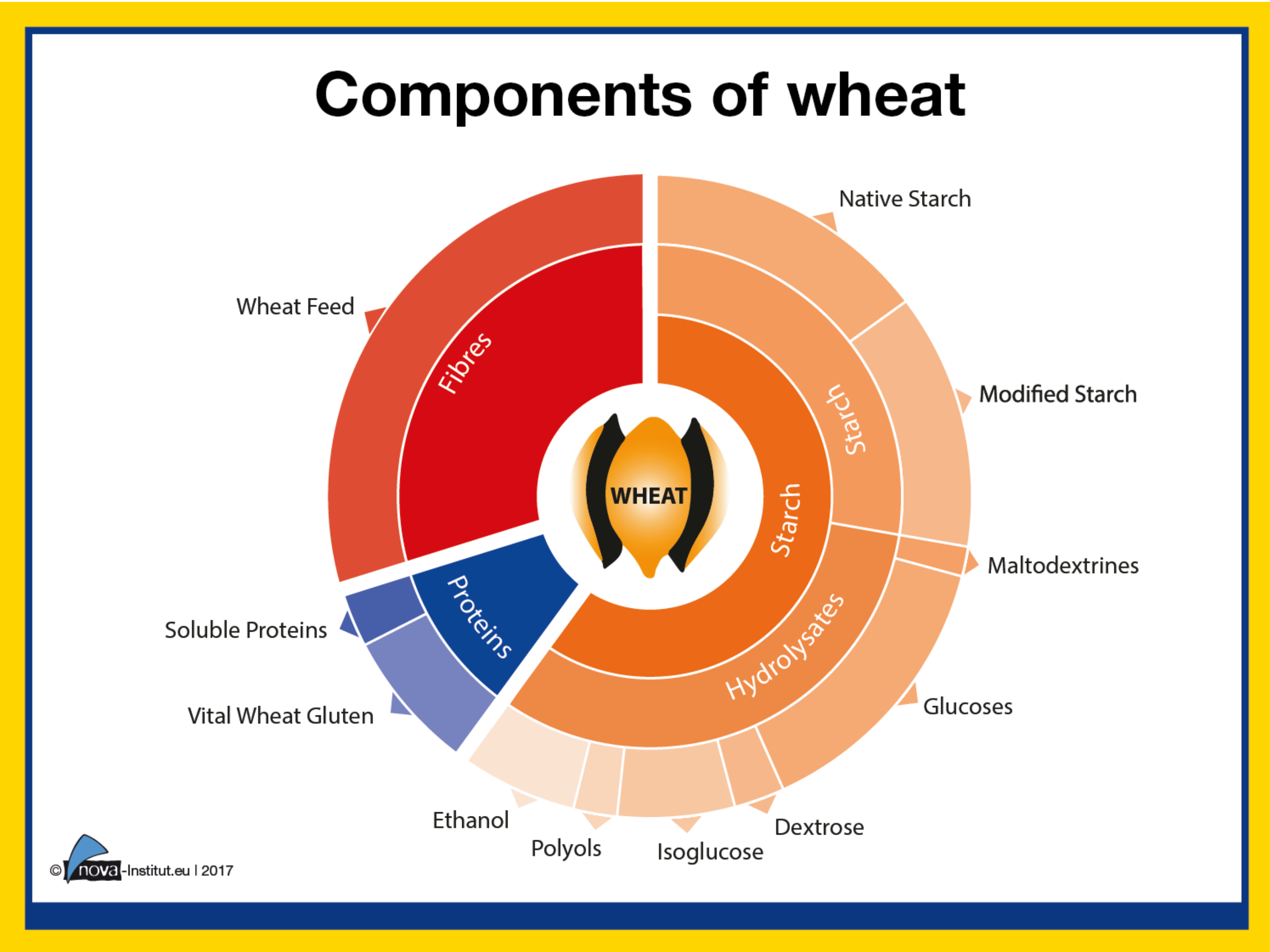

Figure 6: Components of wheat and co-products of wheat processing (source: own drawing)

5 https://www.feednavigator.com/Article/2017/07/18/More-countries-back-EU-soy-declaration

Emergency reserve

Should humankind really face a food crisis, food crops targeted to the chemical and material market can serve as an emergency reserve for food and feed supply – second generation lignocellulose could not. The latter will occupy significant amounts of agricultural land and only secure industrial supply, yet offer no emergency reserve for food supply. The lignocellulosic biomass will only feed the industry – also in a food crisis.

It is quite probable that in case of extremely rising prices on the food and feed markets, suppliers of starch and sugar will decide to sell their goods to these customers, provided there is enough flexibility in their contractual obligations. Such flexible market mechanisms can help to re-direct food crops to the food market in times of crisis.

Another aspect might be relevant too. Since the feedstocks in question are not just purchased by the chemical industry, but also by the energy sector, which is already heavily regulated, and which has a large number of alternatives (e.g. solar and wind power, electric mobility, CO_2-based fuels) at its disposition, it would be possible to implement such reallocation measures first in the energy sector. The organic chemical industry is strongly dependent on a reliable supply of sugars, which is why it should be targeted by such measures the last. Also, a general focus on strictly waste-based materials will not help to contribute to any emergency reserves. Consequently, first generation feedstocks score higher than second generation sugars due to the time factor.

Conclusion

As stated in the beginning, evidence shows that products made from first generation feedstocks do not perform worse than materials made from lignocellulosic feedstocks or from waste with regard to food security. On the contrary, they can even make positive contributions to enhancing food and feed security on a global level. 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 industrial purposes 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 justified when it comes to materials and chemicals made from sugar or starch plants.

2.5 Protein-rich co-products and others

Depending on the feedstock and process, the production of one tonne of fermentable sugar 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 or energy. As shown by Figure 7, 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 maize have been ranked as highest performing, while sugar beet was ranked as medium performing.

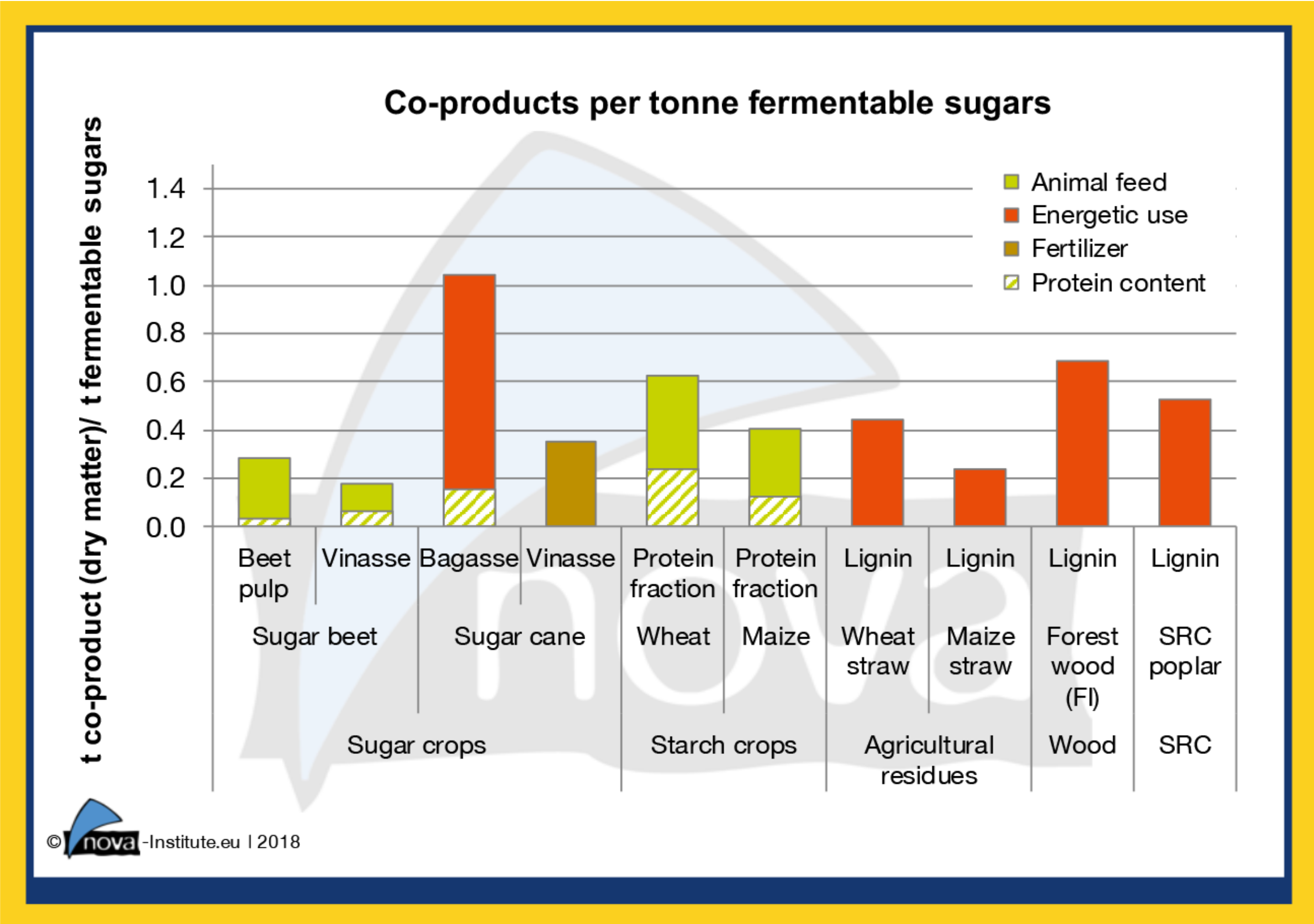

Figure 7: Co-products per t of fermentable sugar depending on feedstock and process (source: own calculations, based on Hansa Melasse 2017, Soccol et al. 2016, Costa et al. 2015, Heuzé et al. 2017, Heuzé et al. 2015 and Wirsenius 2000).

2.6 Employment and rural development, livelihood of farmers and forest workers

Our calculations based on Eurostat and FAOSTAT came to the conclusion that fermentable sugars from crops requiring agricultural cultivation (or semi-agricultural cultivation as in the case of SRC) create more direct employment per tonne of fermentable sugar than woody and waste-based sugars (Figure 8). The direct employment created in sugar processing (about 0.001 FTE/t sugar) is roughly in line with figures from Ostwald et al. (2017). Indirect and induced employment effects have not been taken into account in the present study. Ostwald et al., however, compared direct, indirect and induced economic effects of the Südzucker AG and came to the conclusion, that in the period 2010/11 to 2015/16, indirect and induced effects multiplied direct employment effects by a total factor of 7.2-11.6 in Germany and 8.0-11.4 in Europe (Ostwald et al. 2017).

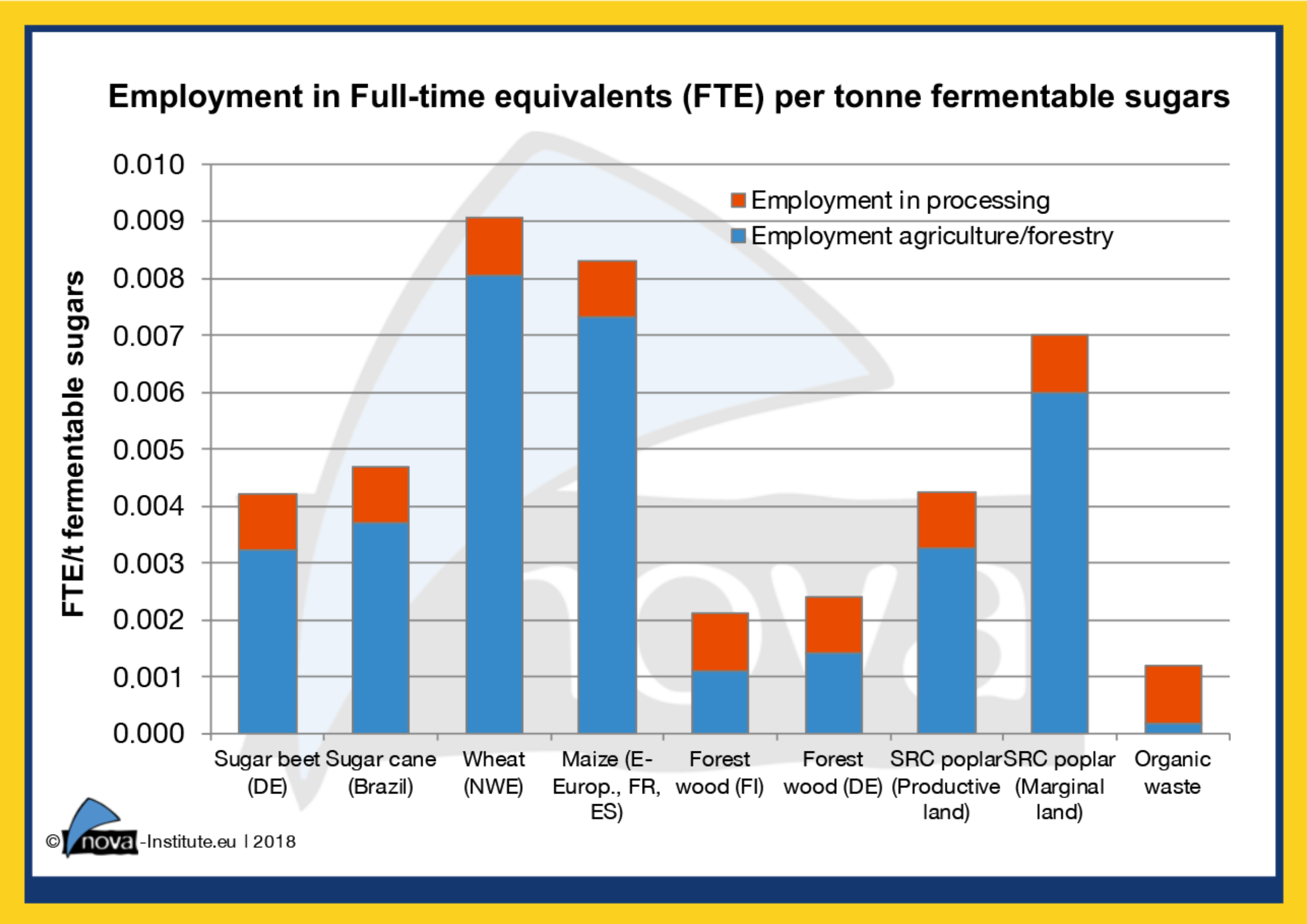

Figure 8: Direct employment generated per 1 t of fermentable sugar in full time equivalents (FTE) (sources: Eurostat, FAOSTAT) Notes: FR = France; NWE = North-West Europe (Germany, Belgium, The Netherlands, France, Sweden, Great Britain); E.-Europ. = Czech Rep., Poland, Hungary; ES = Spain; FI = Finland; DE = Germany.

Producing bio-based chemicals from agricultural crops also helps to reduce agricultural land losses, thereby contributing significantly to stabilising the livelihood of farmers, especially when markets for agricultural products are fluctuating strongly. Since bioeconomy facilities such as biorefineries are mostly built in rural and structurally weak areas, their establishment contributes to the prosperity of the region since the revenue from additional direct jobs will increase purchasing power and benefit other sectors.

Bio-based chemicals from sugars from woody biomass would also support jobs in rural areas, however not to the same extent as materials from agricultural residues or SRC. Therefore, products made from wood-based sugars have 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.

2.7 Land use change (LUC/iLUC)

Land use change effects (both direct and indirect) have so far mostly been calculated for fuel options in the public debate, which is why the study refers to these somewhat 'official' values. Due to methodological uncertainties, it is quite difficult to pinpoint exact affects anyway and any LUC/iLUC assessment should be seen more as a type of "risk assessment". The results based on Laborde (2011) and the "ILUC Directive" (2015/1513) 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.

2.8 Availability and infrastructure

In terms of existing infrastructure, first generation sugars 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. In addition to these constraints, availability of waste feedstocks for biofuels needs also to be considered in competition to other uses. For many feedstocks, there are higher value-adding applications, e.g. in material and chemical industries. 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. It should be noted that there is a significant difference in competition for these feedstocks than for agricultural crops: wastes and co-products only occur in limited volumes as they are dependent on the related production process. They can therefore be seen as 'scarce' resources. Artificially increasing the volumes of such wastes would be directly counterproductive to the European waste hierarchy, which has as its top priority to avoid the creation of waste. Agricultural crops, however, can be grown according to demand and do not create artificial competition and market distortions. Furthermore, it is very questionable to build a long-term industrial and climate mitigation strategy on feedstocks that will be dependent on significant subsidies for an infinite time in order to counterbalance this competition.

2.9 Traceability of feedstocks

For biofuels, there is a regulation that all feedstocks need to provide proof of origin through mass balance certificates. For virgin materials such as agricultural crops or forest biomass, this is relatively straightforward and well implemented. For waste, however, there can be problems with traceability. Often, there is 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 China, for example, has proven to be complex and elaborate, if possible at all.

For bio-based chemicals, there is no obligation such as for biofuels in place. Certification is a voluntary measure used by more and more producers to be on the safe side. In these

cases, the difficulties will be similar to the biofuel situation.
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.

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

The potential social impacts of bio-based materials 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. Therefore, the impact risk of a given feedstock is more dependent on whether it is won from a domestic source or not, and if it is imported, whether a sustainability certification is provided or not. Since this cannot be determined within the scope of this study, the risks for all feedstocks were assumed to be low-to-medium (green/yellow).

The chemical industry can contribute to reducing the risks of negative social impacts and public concerns of the bio-based industry by using more domestic and/or certified feedstocks. A slight minus is the absence of social criteria from the mandatory sustainability criteria imposed by the RED which dominate the market on biomass certification; only some of those voluntary certification systems have implemented social criteria. It should be noted that for certification systems only operating in Europe, such criteria might not be necessary since social issues are usually governed by legislation. And since the certification schemes that do include social aspects (ISCC, RSB, Bonsucro) represent the overwhelmingly largest share of the global market of bio-based feedstocks, the lack of social criteria from the RED is not seen as a major problem. In conclusion, all feedstocks were ranked equally high.

2.11 Biodiversity

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 from agriculture or forestry (for more details and sources see long version of Dammer et al. 2017). 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 fermentable sugar 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 bio-based chemicals 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 practises in agriculture and forestry can differ significantly. Forest residues show medium risk and all waste materials low risk.

2.12 Impact on water, air and soil quality

Data about the impact of different fuels 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 impacts 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.

3. Conclusion: What does this mean for Europe's bio-based chemical industry?

The analysis of twelve different sustainability criteria (for background information and detailed calculations see Dammer et al. 2017) shows that all of the researched feedstocks of fermentable sugars offer significant strengths and weaknesses for a feasible climate strategy:

- All feedstocks of fermentable sugars realise significant reductions of greenhouse gas emissions. While second generation sugars perform better in this regard, the performance of first generation sugars should not be ignored – especially considering the fact that a relevant part of the performance is determined by methodology choices that influence the outcome. The GHG emission reductions of second generation sugars are strongly relativised, when offset against the abatement costs. Focusing Europe's renewable chemicals branch solely on second generation sugars would be an expensive way to reduce GHG emissions and might prevent more efficient climate actions that could be implemented in the chemical industry (e.g. through more economical usage of first-generation feedstocks in combination with energy efficiency measures). It is therefore doubtful whether the strong focus on second generation feedstocks for the bio-based economy is a feasible societal strategy from a climate and economic perspective.

- Also with regard to the often-criticised negative impact on **food security** of materials made from first generation feedstocks, 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 maize). In this regard, the utilisation of short rotation coppice (SRC) for bio-based chemicals and materials poses much stronger competition for arable land, since they use up much larger acreages of arable land and provide no protein-rich co-products. Furthermore, food crops targeted to the chemical and material market can always serve as an emergency reserve for food and feed supply.

- While there are no dedicated studies to check this for bio-based chemicals and materials, several studies have come to the conclusion 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.

- Most bio-based chemicals can be produced from 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, chemical 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, chemicals and materials made from lignocellulosic feedstocks create less **employment** than products from agricultural crops, making the latter valuable for **rural development** in many rural areas of the EU.

- A European industrial strategy which focuses on **biogenic waste** is in part a contradiction to a waste strategy that targets the long-term prevention of 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 negative image of first generation feedstocks portrayed in the public discussion and the concerns of certain stakeholders are in no way founded on scientific evidence.

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

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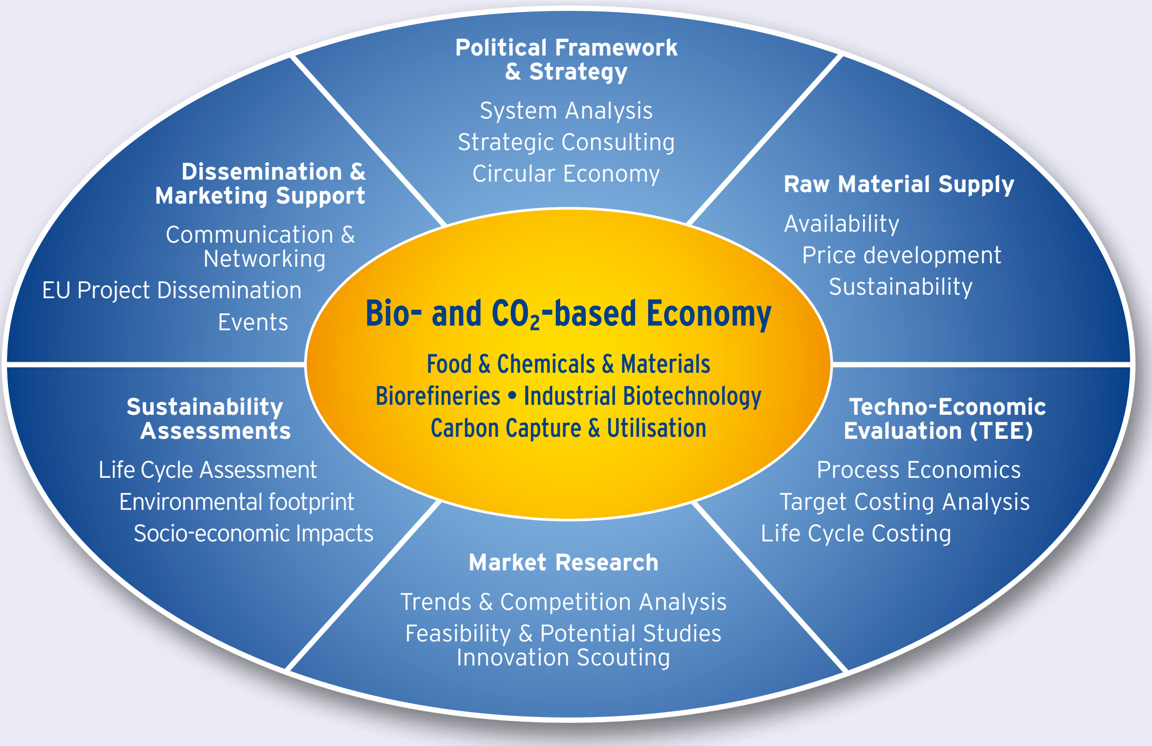

nova-Institute

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).

For the last two decades, nova-Institute has been globally active in feedstock supply, techno-economic and environmental evaluation, market research, dissemination, project management and policy for a sustainable bio-based economy.

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