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PAPER

The Use of Food and Feed Crops for Bio-based Materials and the Related Effects on Food Security

Promoting Evidence-based Debates and Recognising Potential Benefits

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1 Foreword

In 2023, the world faces a global hunger crisis. According to the World Food Programme, "a record 349 million people across 79 countries are facing acute food insecurity – up from 287 million in 2021. This constitutes a staggering rise of 200 million people compared to pre-COVID-19 pandemic levels. More than 900,000 people worldwide are fighting to survive in famine-like conditions. This is ten times more than five years ago, an alarmingly rapid increase" (WFP 2023).

Debates about biomass use and food security should be based on rationality and evidence

Against this backdrop it may seem misanthropic to publish a paper challenging the widely held view that the use of food and feed crops for anything other than food and feed uses – namely, for bio-based chemicals and materials – is detrimental to food security. However, we aim to show that the biomass debate is flawed, subjective and not based on evidence – and as a result, distracts from much more powerful causes of hunger in the world. These are to a large extent climate change, conflict, extreme inequalities in wealth distribution, heavy dependence on food imports from industrial countries, overconsumption of meat, losses along the value chain and the impact of the COVID pandemic (WFP 2023).

The use of biomass for industrial applications, on the other hand, has the potential to replace fossil feedstocks and thus contribute to the urgently needed reduction of fossil carbon emissions into our atmosphere to mitigate climate change. While not denying the dire need to combat world hunger, the authors of this paper argue that using food and feed crops for chemicals and materials will not necessarily exacerbate food insecurity, and in fact has the potential to address one of the leading causes of that insecurity – climate change. The environmental benefits outweigh the potential negative impacts, if done right.

2 Executive Summary

The paper addresses the nexus between the use of food and feed crops for industrial applications, such as chemicals and materials, and the resulting impact on food security. There is a widely held view that non-food applications – meaning biofuels and bio-based materials – of edible crops negatively impact global food security. This argument is most prominent in the fuel and energy debate, but is increasingly applied to chemicals and materials. In this paper, we argue that the cultivation and use of food and feed crops for bio-based materials is not in itself detrimental to food security and can even have positive effects.

To combat hunger, we need to urgently mitigate climate change

The greatest challenge that humanity is currently facing is climate change, which is already one of the leading causes of hunger. To tackle climate change, it is vital that the world reduces its use of fossil resources. While this is possible through decarbonisation in the energy and fuels sector, this strategy is not feasible for organic chemicals and materials, since they are made from carbon-based molecules. In other words, carbon-based fuels can be replaced by other forms of energy, but carbon-based chemicals and materials cannot. Other strategies are therefore needed to transform the chemical and material industries into climate-friendly sectors. Bio-based materials can be an important part of these efforts, since they are made from plants that have absorbed CO_2 from the atmosphere during their growth phase, therefore not adding any embedded fossil CO_2 emissions to the atmosphere at their end of life.

This need to include bio-based solutions in the chemicals and materials sector is a critical part of the overall in the fight against climate change and the transition to a non-fossil carbon future. We therefore urge caution in making direct comparisons between biofuels and bio-based materials. Furthermore, the use of crops grown on arable land – both edible and non-edible – for material purposes is as old as humankind and an important traditional economic factor. It has never been controversial and a slow, gradual shift is not expected to cause major disruptions and price increases. Another important factor is the absence of subsidies for innovative materials in the bio-based chemicals and materials sectors, which means that any shift will take place gradually and without abrupt market effects.

Our analysis shows that using biomass cultivated on agricultural land for purposes other than food and feed does not in itself have a negative impact on food security. On the contrary, growing sustainable, land-efficient food and feed crops can have multiple benefits for local and global food security, climate mitigation and for other factors:

1. The climate wins. There is a need to shift away from fossil feedstocks to achieve climate change mitigation. Bio-based materials are part of the solution and can thus help to mitigate one of the leading causes of hunger in the world.

2. Land productivity wins. The competition between applications is not for the type of crop grown, but for the land. The overall availability of arable land, and therefore food and feed on the planet determines what is possible and what is not. Food and feed crops offer high yields through long-term optimisation and a variety of co-products used simultaneously in a variety of applications, making the most out of the available land.

3. The environment wins due to increased resource efficiency and productivity of food and feed crops and the reduced land area, especially if agricultural practices are improved to better respect soil health and ecosystems;

4. Farmers win because they have more options for selling stock to different markets (food, feed, biofuels, material industry) and therefore more economic security. This can increase investment and ultimately the availability of arable land and ensure sustainable rural development to maintain EU agriculture;

5. Market stability wins due to increased global availability of food and feed crops, reducing the risk of shortages and speculation peaks. The influence of biofuels and bio-based materials on food prices is negligible;

6. Feed security wins due to the high value of the protein-rich co-products of food and feed crops (which can also be used to supply protein for human nutrition);

7. Food security wins due to the increased overall availability of edible crops that can be stored and flexibly distributed in times of crisis (emergency reserve), actually mitigating risks of supply-cycle triggered regional hunger events.

"The bigger picture is not the specific issue of whether food or nonfood crops are being used to produce biomaterials, but rather the integration of any feedstock for biomaterials production into a landscape and its social, environmental, and pricing effects there" (BFA 2022). The choice of feedstock in any given case depends on many factors and is site specific. There is no "one-size-fits-all" solution.

3 Introduction

The world needs to phase out fossil fuels. Bio-based materials are part of the solution as they can substitute fossil-based materials

To tackle climate change, the world needs to step up its efforts and decrease its dependence on fossil resources – and do it sooner rather than later. While this means decarbonisation in the energy sector, this strategy is not feasible for organic chemicals and materials, since they are made from carbon molecules. Therefore, other strategies are needed to transform the chemical and material industries into climate-friendly sectors. Bio-based materials can be an important part of these efforts as they can substitute fossil-based materials, next to recycled and CO_2-based materials. Bio-based materials are made from plants that have absorbed CO_2 from the atmosphere during their growth phase and do therefore not add any embedded fossil CO_2 emissions to the atmosphere at their end of life.

Bio-based materials are a versatile group of products that are used in manifold applications, ranging from packaging, durable plastics, textiles, detergents and fine chemicals to lubricants, building materials and a wide range of consumer products. Bio-based materials can be derived from a multitude of forming processes. This includes chemicals and materials made from fermentation or other chemical, biological or physical conversion processes as well as materials from wood and fibres that make use of larger structures of the biomass. The feedstocks used for the many different materials can differ widely, too: Sugar cane and sugar beet as the main sugar crops; corn, wheat, cassava as the main starch crops; oil crops such as palm and rapeseed; wood; fibre crops such as cotton, jute, flax and hemp; and all kinds of biogenic by-products, residues and waste or even marine biomass from macro- and microalgae are in principle usable in one way or another. This paper focuses mostly on uses of carbohydrates (mainly sugar and starch) as well as oil crops.

Biomass use is often criticised due to food security concerns

There is a widely-accepted assertion that non-food applications – meaning biofuels and bio-based materials – of biomass, which are produced from food and feed crops negatively influence global food security. This argument – and the resulting public pressure – has been the main reason for the several revisions of the Renewable Energy Directive (RED) capping the production for biofuels from food and feed crops. The pressure is also felt in the material sector, which is now often asked by customers and authorities to shift to so-called second- and third-generation feedstocks, i.e. ligno-cellulosics, biogenic waste or algae.

We describe in this paper that the cultivation and use of food and feed crops for bio-based materials are not detrimental to food security per se and in turn can even have positive effects and provide opportunities to accelerate the targeted green transition.

Lack of evidence that using food and feed for bio-based materials leads to hunger

There is a significant lack of evidence to support the argument that using food and feed crops for anything other than food or feed as such leads to hunger (see chapter 7). On the contrary, there are several arguments that the opposite may be the case and food and feed crops grown for other purposes can also contribute to increased food security on a global level – under the right framework conditions.

It should be noted that this paper focuses on the specific aspects related to food and feed crops being used for industry and why they are not per se worse than other feedstock options such as second generation or wood in terms of their impact on food security. It does not intend to comprehensively analyse the complex causalities that support or endanger food security, which are related to climate change, international politics, subsidised food exports, significant food losses across supply chains, unbalanced distribution of wealth between the global North and South and more. Neither is this paper aiming to provide a comprehensive analysis of biomass availabilities and potentials to evaluated how much demand in the different sectors can be covered.

First- and second-generation crops

Food and feed crops are defined as edible crops grown on arable land. The term “first generation crops” often refers to the edible parts of these crops (e.g. carbohydrates and oils). “Second generation crops” refers to lignocellulosic crops, such a forest wood or fibre crops, but can also stem from food and feed crops. Then, the term refers to the non-edible lignocellulosic part of these crops which are generally “by-products” such as straw or leaves that traditionally are not utilised to a large degree, but either used as animal bedding, burned or left on the field for soil health. Food and feed crops therefore provide both “generations” of biomass in one plant and are best to be considered as part of an overall biorefinery which processes agricultural inputs to a range of products – carbohydrates, fats, proteins and cellulose – which have utilisation across food, feed, materials and energy. It should be noted that most of the discussion between first, second and third-generation utilisation refers to the carbohydrate (starch/sugar) parts of the plants, since these can be replaced also with lignocellulosic biomass. For plant oils, there is no real alternative from other (non-oil) plants, which is why most of the paper focuses on the comparison of different sources of carbohydrates. However, oil plants represent a significant share of feedstocks for bio-based chemicals in the oleochemistry and their use is beneficial in various regards, which is why they are also included to a lesser extent. For all biomass components, use of by-products and wastes presents opportunities in terms of sustainability.

Energy can be decarbonised, but for materials and chemicals, carbon will always be needed

A general issue that should be kept in mind when reading the paper is also that while carbon-based fuels can be phased out in the long run, since the use of liquid fuels in car transport can be replaced by electromobility or hydrogen, there is no such option of decarbonisation for chemicals and materials – they can only be defossilised. So, we urge to apply caution when directly comparing biofuels and bio-based materials. Another important factor is the current absence of subsidies for innovative materials in the bio-based chemicals and materials sectors, which means that any shift will take place gradually and without abrupt market effects.

Residues and waste are sustainable feed-stocks, but have limitations

It should also be clear that we do not argue that using food and feed crops for industry is always the most sustainable solution. Using alternative bio-based raw materials, especially from residues, waste or perennial crops cultivated on marginal land, may often be superior from a pure sustainability perspective. They have other limitations, though, for example in availability and economic viability.

The situation is complex – multiple comparisons and assessments needed to decide on the 'best' crop

And in several contexts, due to the strong conviction that using food and feed crops for non-food applications is 'bad' per se, the focus has shifted to using lignocellulosic crops cultivated on arable land in so-called short rotation coppice (e.g. in European research programmes) – which even exacerbates competition for land, due to low yields in fermentable sugars compared to sugar beet. The situation is complex and multiple assessments must be made to decide on the 'best' crop for a specific industrial process and application.

4 The need to shift away from fossil feedstocks

Approx. 72% of GHG emissions stem from fossil fuels. Renewable energies and renewable carbon will enable defossilisation

Both traditional and innovative uses of bio-based feedstocks in organic chemicals and materials replace fossil resources. Using the latter is the main reason for global warming and the resulting change in our climate. According to recent climate statistics, approximately 72% of all greenhouse gas (GHG) emissions that cause global warming stem from fossil feedstocks (Olivier and Peters 2019, in line with latest IPCC reports). This means that a drastic shift away from fossil feedstocks is a core element of any strategy seriously aiming to reduce climate change to a minimum and stay within the 1.5° goal of the Paris agreement. While electrification can lead to an almost complete decarbonisation in the energy sector, this is not possible for the chemical and material industries that need carbon in their molecules – see potential demand developments in Figure 1. Here, a shift to alternative, renewable carbon sources is the corresponding strategy. Renewable energies and renewable carbon will enable the defossilisation of our economic system (see Figure 2, and for more details see Kähler et al. 2023).

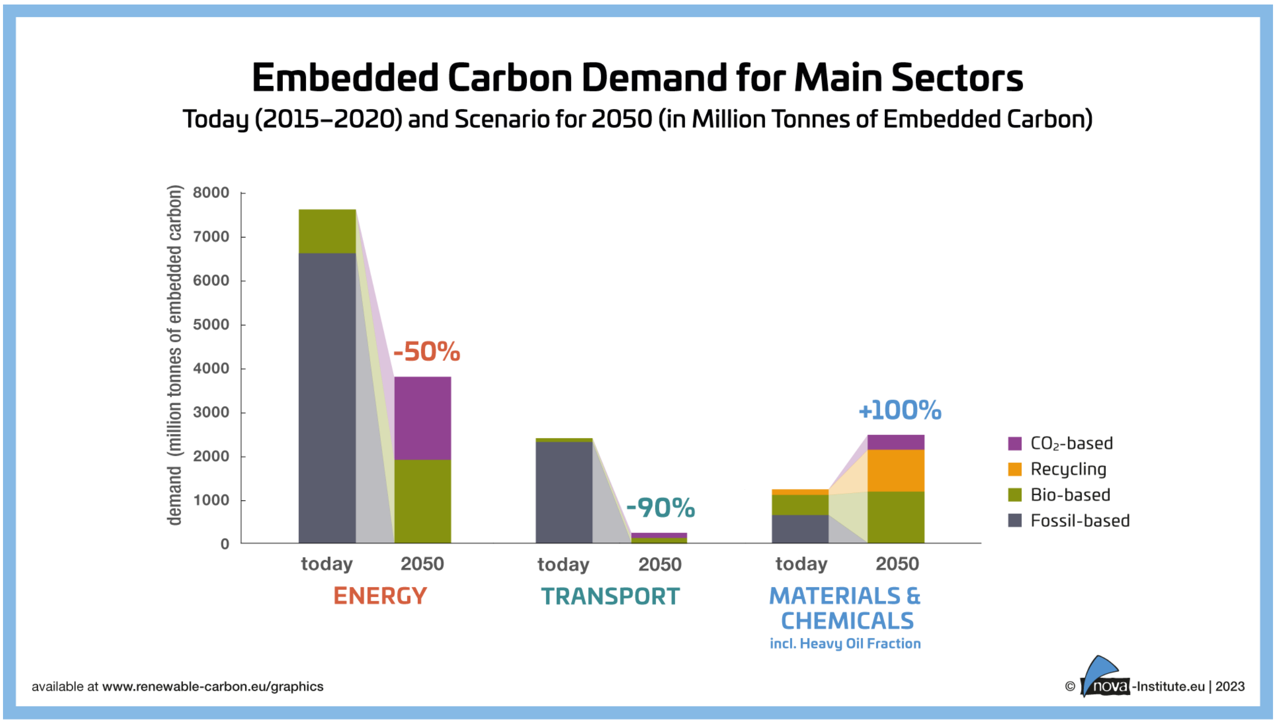

Figure 1: Embedded carbon demand for main sectors, today and 2050 (Source: Kähler et al. 2023)

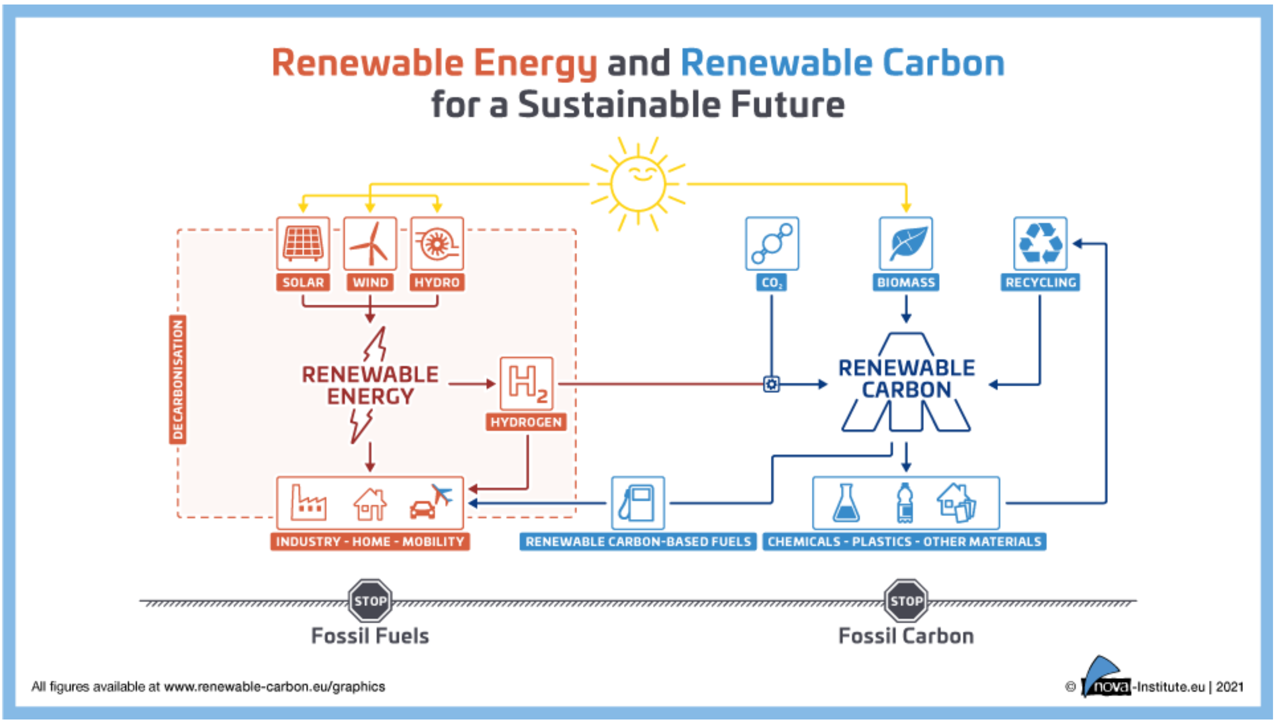

Figure 2: Renewable energy and renewable carbon for a sustainable future (Source: nova-Institute 2021)

Biomass is one of three available renewable carbon sources and will continue to play an important role in chemicals and materials

As Figure 1 shows, biomass is one of the three available renewable carbon sources – direct CO_2 utilisation and recycling being the other two. While the potential of biomass is limited by the availability of arable land, it does and will still have a role to play in the substitution of fossil resources, as this material stream is available, produced from existing and efficient agriculture and technologies for utilisation have been commercialised at scale. As mentioned above, their role in energy and fuels will be limited and increasingly substituted by electrification and hydrogen with other renewable sources. But in the materials sector, their contribution will be continuous, growing and valuable. For an efficient transition to a more bio-based chemicals and materials industry that can become as climate friendly as possible in the shortest possible time, it is of utmost importance to keep feedstock options open and flexible, always ensuring that sustainable cultivation and extraction is given. Sustainability considerations are complex (see section 6), but no feedstock should be excluded a priori.

Mitigating climate change and improving food security are two sides of the same coin

Mitigating climate change and improving food security are two sides of the same coin. Next to the COVID-19 pandemic and conflicts, climate change is still the main cause for hunger in the world, which is confirmed by a host of research and data (World Food Program 2022a, IPCC 2019, FAO 2021, FAO 2015). "If average global temperature rises by 2°C from pre-industrial levels, an additional 189 million people are expected to be pushed into hunger. In a 4°C warmer world, this figure could rise to a staggering 1.8 billion" (World Food Program 2022b).

Thus, any solution can be considered generally beneficial to food security that will help to mitigate the increase in world temperatures – if implemented responsibly and sustainably. As such, the use of biomass as an alternative to fossil resources in chemicals and materials can help to improve food security in the medium or long run.

5 Availability of biomass for different applications

5.1 Worldwide land use

Using biomass is limited by land availability and other environmental factors

While biomass can play a valuable role in replacing fossil resources, its potential is limited by the availability of arable land and yields as well as biodiversity loss and other environmental factors such as water use, eutrophication, etc. 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.**

Food and especially animal feed are by far the biggest uses of biomass today

In the current use of arable land, food and feed are by far the priorities for biomass use, followed at a distance by bio-based products, bioenergy and biofuels. Figure 3 shows the use of the 11 billion tonnes of biomass harvested (including grazing) worldwide in 2020. Animal feed predominates with a share exceeding 70%, which is expected to increase even further due to growing meat consumption. "Material use" in the graph includes harvested agricultural biomass use in the chemical sector, the pulp and paper sector (without wood, only starch), for natural fibres (predominantly cotton) and animal bedding.

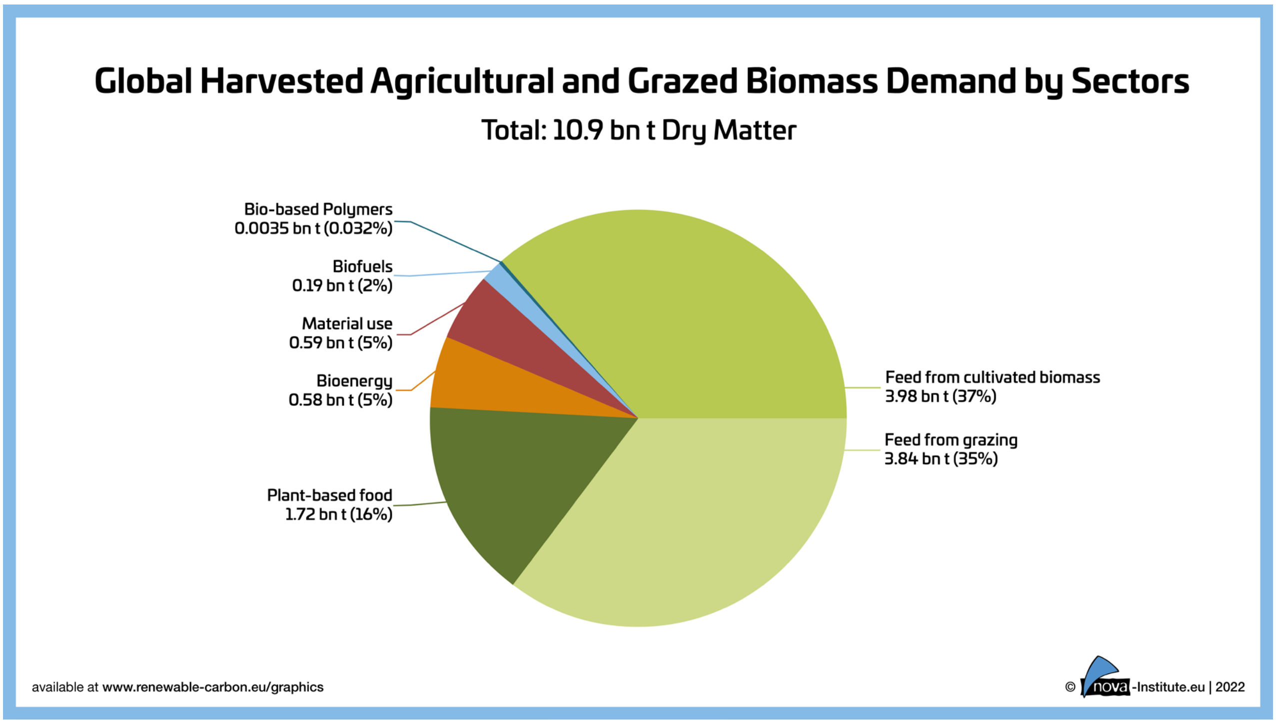

Figure 3: Worldwide allocation of biomass, including grazing, by production target (main product) in 2020. Respective amounts include raw materials and their by-products, even if their uses fall into different categories (Source: Partial update of Piotrowski et al. 2015 (own calculations 2022))

Arable land should be used both efficiently and sustainably

Food and feed crops show much higher yields than lignocellulosic crops

With arable land being the limited resource that it is, it should be used most efficiently and sustainably, aiming at keeping soils fertile and restoring degraded land. Figure 4 shows impressively that food and feed crops have a very high land efficiency, especially if the co-products are used as well. To allow for comparability, we converted all yields to fermentable sugar yields that can be used for fermentation processes in the chemical industry. Forest wood is included in Figure 4, since it is often discussed as a second-generation option for obtaining fermentable sugars. There are also other highly efficient first-generation crops, such as plant oils, which are not included in the figure due to comparability reasons, since they cannot be converted to fermentable sugars. Their usable fractions consist mainly of oil and proteins (see also section 9), which make them extremely valuable for a variety of material applications and the food and feed sector. The land efficiency of food and feed crops is not surprising, considering that these have been cultivated and bred for millennia. They are optimised for crop rotation and to regional climates and in all cases they all deliver multiple components such as carbohydrates, proteins, oils, fibres and more (see also section 9). It is rightly criticised that the "high input / high output" system for today's crop cultivation often leads to losses in soil fertility and degraded land. There is high potential for modifying agricultural systems to become more sustainable, which we illustrate in chapter 5.2.

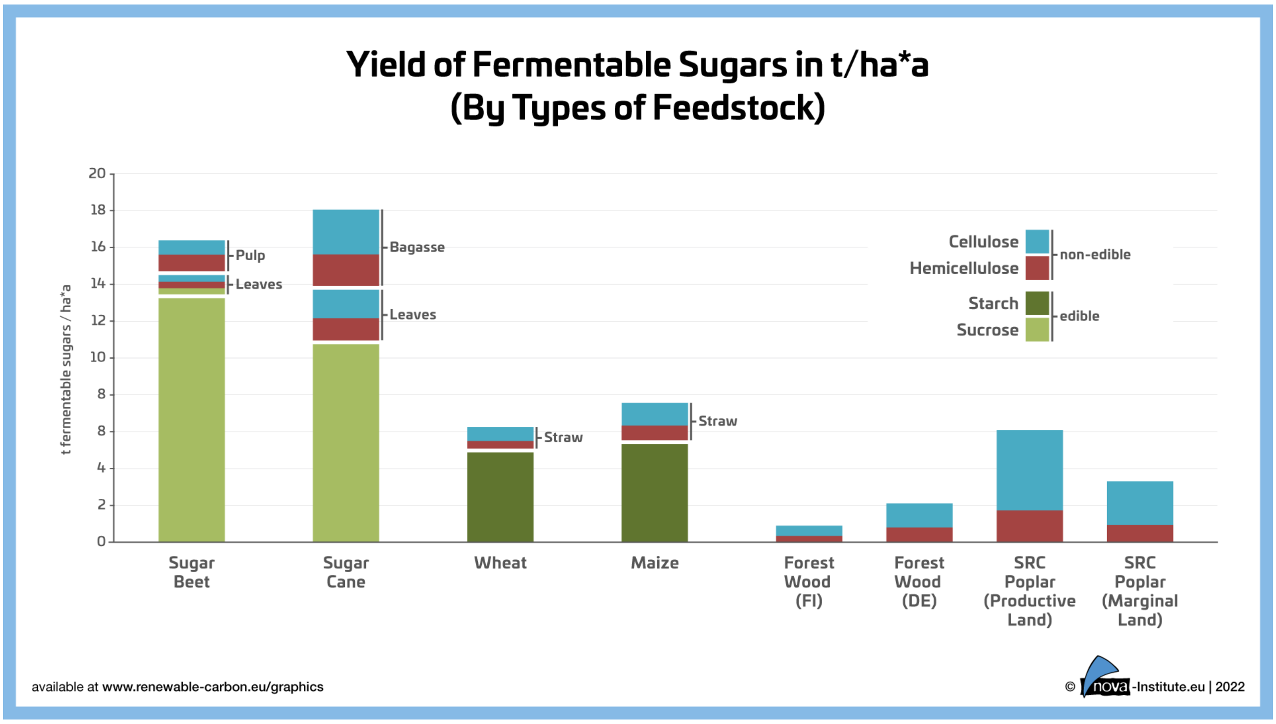

Figure 4: Fermentable sugar yield in t/ha*a for different types of feedstock assuming utilisation of main and co-products. For the co-products, a sustainable extraction rate of 50% (Fischer et al. 2007) was assumed (Source: nova-Institute 2022, based on Dammer et al. 2019)

The use of food and feed crops for industry is as old as humankind

Furthermore, the use of crops grown on arable land – both edible and non-edible – for non-food purposes is as old as humankind and an important traditional economic factor. Worldwide, 12,4 million tonnes of starch are used in paper (Skoczinski et al. 2021), which is ten times as much as is used for bio-based polymers. In addition, the existing turnover generated by first generation biomass for pharmaceuticals, fine chemicals, chemicals and materials in the EU is significant and has never been cause for controversy. The Joint Research Center and nova-Institute (Ronzon et al. 2017) have developed a methodology to estimate the share of bio-based products in EUROSTAT statistics, which was further expanded through the BioMonitor project (Hark & Porc 2022). We estimate that in PRODCOM Class C20 (Chemicals), excluding biofuels, the share of food and feed crops in total biomass use ranges between 50% and 60%, corresponding to a volume of 11.4 million tonnes first-generation biomass and 21.2 billion € turnover. With regard to pharmaceuticals, the share of food and feed crops of overall biomass usage is estimated to be even around 90%, since wood, specialised crops and waste are not utilised in this sector, which corresponds to a volume of 24.7 million tons of first-generation biomass and a 146.1 billion €. This means in summary that food and feed crops in the European Union generate an annual turnover of more than 165 billion € in the chemical and pharmaceutical sectors, not even counting starch for paper, which is in a different statistical Class. When discussing a ban of food and feed crops for industrial applications, it is important to keep this information in mind, as it would fundamentally change various existing, mature industries and cause dramatic change of established product categories to transition to fossil-based material alternatives (e.g. switch of starch as strength additive in paper and board manufacture to utilise fossil resin-based alternatives). The expansion of the bioeconomy in addition to the current baseline is projected to be small compared to existing utilisation which has never been a cause for controversy.

Cotton, for example, is a widely accepted crop for textiles, taking up huge amounts of land areas and having extremely detrimental effects on soil health due to high amounts of pesticides and fertilisers being needed for effective cultivation. A review of literature showed that producing fibres from cotton has higher negative environmental impacts than polylactic acid (PLA) fibres produced from starch or sugar crops:

Table 1: Environmental impacts of fibre production cotton vs. PLA (Sources: Essel and Carus 2015, based on Shen and Patel 2010, Turley et al. 2009, Vasile 2000, Vink et al. 2010; Arefi 2018; Korol et al. 2019)

Impact per kg of fibre	Cotton (non-food)	PLA (from sugar or starch crops)
Water use in litre	2,000–20,000 l	80–240 l
Land use	8 m^2	2–4 m^2
Global Warming Potential	0.7–7.8 kg CO_2e	0.9–2.7 kg CO_2e
Non-renewable and renewable energy use	58 MJ	80 MJ

Whether a crop is a food crop or not is no appropriate criterion to judge environmental effects or competition for land

This comparison shows clearly that while cotton is a non-food crop, its cultivation takes up much more arable land than fibres from PLA would do (factor 2–4), which detracts from land available for food production. This illustrates that the fact whether a crop is a food-crop is not appropriate to judge environmental effects or competition for area. Compared to the amount produced worldwide for animal feed, or what is lost to storage, transport or goes unused by consumers (30%), the proportion of crops used for materials and energy is negligible (Figure 3).

Plant-based plastics today only make up for miniscule land use

The example of plant-based plastics shows how miniscule such products groups are in terms of land use: in 2020 it accounted for only 0.032% of the biomass produced worldwide (excl. wood, see Figure 3. The share of agricultural area needed for this is actually even smaller, at only 0.005% – because particularly efficient plants such as corn and by-products were used. If we assume an annual growth of 10% – more than double that of petrochemical plastics – the area needed increases to 0.088% of the world's agricultural area by 2050. One study calculates that "even if we would base all present world-wide fossil plastics production on biomass as feedstock instead, the demand for feedstock would be around 5 percent of the total amount of biomass produced and harvested each year" (van den Oever et al. 2017). While this is certainly not nothing, and also all other parts of organic chemistry need to switch to renewable carbon to be sustainable, it is also highly improbable that this scenario will become reality. From a holistic, sustainable material sourcing perspective, it seems much more likely that mechanical and advanced recycling will become the main sources of supply, followed by usage of CO_2 and then biomass.

5.2 Potentials for increasing sustainable biomass availability

By 2050, the world will need 50% more food and feed than in 2012

As of the beginning of 2022, the world's population is around 7.95 billion people (UNFPA 2022). Global population is projected to reach more than 9.7 billion people by 2050, possibly exceeding 11 billion by the end of the century. To meet projected food demand, agricultural systems need to produce almost 50% more food and feed in 2050 than in 2012 (FAO 2017). One major driver of increased demand especially for animal feed is growing prosperity in developing and emerging nations.

Many factors can positively influence the availability of biomass

While it was not possible within the scope of this paper to conduct a comprehensive study on biomass potentials, we would like to point out qualitatively how the availability of sustainable biomass for food and other applications may be increased significantly.[1] As the numbers above show, the industrial material use of biomass makes up for only a very small share of biomass competition. Other factors have a much greater impact on food availability and could be influenced by policy to increase food security. Implementation should always respect sustainability principles related to environment (for example

1 RCI is planning to conduct and publish a comprehensive study on biomass potentials in 2023/2024.

respecting high conservation values and high carbon stocks as well as biodiversity), but especially also human rights related to land and water.

Increasing yields through traditional approaches

1. Increasing yields through traditional approaches: Innovative (and traditional, but often forgotten) agricultural practices such as crop rotation and inter-cropping have the potential to increase yields while also combatting desertification through improved soils and mitigating climate change through increasing carbon stocks in soil. These aspects are mostly neglected by mainstream agricultural policies and financing systems nowadays. Tremendous potential for increasing yields in developing countries is hampered by a lack of investment in well-known technologies and infrastructure and unfavourable conditions such as no access to credits, fertilizers and markets, insufficient transmission of price incentives, and poorly enforced land rights.

Increasing yields through innovative technologies

2. Increasing yields through innovative technologies: Research on biotechnology to e.g. improve soil, plant resilience and the efficiency of photosynthesis might also play a role in increasing yields. High-tech approaches such as urban farming and precision farming that reduce the need for fertiliser and pesticides, as with drones and robotics, can also contribute to an agriculture with higher output at lower input.

Reducing sealing of land

3. In Europe, an average of 3% of land has been sealed every year between 2006 and 2015, with a steadily increasing trend (EEA 2020). While not all of the sealed land is arable, increasing imperviousness is a significant factor for loss of agricultural areas. Smarter housing and industry development planning could contribute to preserving relevant amounts of arable land.

Using marginal land areas

4. Using marginal lands (degraded land that is not usable for normal farming) to cultivate biomass for industrial uses is often cited as a viable option to increase biomass yields without increasing competition for agricultural land. Especially perennial lignocellulosic crops such as miscanthus, switchgrass, poplar, willow or eucalyptus are considered as promising options, since they grow on these lands and even help to counter land degradation and to restore ecosystems. However, while these crops withstand marginal conditions well, their biomass yield and quality do not ensure acceptable economic returns to farmers and cost-effective biomass conversion into bio-based products yet and require additional research and optimisation, before becoming viable options from an industrial perspective (Pancaldi & Trindade 2020).

Eating less meat

5. Incrementally reduced meat consumption would free up a huge amount of arable land for other uses, since currently 70% of land is used for feed (see Figure 3) – or even switching meat consumption from beef to chicken would have dramatic impact on land utilisation. 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). The huge amounts of biomass utilised for animal feed worldwide mean that this is actually the lever with the most potential to free up large areas of land, but it is a very sensitive topic and, in most cases, a “no-go”-area for policy makers. Trends towards plant-based diets in some industrialised countries can be observed, but are globally more than counterbalanced by increasing wealth and corresponding growth in meat consumption in developing and emerging nations. Also here, high-tech approaches to synthetic meat and cow’s milk have the potential to free up

large areas of land, but it remains to be seen whether acceptance by consumers will be sufficient to achieve this effect.

Reduced use of land areas for biofuels

6. Decreased areas used for biofuels: In the next two decades, the demand for diesel and gasoline for passenger cars will decline significantly due to the increase in electromobility and hydrogen as fuel. While biofuels will continue to play a key role in the transition to more sustainable alternatives for the transport sector in the immediate future, in the long-term, probably only the aviation sector will continue to require carbon-containing fuels. This means that also the demand for carbon-containing fuels, including biofuels, is expected to decrease significantly, freeing up areas that can be used for other purposes.

Reducing food losses

7. Reducing food losses (wasting) will also free up huge areas of arable land. Roughly one-third of food produced for human consumption is lost or wasted globally, amounting to about 1.3 billion tonnes per year (FAO 2011). A recent study by the World Wildlife Fund (WWF) even assumes a significantly higher value of 2.4 billion tonnes (WWF 2021). This key area of loss could be addressed through improvements in supply chains, cooling chains as well as modern packaging solutions – but also through more regional production and seasonal consumption patterns.

Increasing efficiency of biomass processing through innovative technologies

8. Increasing the efficiency of biomass processing for all applications by the use of modern industrial biotechnology and new chemical catalysts.

All aspects mean that political reforms and significant investments are necessary, but the base is already there in many areas as well. This means that such transitions are definitely doable and are already happening.

With limited arable land, the most land-efficient crops should be grown on these areas to produce first food and feed, and then materials and fuels – 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 section 9). **Additional areas with food and feed crops also provide a higher overall availability for sugar and starch** (see section 10, too).

6 Overall environmental impact of crop cultivation

Using biomass responsibly and sustainably is not only a question of land efficiency. The overall environmental impact of crop cultivation needs to be considered, too. Figure 5 shows the multitude of impact categories that define the environmental sustainability of a given feedstock according to the EU's Product Environmental Footprint (PEF). It illustrates for example that palm oil, which is often criticised for its effects on land use change, is one of the best choices under the variety of criteria assessed in this calculation, such as land use and water use.

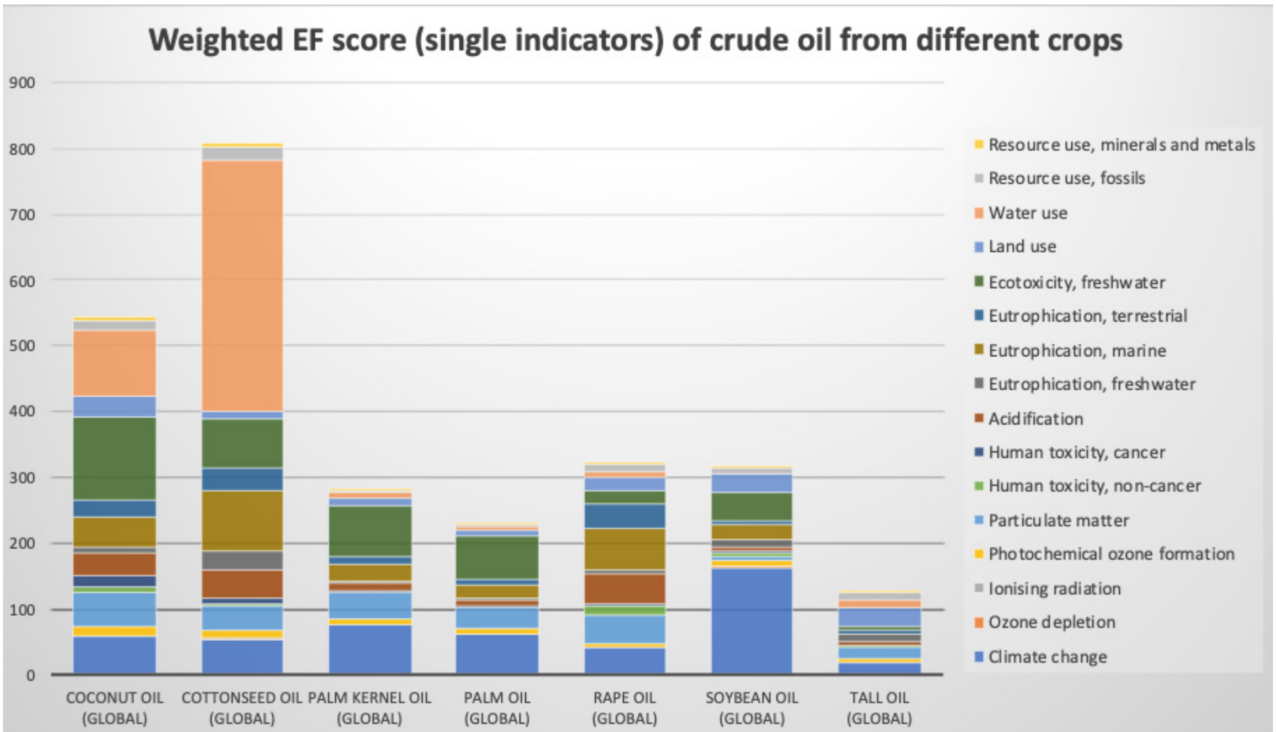

Figure 5: Environmental impact of different feedstocks for bio-naphtha feedstocks, weighted single indicators (Source: own calculations 2022. Calculated with SimaPro in the version 9.2.0.1, based on ecoinvent data in the version 3.7.1 and EF 3.0 Method (adapted) V1.03 and EF 3.0 normalization and weighting set (2020))

Best practices to improve environmental impacts of agriculture; "regenerative agriculture"

There is a range of best practices that can be employed to improve the environmental impact of agricultural cultivation. "Regenerative agriculture" receives a lot of attention lately due to its potential to improve agricultural sustainability. The term describes farming and grazing practices that, among other benefits, reverse climate change by rebuilding soil organic matter and restoring degraded soil biodiversity – resulting in both carbon drawdown and improving the water cycle. Practices include no tilling, applying cover crops, crop rotation, compost and animal manures instead of synthetic fertilisers and well-managed grazing practices to stimulate root growth and micro-nutrient availability (Regeneration International 2017). This is of course far from current industrial agricultural practices, but for the latter, there is also a host of best practices that can already help to reduce footprints, specifically with regard to fertiliser use and managing water cycles (see for example Good Agricultural Practices as described in sustainability certification systems ISCC/RSB).

First- and second-generation feedstocks have different advantages and disadvantages; there is no clear winner in terms of sustainability

In another publication (Dammer et al. 2019), we analysed different feedstock options – sugar beet, sugar cane, wheat, maize, forest wood, short rotation coppice, forest residues, post-consumer wood, agricultural residues and organic waste – for fermentable sugars, which are one important feedstock source for bio-based chemistry, and the most important one for biotechnology. The analysis took a holistic sustainability perspective, including environmental, economic and social aspects, according to widely accepted sustainability certification systems. The study came to the conclusion that all of the evaluated feedstocks of fermentable sugars realise significant reductions of greenhouse gas emissions compared to their fossil incumbents (see Figure 6). While second generation sugars performed better in this regard according to the recognised calculation rules in the Renewable Energy Directive, 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, e.g. cut offs of emissions or other allocation choices made by political decisions. The GHG emission reductions of second-generation sugars are strongly relativised, when offset against the abatement costs, since producing them is also significantly more expensive than those from first generation crops. 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 suggested by critical stakeholders is a feasible societal strategy from a climate and economic perspective.**

Also, with regard to biodiversity and soil quality, it was shown that managed forests as sources for second-generation feedstocks can have huge impact on ecosystems and therefore on these criteria. This is due to the removal of all deadwood, underbrush etc. in managed forests which removes significant parts of habitats for all kinds of different species living in natural forests. It should be noted that it is virtually impossible to make generalised claims about the impacts on biodiversity that any type of cultivation can have – it is extremely dependent on the location-specific conditions and practices. (Dammer et al. 2019, Joly et al. 2016).

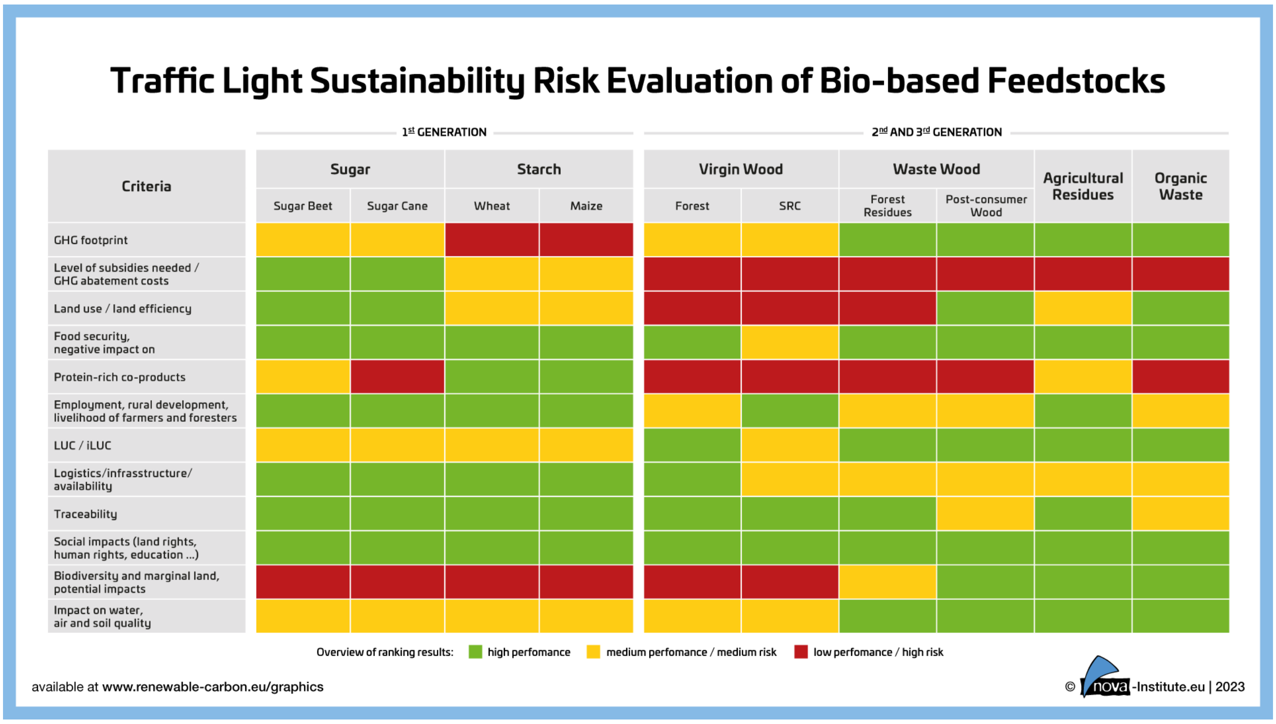

Figure 6: Traffic-light sustainability evaluation of feedstocks used for fermentation of sugar (Source: nova-Institute 2023, based on Dammer et al. 2019)

The choice of feedstock depends on many factors – there is no "one-size-fits-all" solution

A recent publication by the Bioplastics Feedstock Alliance, which is convened by the World Wildlife Fund (WWF), highlights the importance of assessing each feedstock's impact in its specific local environment and provides an evaluation tool enabling every producer to carry out a detailed assessment. Food security is also considered as one criterion and the document states that **"the bigger picture is not the specific issue of whether food or nonfood crops are being used to produce biomaterials but rather the integration of any feedstock for biomaterials production into a landscape and its social, environmental, and pricing effects there"** (BFA 2022). The choice of feedstock in any given case depends on many factors and is site specific. There is no "one-size-fits-all" solution.

Sustainability certifications for biomass

Nowadays, there is a multitude of recognised sustainability certification schemes both for agricultural and forest biomass – Bonsucro, Forest Stewardship Council (FSC), International Sustainability & Carbon Certification (ISCC), Programme for the Endorsement of Forest Certification (PEFC), REDCert, Roundtable on Sustainable Biomaterials (RSB), Roundtable on Sustainable Palm Oil (RSPO), Better Biomass, etc. Their use has become mainstream in the fuels sector due to the requirements of the Renewable Energy Directive, but also many chemicals and materials producers only work with certified sustainable biomass on a voluntary basis. The criteria catalogues of these certification systems show varying degrees of comprehensiveness and strictness, but the certificates are a positive first step to ensure the sustainable use of biomass.

7 Economic stability for farmers

Additional income for farmers from selling to chemical industries

Biofuels policy is often named as an important tool to provide additional outlets to farmers, ensuring stability also in times of shifting prices for food commodities. Even if they are not regulated or incentivised, bio-based materials can play a similar role. **Biomass supplied to chemical industries can provide an attractive additional income to farmers.** Since industry is dependent on long-term supply stability, there are opportunities for farmers to close long-term framework contracts. This is not always the most attractive option from a price perspective, since it also includes fixed prices over a longer period of time and farmers like to adapt their portfolio in the next year to supply crops for which prices have increased, but in terms of security this is a valuable tool. There are positive examples such as the thistle biorefinery in Sardinia which creates demand for crops that can be grown on relatively dry land, offering income to a vulnerable community of farmers (Yazan et al. 2016).

Optimised food and feed crops offer multiple uses of constituents in the biorefinery approach

Keeping these outlets open to a multitude of feedstocks, as opposed to e.g. only niche or lignocellulosic crops, ensures flexibility both for farmers and the chemical industry. Farmers are usually sceptical of cultivating multi-annual crops or niche crops, because it makes them inflexible, unable to react to sudden market changes and dependent on one specific market – thus making required investments unattractive. On top of that, optimised food and feed crops that offer multiple uses of their multiple constituents in the biorefinery approach offer economic benefits for growers as well as for processing industries. Also, new crops require decades of development and acceptance to mitigate agricultural risks, optimise yields and justify investment in equipment, etc. It is extremely challenging to introduce new crops, since farmers need to make seed purchases and plant cycle decision even up to 2–3 years ahead of the planting season, which means they have to make decisions before they know about the commodity cycles. That means offtake would have to be guaranteed by processors or customers to remove the uncertainty – which is a risk not likely to be carried. Cultivating large crops mitigates these risks. In many countries, farmers form cooperatives to have a better negotiation position vis-à-vis the chemical industry, which offers additional benefits.

Lower-quality cereals are often used for industry

With a view to food and feed crops as supply for the chemical industry, **it is often the case that cereals of lower quality are used for material and fuel production which offers additional income to farmers.** Without this option they would have to dump these products on world markets, which is often cited by NGOs as one of the long-term causes for food insecurity in the global South (Oxfam International 2005). This local outlet therefore also has a potentially stabilising effect on global food prices.

8 Influence on food prices and shortages is negligible

Main reasons for hunger as named by the World Food Programme do neither include biofuels and bioenergy, nor bio-based materials

As the evidence in the previous chapters has shown that overall availability of biomass on the planet is not necessarily an issue and is not significantly negatively impacted by biofuels or bio-based materials, 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 regularly lists the reasons that are the main drivers of hunger, and these have been for many years poverty, lack of investment in agriculture, climate and weather, war and displacement, unstable markets, food wastage. Since 2020, the COVID-19 pandemic has joined this list of culprits and the latest list warns mostly of "**conflict, economic shocks, climate extremes and soaring fertilizer prices" (World Food Programme 2023)**. Biofuels and bioenergy on the contrary are noticeably absent from it. They would increase the poverty gap if they contributed significantly to price increases, which was the argument most often heard after the food crisis in 2008, when food prices spiked for about 15 months, and then shortly afterwards again in 2011. 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 in 2010:

> *"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."*

Reasons for price peaks in 2008 were complex. Current peaks due to Ukraine war and soaring petroleum prices

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 (Vidal 2011, Mittal 2009), 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 (see Figure 7). While both biofuels and wheat are now experiencing price increases, this is arguably caused by strong increases in the oil price and shortages due to the Ukraine conflict.

A recent study with focus on soybean oil found that the demand for biofuels from soybean oil has limited impact on overall food prices. Slight increases of prices for oil and oil-derived products are counterbalanced by lower prices for meat and animal products due to higher availability of protein meal from increased soybean production (Lusk 2022).

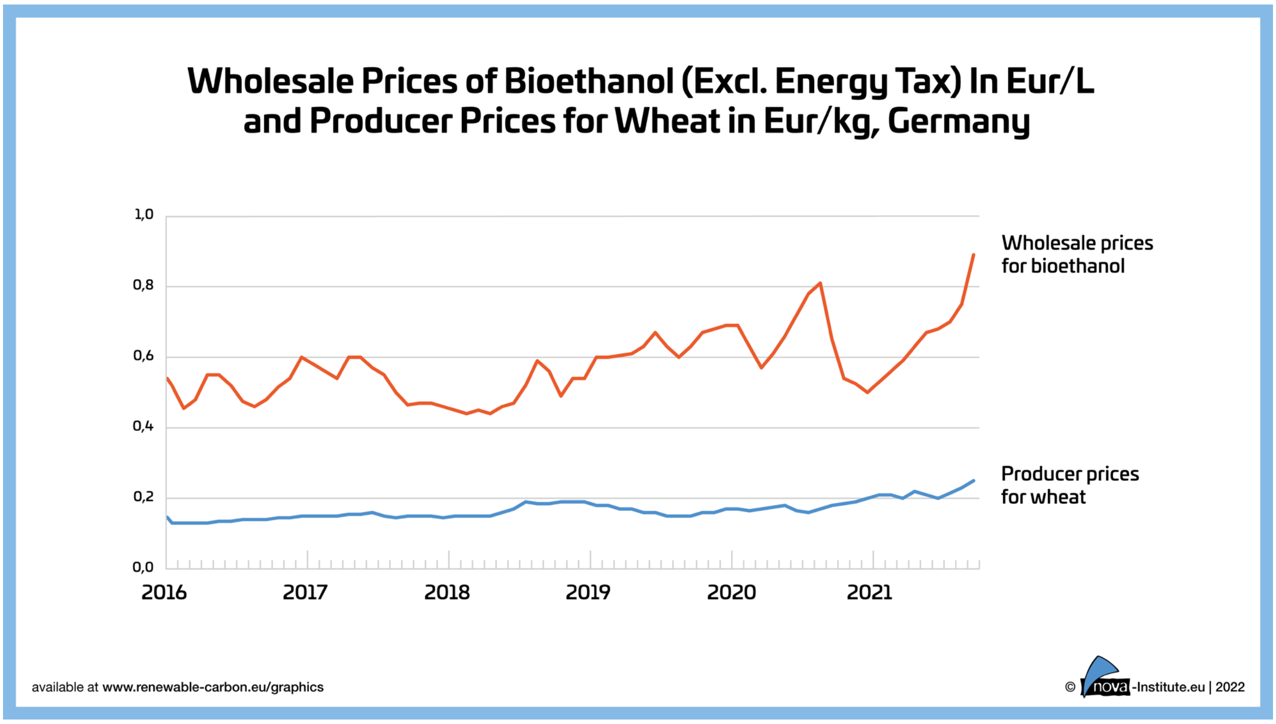

Figure 7: Wholesale prices of bioethanol and wheat (Source: UFOP 2021 based on AMI/LK/MIO)

Extreme dependence of developing countries on cheap imports of staple crops

It can also be discussed whether very low prices for food and feed crops are a good thing because it usually means that there is no incentive for investment in agriculture. The extreme dependence of developing countries on cheap imports of staple crops from other countries will always keep them vulnerable to market disruptions. Extreme peaks such as in 2008 and in 2022 certainly cause volatility, but it does not necessarily make sense to condemn – steady – increases in market prices for food and feed crops that would incentivise investments in the countries of the global South and transform the worldwide agricultural systems towards more regionalised value chains, higher overall yields and self-sufficiency. This is also the strategy promoted by organisations such as the FAO and the World Food Programme, since shipping large amounts of cheap grains to the global South will only continue to weaken local farmers or force them to cultivate high-value products for rich countries (e.g. Avocado).

The recent developments around wheat shortages due to the war in Ukraine are a very topical reminder of the vulnerability of food markets. However, this also confirms that oil prices and conflicts have a much greater impact on food prices than the use of food and feed crops for industry. Another important factor is a lack of long-term storage capacities (see also chapter 10).

9 Contribution to protein supply for humans and animals

Protein is much more valuable for nutrition than carbohydrates

In terms of valuable nutrition, protein supply is much more important to both human and animal welfare than the supply with carbohydrates. Carbohydrates act primarily as energy suppliers – a function that can also be provided by proteins and fats. Fats and proteins, however, are essential building blocks for the body and cannot be replaced as such. A severe lack of protein leads to a form of undernutrition called "protein-energy undernutrition (PEU)" (Morley 2022), 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.

Significant amounts of protein-rich by-products from biofuels and bio-based materials

Biofuels and bio-based materials, however, are either made from fermentable sugars, which are carbohydrates, or from plant oils. **When crops such as sugar beet, wheat or rapeseed oil are processed into these products, there is a significant amount of protein-rich co-products which are fully utilized in feed applications** (Figure 8, Figure 9). 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.

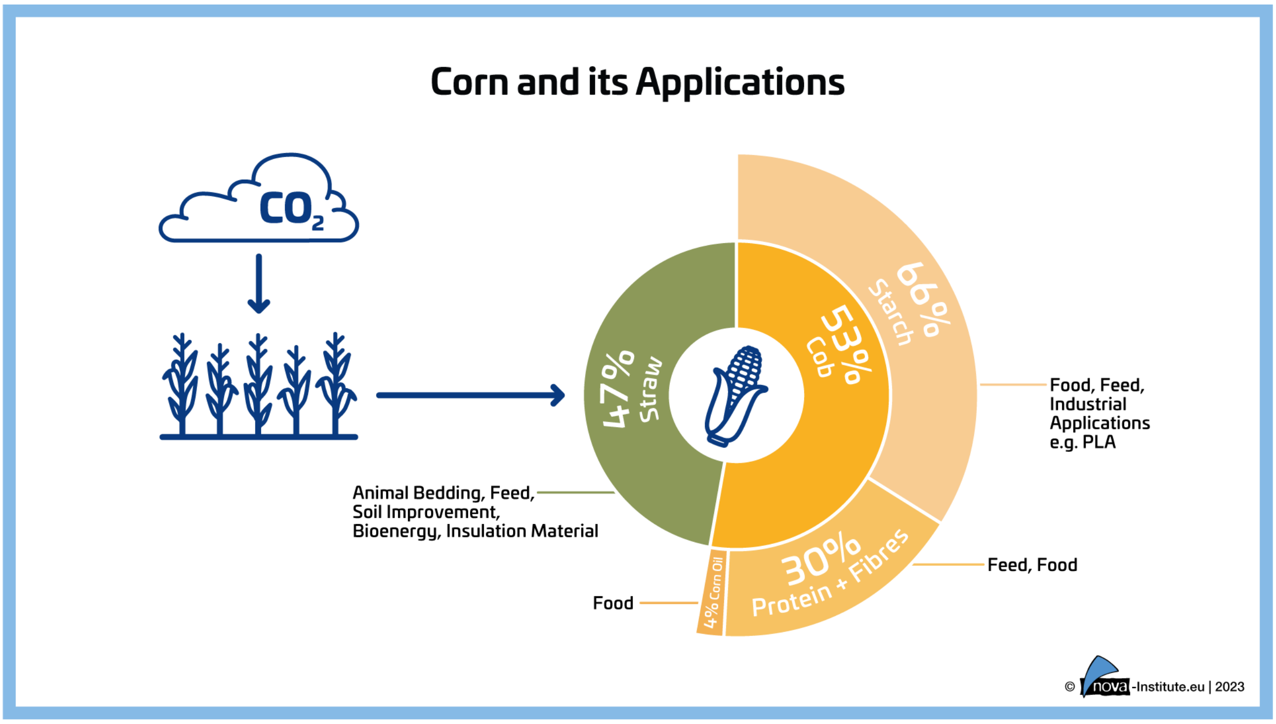

Figure 8: Co-product utilisation from corn (Source: nova-Institute 2023)

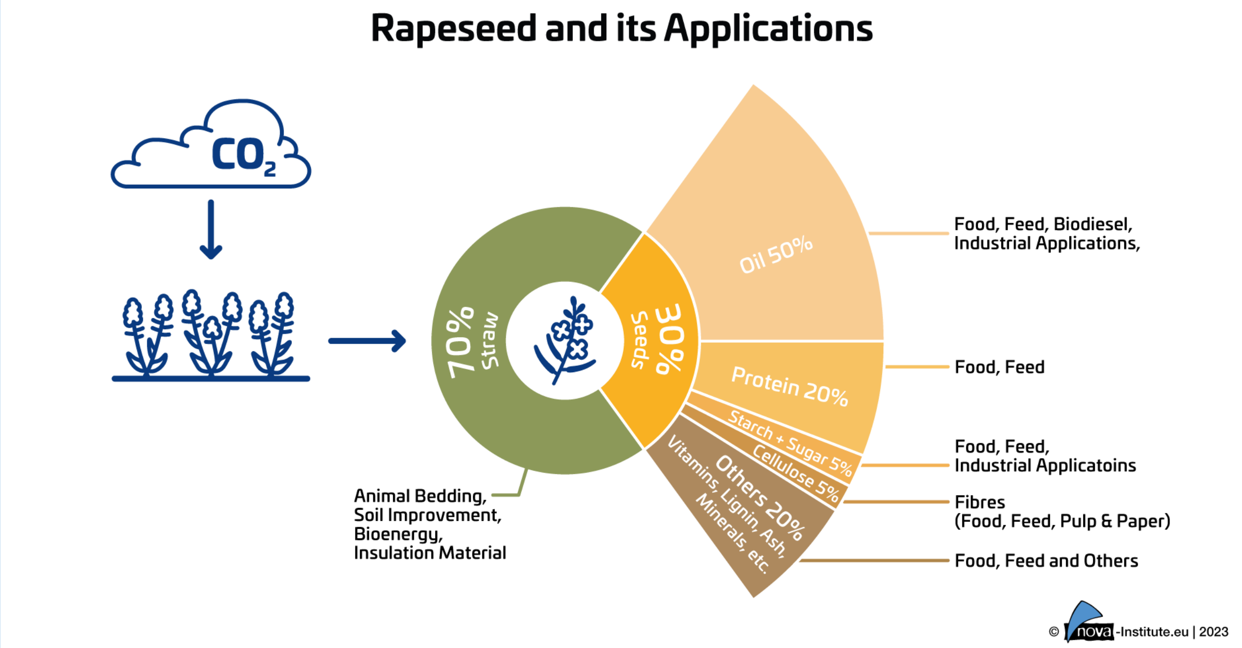

Figure 9: Co-product utilisation from rapeseed (Source: nova-Institute 2023, based on Wirsenius 2000)

Figure 9 shows the high proportion of proteins in rapeseed, which is mainly used in combination with fibres for animal feed and replaces soy protein. The perspective that proteins are the main products and oil the by-product is also conceivable. Data from 2021/2022 shows that the main global oilseed products made from palm, rapeseed, soy, sunflower and others go to a very large extent to food and feed applications, while also supplying valuable feedstocks to the oleochemical sector. Consumption in the animal feed sector was 348 million t in 2021/22, dominating the total with a share of 68%, followed by 114 million t for food (share 22%), while the entire industrial sector incl. biodiesel received 24 million t (share 5%). Demand in all sectors has increased by about 25% since 2014/15. If we look specifically at the (oleo)chemical and materials sector (cosmetics, laundry detergents, paints, lubricants), the share is even lower: 4 million tonnes (share 0.8%, UFOP 2023).

Cultivation of protein-rich crops in Europe is valuable to prevent land-use changes in the global South

If these crops are less cultivated in Europe due to a phasing out of first-generation biofuels and other pressure from public debate, there is an increased need for importing protein-rich feed products from other regions, such as soy from Brazil. This has huge impacts on land use, land use change and transport emissions. This is a very current topic, since certain NGOs and politicians start to call for a ban of food and feed crop cultivation for biofuels in Germany and The Netherlands in the context of the current food crisis due to the war in Ukraine. A recent publication by the independent Energy Watch Group shows very pointedly, how such demands are completely misled, since the protein produced from such crops will automatically be replaced by imports, most commonly from the global South (Gruber and Fell 2022). Another recent study shows that increases in wood areas by 12.6 mln ha in Europe between 1990-2014 are contrasted by corresponding reductions of highly biodiverse forest areas in the global South by 11.3 mln ha – out of which a staggering 9 mln ha can be traced back to oil and protein exports from Brazil for European biodiesel and protein demand (Winkler et al. 2021). The phase-out of crop-based biofuels is justified due to electrification potentials, but it is a dangerous development if these claims about the use of food and feed crops are generalized and were to be applied to the chemicals sector.

Actually, the need for increased and independent protein production in Europe is well acknowledged by policy makers which can be seen in the "European Soya Declaration", signed in July 2017 by 14 Member States. The Declaration lists measures to reach this objective and thus contribute to more sustainability in European agriculture, especially by promoting the locally adapted cultivation of legumes, fostering optimised feeding, informing consumers about the inclusion of plant-based protein sources in diets, and enhancing support for import certifications (BMEL 2021). However, co-production of protein-rich components from other crops offers the clear benefit of adding economic value, since farmers gain two outlets from one crop from one area.

10 Food and feed crops acting as emergency reserve

Additional cultivation of food crops would have multiple benefits

In the case that humankind really faces a food crisis, food and feed crops targeted to industrial markets can also serve as an emergency reserve for food and feed supply – second generation lignocellulose cannot be used as such, because the human digestive system cannot process woody biomass. If for example, industry were to build up additional wheat supplies for their own uses, this would have multiple benefits. First of all, the overall available amount of wheat increases, since industry does not compete for existing volumes, but would use additional areas. If there is higher demand for wheat at time of planting, more wheat would be grown in the given season. Secondly, these amounts could act as a virtual storage for times of crisis such as observed in 2022. If everything is business as usual, industry will utilise the feedstock as planned for chemicals and materials. But if food supplies become tight, the resources could be redirected towards the food market, perhaps with compensation for the industry for their losses in production that year. This would be a much more economical way to build up wheat storages than anything else. The necessity of increasing storage capacities in food value chains has been stressed by more and more experts recently (Akkad 2022, Gaboury 2022).

Flexible policy mechanisms to adapt to changing markets

It is a challenge to implement a system that can react to varying demand. In the case of biofuels, flexible policy mechanisms that are able to adapt to changing markets have been discussed in research and are generally considered to be an effective tool to increase food security (Vural Gursel et al. 2020), as even advocated by the former Director of the United Nations' Food and Agriculture Organization (da Silva 2014). Such measures would allow to increase the production of fuels in times of excess feedstock availability (and correspondingly low prices) and reduce it when feedstock availability is low (and prices are high). Actual implementation of such measures is rare and can only be observed in Brazil and the US. Evidence of their effectiveness is considered lacking so far (Vural Gursel et al. 2020).

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 – when crops become scarcer, feedstock prices rise, mainly driven by the food market. This means that also lower qualities are taken up by the food market at prices too high for biofuels producers, making this particular feedstock automatically unattractive for them. In such cases, they will typically resort to using an alternative feedstock or even stop production. Strong fixed quotas, combined with the according incentive structures, such as in the European Union, however, can slow down this process. Flexible quotas for fuels and corresponding measures in material industries are therefore still a preferable option from this point of view.

For bio-based chemicals and materials, there is no system of incentives that can be adapted to react to varying demand. Here, the challenge would be to implement a system that ensures additional cultivation of food and feed crops by industry that can be re-directed in times of crisis without detrimental effects such as loss of jobs or innovation in the chemical sectors.

Non-food biomass and residues cannot contribute to emergency reserves

Non-food biomass cultivated on arable land will only feed the industry – but maintain the pressure on food and feed markets. Also, a political focus on strictly waste-based fuels will not help to contribute to any emergency reserves.

11 Conclusion

Using biomass cultivated on agricultural land for purposes other than food and feed does not in itself have a negative impact on food security. On the contrary, growing sustainable, land-efficient food and feed crops can have multiple benefits for local and global food security, climate mitigation and for other factors:

Seven potential positive impacts of increased use of food and feed crops for chemicals and materials

1. The climate wins. There is a need to shift away from fossil feedstocks to achieve climate change mitigation. Bio-based materials are part of the solution and can thus help to mitigate one of the leading causes of hunger in the world.

2. Land productivity wins. The competition between applications is not for the type of crop grown, but for the land. The overall availability of arable land, and therefore food and feed on the planet determines what is possible and what is not. Food and feed crops offer high yields through long-term optimisation and a variety of co-products used simultaneously in a variety of applications, making the most out of the available land.

3. The environment wins due to increased resource efficiency and productivity of food and feed crops and the reduced land area, especially if agricultural practices are improved to better respect soil health and ecosystems;

4. Farmers win because they have more options for selling stock to different markets (food, feed, biofuels, material industry) and therefore more economic security. This can increase investment and ultimately the availability of arable land and ensure sustainable rural development to maintain EU agriculture;

5. Market stability wins due to increased global availability of food and feed crops, reducing the risk of shortages and speculation peaks. The influence of biofuels and bio-based materials on food prices is negligible;

6. Feed security wins due to the high value of the protein-rich co-products of food and feed crops (which can also be used to supply protein for human nutrition);

7. Food security wins due to the increased overall availability of edible crops that can be stored and flexibly distributed in times of crisis (emergency reserve), actually mitigating risks of supply-cycle triggered regional hunger events.

"The bigger picture is not the specific issue of whether food or nonfood crops are being used to produce biomaterials, but rather the integration of any feedstock for biomaterials production into a landscape and its social, environmental, and pricing effects there" (BFA 2022). The choice of feedstock in any given case depends on many factors and is site specific. There is no "one-size-fits-all" solution.

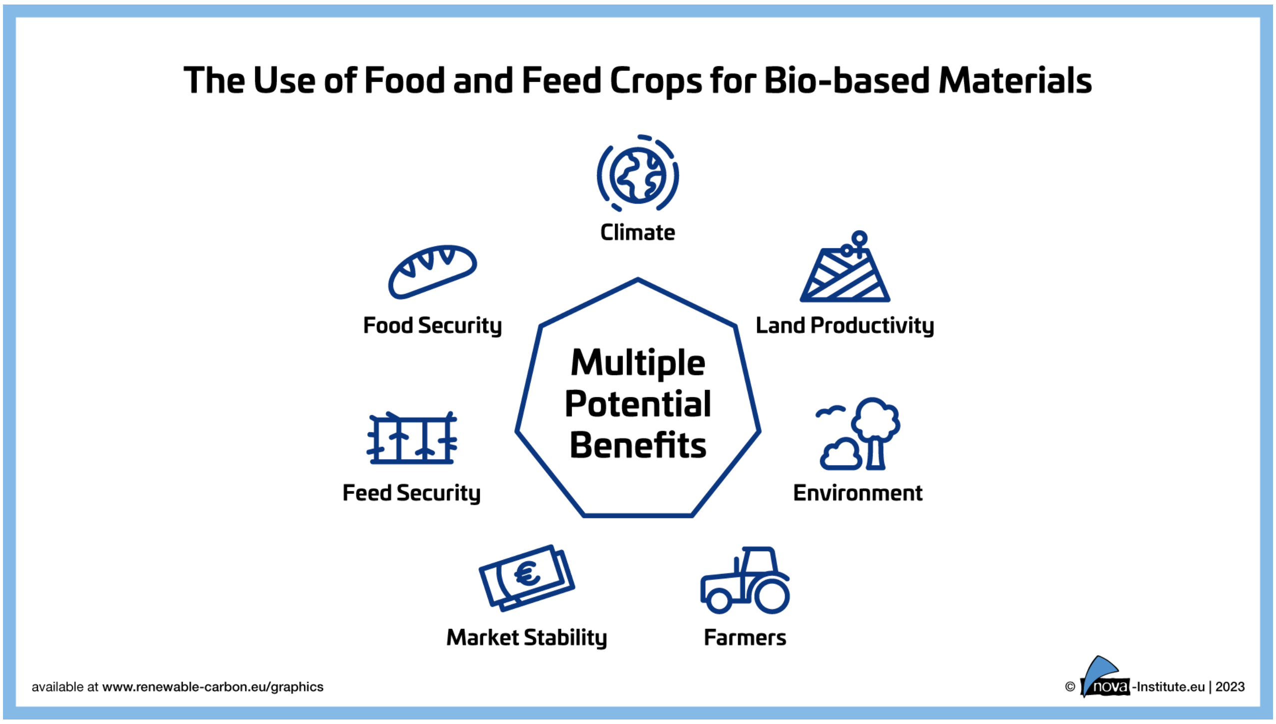

Figure 10: The Use of Food and Feed Crops for Bio-based Materials – Multiple Potential Benefits

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