June/2023

Land and biomass use for food, raw materials, and fuels

The Brazilian success case

Summary

Introduction

The motivation to write this paper stems from a few interrelated questions:

Is it ethical to produce materials from primary crops?

Would this increase food prices?

Are there negative impacts on biodiversity?

Humanity has been using materials derived from biomass for millennia. Wood, textiles, leather and paper are examples; and they all require land to be produced. **The notion that food competes with materials for land is justified only if land is scarce and food is in shortage.**

According to the World Food Programme1, one-third of food produced for human consumption is lost or wasted globally. This loss amounts to about 1.3 billion tons per year, which in value represents approximately US$ 1 trillion. All the food produced but never eaten would be sufficient to feed two billion people. That's more than twice the number of undernourished people across the globe. Hunger is not caused by shortage of land.

On the other hand, further expansion of land is a valid concern when the following factors are considered:

- according to the United Nations, population might reach 9,7 billion by 2050;
- biodiversity loss[2] is growing at alarming rates;
- desertification[3] is affecting the lives of over 1,5 billion people and;
- land system change is reported to be at an increasing level of risk[4].

However, to better understand if it makes sense to use primary biomass such as sugarcane and maize for polymer production, we should look at two key aspects: land use and the cascading principle of biomass use. It will be demonstrated that the amount of land needed to help the plastics industry reduce its dependency on fossil feedstock should not pose a risk to food production, especially if the cascading principle is embedded into the policies that support the bioeconomy.

[1] 5 facts about food waste and hunger
[2] Biodiversity loss and its impact on humanity
[3] Action Against Desertification
[4] The nine planetary boundaries

Land use for bioplastics production

The chart below from European Bioplastics Association[5] shows that even with optimistic growth projections, land use for biobased plastics production is negligible.

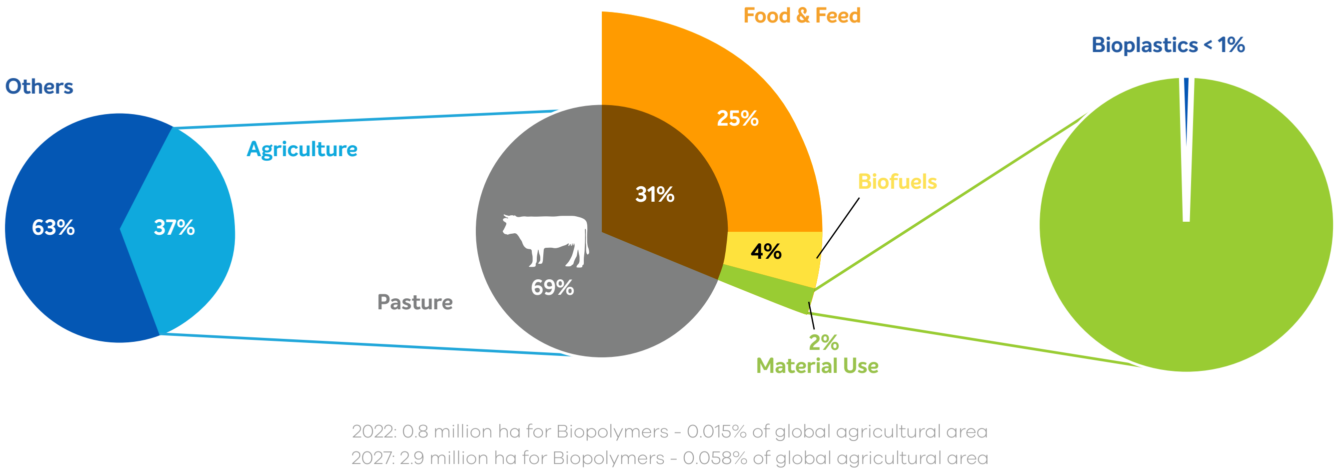

Figure 1. Global use of land for food, fuels, and materials.

In fact, what stands out at first glance is the amount of pastureland. If you take Brazil as an example, the country has one of the lowest occupation rates in the World (around 1.1 heads of cattle per hectare while the world average is 4 heads/ha). **Pasture intensification could free another 120 million ha for agriculture without reducing beef and dairy production. That is an area larger than Ukraine, France and Spain combined.** Another important observation is the amount of land being used for biofuels. Biofuels have been around for several decades and when produced responsibly and following sustainable sourcing criteria such as the ones listed in article 29 of the EU Renewable Energy Directive, they play a significant role in reducing carbon emissions when replacing fossil fuels[6] (mostly in road transportation). However, countries like Germany are questioning the effectiveness of the use of land for fuels, considering that the current production of over 170 billion liters of biofuels globally covers only around 5% of the transport fuel consumption[7]. This means there are limitations to the share biofuels made from primary crops can have on the transport sector that is slowly but surely moving towards electrification. And why are we highlighting the land use to produce biofuels? Because the same way plastics are derived from fossil fuels, **biobased plastics can be made from biofuels.** Some prominent examples are biobased polyethylene & EVA (ethylene-vinyl-acetate) from bioethanol and bio-attributed[8] polymers from bio-naphtha, a co-product of renewable diesel and aviation fuel produced not only from vegetable oils but also tallow, used cooking oil and other sustainable sources. As the plastics industry is significantly smaller than the fuels industry, the feedstock used to produce biofuels nowadays would be enough to produce at least 25% (one quarter) of the whole consumption of plastics.[9] The assumption made was that ethanol would be used

[5] Bioplastics market data
[6] German environment minister hopes to phase out biofuels from 2030
[7] European Commission, Directorate-General for Environment, Biobased plastic: sustainable sourcing and content: final report, Publications Office of the European Union, 2022
[8] Bio-attributed plastics use the mass balance concept to trace back the biobased feedstock in systems where it is not possible to segregate biobased from fossil feedstock.
[9] Considering 110Gl of ethanol (47,8Mt ethylene) + 59Gl of renewable diesel (41,2Mt of olefins) => 94,3Mt of 95% biobased plastic potential.

to produce ethylene and biodiesel would migrate to renewable diesel (hydrotreated vegetable oils – HVO) with 70% yield in producing monomers for polymer production[10], helping detach the sector from finite fossil resources. In the European Commission's report **Biobased plastics, sustainable sourcing and content[7], it is estimated that 4% of the global biomass would be enough to produce all plastics demand.**

Cascading principle of biomass use

Another concept that is relevant to this topic is the **cascading principle of biomass use[11,12].** This principle depicted in figure 2, shows how food and higher value applications such as pharmaceuticals and fine chemicals should have priority, followed by materials and finally energy. This makes even more sense if one considers that while food, chemicals and plastics can't be decarbonized, energy and fuels have other renewable alternatives that are expected to grow sharply in the next decades.

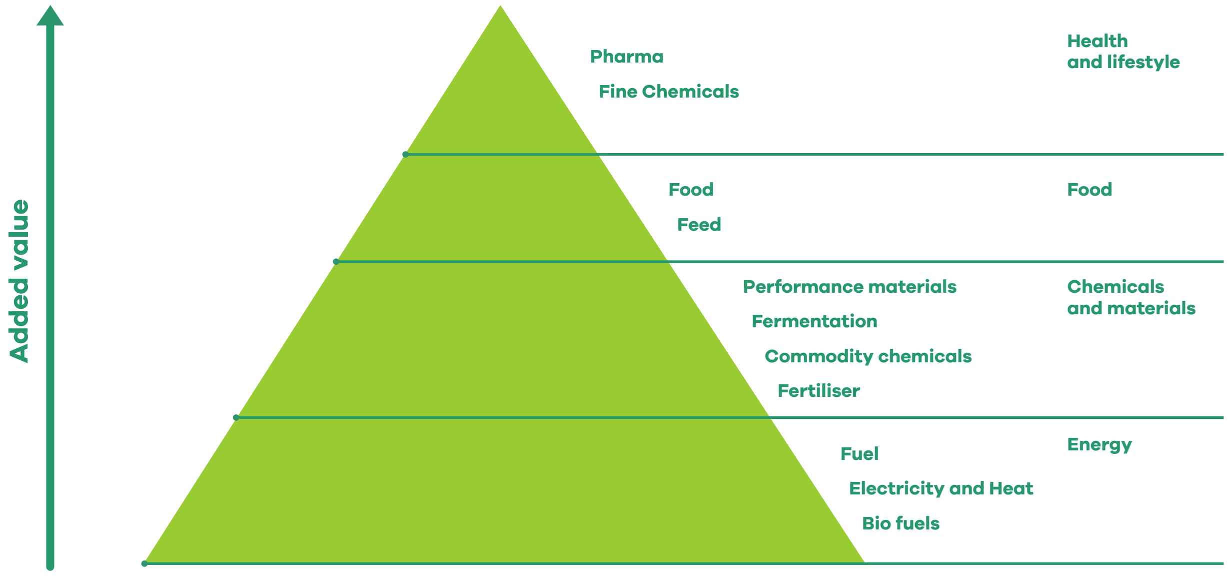

Figure 2. Biomass value pyramid in the bioeconomy[11]

The whole idea is to maximize the value extracted from biomass and the land used to produce it, with clear priority to food production over materials and fuels. In practice though, this principle isn't always followed, as there is land that could be used to grow food crops being used to cultivate trees for wood, paper, natural rubber, cotton, tobacco and biofuels, although the latter is either produced alongside with food/feed or can easily be replaced by a food crop when needed. The area to produce these goods adds up to 372Mha[13]. Focusing on using domestic and industrial waste and side streams from biomass value chains, also known as second-generation (2G) feedstock, should be one of the priorities for industry and policy makers, but not the only one. The urgency to reduce GHG emissions is only growing and if we simply wait for the development of second-generation feedstock to scale, it might end up being too late. In other words, the choice right now is not between second generation or crop-based feedstocks but rather a choice between fossil derived feedstocks and bio-based feedstocks

[10]Polymers are the family of materials popularly known as plastics
[11]Adapted from: Eickhout, B. (2012). A strategy for a bio-based economy
[12]Solutions for a Sustainable Bio-based Economy Making Better Choices for Use of Biomass Residues, By-products and Wastes *Sustainable Bio-based Economy II (cedelft.eu)
[13]faostat/en/#data

(a mix of crop-based and second-generation with the latter gaining prominence over time). As shown in Figure 3, according to the International Energy Agency[14] the market for crop-based biofuels will peak in 2030. This will open feedstock availability for bio-based plastics to grow without the need for additional land throughout the next decades.

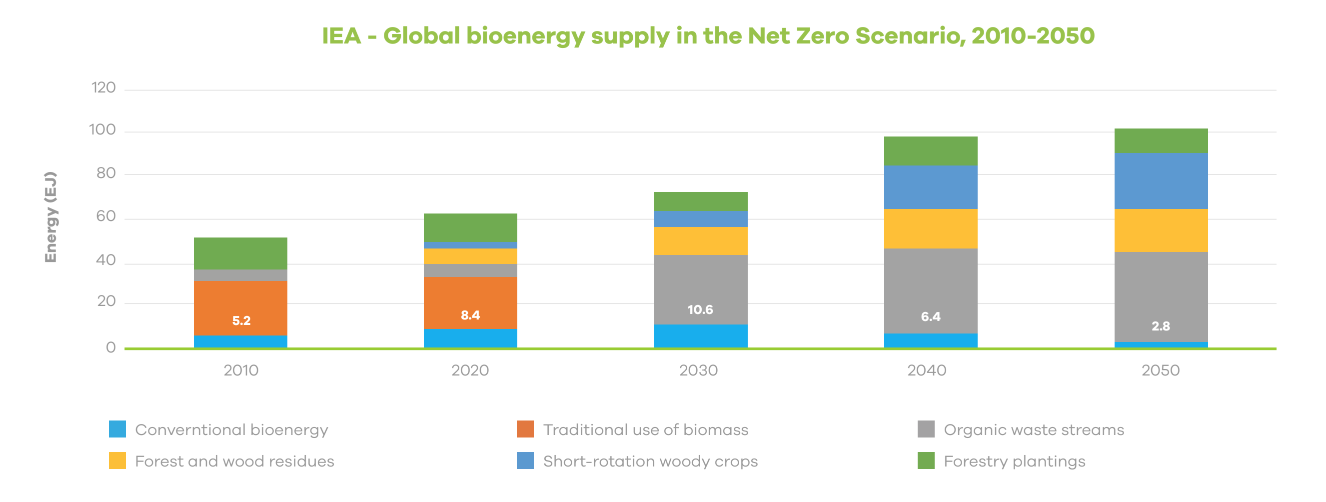

Figure 3. Net-zero scenario for bioenergy supply according to the IEA.

To summarize, bio-based plastics can be sustainably produced from primary sources of biomass if:

- there is land available for sustainable agricultural expansion and no food shortage;
- agriculture does not expand onto high biodiversity biomes;
- feedstock is produced preferably alongside with food or feed (cascading principle);
- the overall environmental footprint from farm to product is significantly reduced compared to the fossil counterpart (proven by life cycle assessment).

The successful case of sugarcane in Brazil

Brazil has been growing sugarcane since the 16th century and it has the most advanced agricultural technology in the world for this crop. Nowadays, while occupying around 1% of the country's land[15], sugarcane supplies over 16% of Brazil's energy demand[16] while responsible for 36% of the world's sugar exports.

[14]What does net-zero emissions by 2050 mean for bioenergy and land use?
[15]plataforma.brasil.mapbiomas.org
[16]Matriz Energética e Elétrica

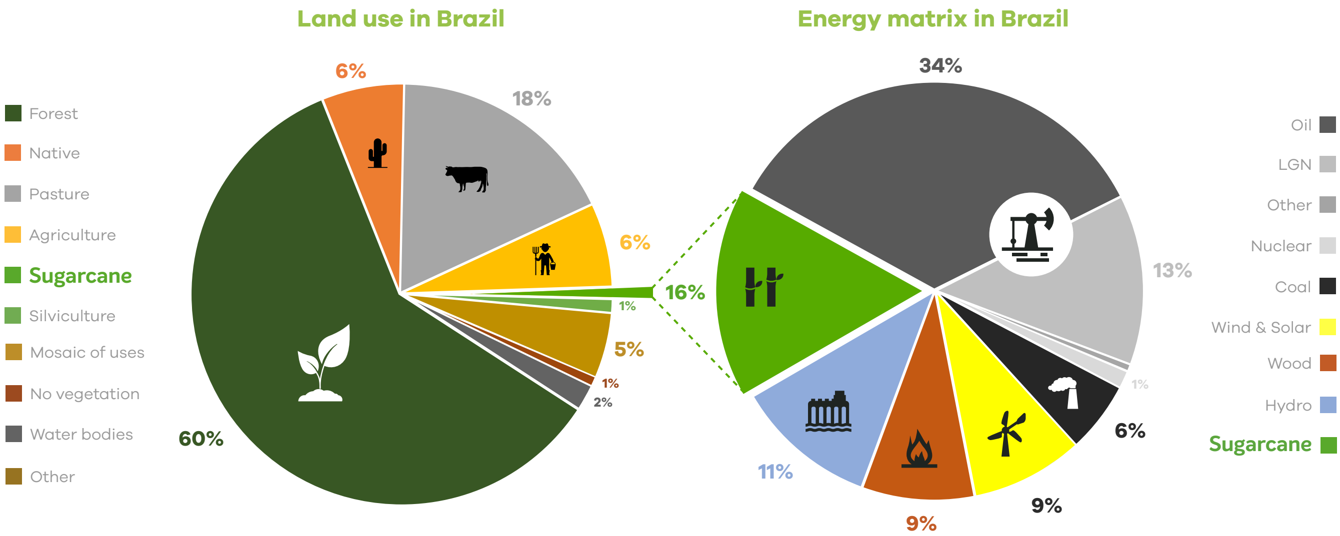

Figure 4. Sugarcane provides approximately 16% of the Brazilian energy consumption.

The sugarcane industry evolved remarkably since the 1970s and producers have learnt to maximize the value creation per hectare by adding to sugar the production of ethanol and electricity. In modern mills, the first press squeezes out the sugar juice that goes to sugar production while subsequent presses with hot water, extract residual sugars that blended to molasses go to fermentation tanks where a kind of wine is produced. In the distillery the ethanol is extracted leaving behind a by-product called vinasse. This residue that is rich in potassium and organic matter, is either applied directly to the field as a source of water and nutrients or is used to produce biogas and compost, a perfect example of the cascading principle of biomass use.

Figure 5. The cascading principle applied to sugarcane: sugar (food), biobased PE (material), ethanol (on purpose fuel), bagasse incineration (energy recovery).

To demonstrate that this leadership in sugar and ethanol hasn't negatively influenced food availability, Figure 6 shows how the production of cereals has been growing steadily over the past two decades.

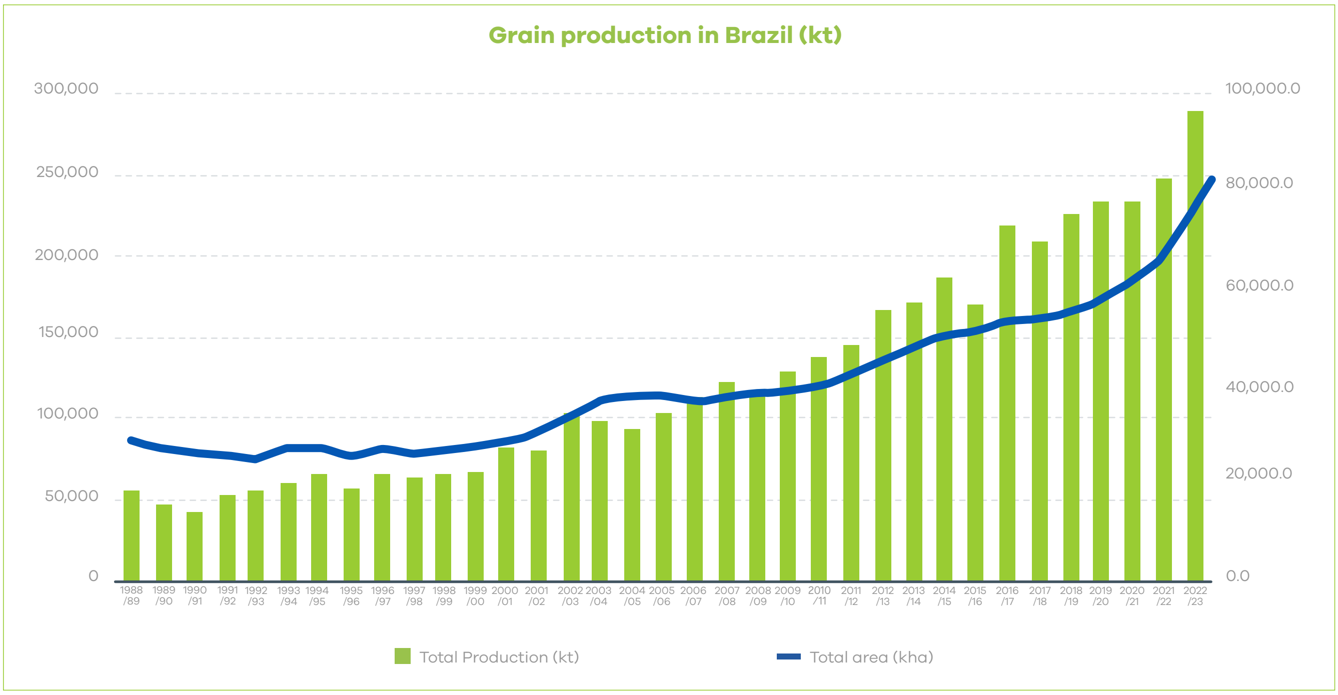

Figure 6. Evolution of harvested area, yield, and production of cereals (soy, corn and wheat) in Brazil[17].

Throughout two decades, the increase in agricultural productivity and implementation of second crops within the season, has allowed production to triple while land use only doubled and now occupies 69Mha (14% of the area covered by forest). In 2022, Brazil exported 27,3Mt of sugar, keeping its leadership in sugar exports globally, together with other commodities as shown in Figure 7.

	Soy	Coffee	Orange juice	Sugar	Chicken	Beef
Production	1st	1st	1st	1st	3rd	2nd
Exports	1st	1st	1st	1st	1st	1st
Exports global share	50%	33%	75%	36%	32%	24%

Figure 7. Brazilian ranking and share of some food crops[18].

[17]Portal de Informações Agropecuárias
[18]Panorama do Agro. A CNA defende, trabalha e fala em seu nome e de todos os produtores rurais do Brasil

Sustainable practices

Brazil has been cultivating sugarcane for centuries, but it was in the 1970s that it started investing in sugarcane to also produce bioethanol as an alternative to fossil fuels. Half a century of experience and investments in R&D, have helped the sector develop sustainable practices that are worth highlighting.

In the state of São Paulo, where 60%[19] of the country's sugarcane is planted, crop rotation with leguminous vegetables is a common practice that helps fix nitrogen in the soil. Hence, 15% to 20% of sugarcane producing areas are also used for the cultivation of soybean, beans and peanuts, supplying the food market.

Another remarkable practice is the biological pest control program. There are more than 3 million hectares where "natural enemies" (*Cotesia flavipes and Trichogramma galloi*) are used to control the sugarcane borer (*Diatraea saccharalis*) and Metarhizium anisopliae used to control the spittlebug (*Mahanarva fimbriolata*)[20]. This reduces the use of chemical pesticides that are only used when really needed. In order to preserve and restore biodiversity, some farms have established green corridors linking two protected areas. Braskem fosters the further development of these practices through its Responsible Ethanol Sourcing Program[21]. Furthermore, according to UNICA (Brazilian association of sugarcane industry), since 2007 when the Green Protocol was signed, their associated mills have planted over 46 million seedings to recover over 200kha of riparian areas and protected 7,315 springs. Sugarcane producers are increasingly monitoring bee populations and are using their permanent preservation areas to enhance habitats for them to thrive.

Figure 7. Sustainable practices in sugarcane: (1) Cotesia flavipes inoculating sugarcane borer (biological pest control), (2) Green corridors, (3) native tree nursery, (4) mechanical harvesting, (5) bee population monitoring.

[19]Boletim da safra de Cana-de-açucar
[20]Controle biológico da cana no Brasil é o maior do mundo
[21]Responsible ethanol sourcing

From a social perspective, the sector has gone a long way from relying on migrant labor, reportedly found to be working in extremely unfavorable conditions, to a new reality in which the focus is on retaining and developing local workers. The main driver for this positive agenda were clients and legislation both in Brazil and abroad (e.g. RED-II in Europe). Linked to the need to comply with legislation, third party certification schemes such as Bonsucro were created. A relevant fraction (over 10%) of the Brazilian sugarcane is Bonsucro certified. From the private sector, another responsible sourcing program worth mentioning is ELO from Raizen, the largest bioenergy company in Brazil, that recently received SAI (Sustainable Agriculture Initiative Platform) recognition. This program aims to promote the sustainable development of Raizen's sugarcane producers that must comply with 34 environmental, social, and economic sustainability criteria. It also aims to engage sugarcane suppliers in the progressive adoption of measures that encourage the promotion of economic sustainability, respect for the environment, human, and labor rights.

Regenerative practices in sugarcane have started way before this became a trend. A complete range of procedures that help enhance soil carbon content and biodiversity are shown in Figure 8. Clockwise from top right (1) part of the leaves and straw are left on the field increasing soil carbon and moisture retention, and preventing erosion[22] (2) direct planting without tillage also helps prevent erosion[23] (3) filter cake, a by-product from the sugar mill, helps fertilize and retain soil humidity[24] (4) Fertigation is the process of applying vinasse (an abundant by-product from the distillery) to the field in a controlled manner as a source of water and potassium (5) plantation of beans in between seasons helps fix nitrogen while providing an extra source of food and income to farmers[25].

Figure 8. Sustainable practices that promote healthy soil.

And finally, a very important national initiative that promotes the sustainable development of the biofuels sector in Brazil is **Renovabio**, the National Biofuels Policy that rewards producers with sustainable practices and **demands zero deforestation.**

[22]Shades of Green, Sustainable Agriculture in Brazil, Evaristo de Miranda
[23]O que é Plantio Direto?
[24]A aplicação de torta de filtro no canavial, além de nutrir ajuda a reter a umidade no solo. Mas é essencial ser aplicada com o equipamento correto
[25]Feijão com Cana

Expanding ethanol production helps protect biodiversity, recover soil and remove carbon.

Sugarcane ethanol production in Brazil reached a record of 34 billion litres in 2019[26]. An industry assessment[27] of potential areas for production expansion shows that land is available to supply the production of 205 billion litters of ethanol, without entering sensitive biomes such as the Amazon, Pantanal and Atlantic Forest. **The study scenarios considered the establishment of environmental reserves in 20% of the planted area** and considered that areas of forest, indigenous reserves, parks, etc., are not used for the expansion of sugarcane production. Another aspect to be mentioned is that the cultivation of sugarcane provides degraded pasture soil recovery. This data corroborates with the Brazilian sugarcane agroecological zoning program[28] and more can be found in a paper published by in the scientific journal Land[29] that reported a net carbon removal of 9.8 $TgCO2 \cdot yr^{-1}$ within the 2000 – 2020 period. When considering vegetation recovery, an even larger 17 $TgCO2 \cdot yr^{-1}$ were removed. Responsible farming in Brazil that follows the country's forestry code, is helping protect and restore nature in Brazil.

Future projections for bio-based plastics

There are many projections for plastics demand and feedstock[30]. Based on these different references we estimate that with the right legal incentives, approximately 20% of the plastics consumed by 2050 will be bio-based (the majority will be recycled). This would result in a demand of roughly 80Mt of bio-ethylene. In the hypothetical case of the full volume coming from sugarcane ethanol, that would translate to 182 billion litres, which is below the 205 billion litres sugarcane ethanol capacity mapped just in Brazil[26]. At the current agricultural yield this would require 26Mha of land. However, with the technological advancements in second generation feedstock (mainly cellulosic by-products), output per hectare is expected to grow 50%. In other words, production of 80Mt of PE would require 17,2Mha of land, which is roughly 2% of the country's territory and 6% of the arable land. What's more, considering responsible sourcing programs are in place and that producers are compliant with legislation, this would mean **at least 4,4Mha of native vegetation protected by the sugarcane farmers.**

External positions on the topic

A recent publication by the WWF America (Bioplastic Feedstock Alliance) 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 non-food 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"**

[26] Cana de açúcar - Industria
[27] Análise da ocupação do solo e impactos na biodiversidade: etanol e cana
[28] Sugarcane Agroecological Zoning - To expand production, preserve life, and ensure a future
[29] Guarenghi, M.M.; Garofalo, D.F.T.; Seabra, J.E.A.; Moreira, M.M.R.; Novaes, R.M.L.; Ramos, N.P.; Nogueira, S.F.; de Andrade, C.A. Land Use Change Net Removals Associated with Sugarcane in Brazil. Land 2023, 12, 584
[30] Kähler, F., Porc, O. and Carus, M. 2023. RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. Editor: Renewable Carbon Initiative, February 2023. Available at

(WWF 2022)[31].

The choice of feedstock in any given case depends on many factors and is site specific. There is no "one-size-fits-all" solution.

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[32].

Conclusions and final reflections

The concern around land use and food security is valid and should be assessed for every supply chain and every country. However, the notion that food competes with materials for land is justified only if land is scarce and food is in shortage.

Within the cascading principle of biomass use, materials should have priority over fuels. For historical reasons, we are using 205Mha of land for biofuels, 291 times more than the current use for plastics. As these biofuels migrate to waste-based feedstock, a portion of the primary crops currently used can migrate to food and bio-based plastics, in line with the cascading principle.

Incentivizing the diversification of biomass use has positive social impacts such as the development of areas outside the great urban centres that are under high social and environmental pressure, while keeping a land buffer for food production (supply and demand balance themselves with food having priority).

Many organizations are in favour of responsibly produced biopolymers including the UN and WWF. While there are many stakeholders who openly give preference to second generation (waste-based) feedstock, it is important to realize that this preference cannot be used as an argument for not using primary sources of biomass. We must drastically curb down the use of fossil fuels and we do not have the luxury of waiting for the maturation of new technologies based on waste, as climate change is in fact the biggest threat to biodiversity and our ecosystems.

[31]World Wildlife Fund (WWF) / Bioplastic Feedstock Alliance 2022: Methodology for the Assessment of Bioplastic Feedstocks. Washington, DC 2022.
[32]Dammer, L., Carus, M., Porc, O. 2023: The Use of Food and Feed Crops for Bio-based Materials and the Related Effects on Food Security. Renewable Carbon Initiative (ed.), Hürth 2023.

List of Figures