- IDEALFUEL -

Lignin as a feedstock for renewable marine fuels

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Publishable summary

This report aims to thoroughly examine the eligibility of lignocellulosic biomass, specifically forestry and agricultural materials, for biofuel production while ensuring sustainable practices in their production, handling, and utilization. The sustainability of these materials will be assessed and compared to other potential feedstocks for biofuel production. Compliance with sustainability criteria, as outlined in the Renewable Energy Directive II (REDII) (2018/2001/EU), including considerations of environmental impact such as Greenhouse Gas (GHG) emissions, indirect land use change (ILUC), deforestation, and biodiversity, will be evaluated. Socioeconomic impacts will also be discussed, along with emerging sustainability themes and voluntary schemes like International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB), as well as the concept of cascading use of biomass. Additionally, the report addresses the crucial issue of feedstock availability, particularly in the European Union (EU), emphasizing the significance of efficient forest, agricultural, and waste management. The report includes a comprehensive table presenting collected information on the sustainability of various feedstocks applicable to biofuel production.

Contents

Abbreviations

Abbreviations	Definition
CO_2	Carbon Dioxide
EC	European Commission
EGD	European Green Deal
Eq.	Equivalents
EU	European Union
FFAs	Free Fatty Acids
GHG	Greenhouse Gas
IFPRI	International Food Policy Research Institute
ILUC	Indirect land-use changes
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability and Carbon Certification
Kt	Kilotons
Mt	Million tons
Mtoe	Million Tons of Oil Equivalent
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
RSB	Roundtable on Sustainable Biomaterials
SFM	Sustainable Forest Management
SOC	Soil Organic Carbon
UCO	Used cooking oil
WVOs	Waste Vegetable Oils

1 Introduction

The increasing demand for sustainable sources of energy and materials has made feedstock sustainability a critical issue for the bioeconomy sector [1]. Today, the main feedstock to produce biodiesel for the European market are vegetable oils [2], more specifically from rapeseed, palm, and soybean oil, Used Cooking Oil (UCO), and Waste Animal fats [3]. This brings the risk of a dramatic increase in demand for unsustainable feedstocks [3] since the latter are limited in their ability to cater to the entire demand for fueling. Hence, it is essential to diversify feedstock to alleviate the pressure on specific value chains and possibly reduce emissions throughout the production cycle [4].
The future of lignocellulosic biomass in Europe is looking bright with several innovations and trends on the horizon. There is a growing demand for biobased fuels and the forest and agricultural sectors have a unique opportunity to contribute to meeting this demand [5]. However, understanding the implications of using lignocellulosic biomass to meet EU objectives, and how biomass rests within the EU policy framework requires a look at the nature of biomass itself, the various legislation that influences biomass use, and a closer examination of what we understand to be 'sustainable' biomass [6]. Three main pillars should be considered for a comprehensive sustainability assessment of feedstocks, and these are the environmental, social, and economic impacts [7].
Lignocellulosic biomass is described as the organic matter resulting from living ecosystems including forests, cultivated land, and oceans [8]. It is mainly composed of cellulose (9%–80%), hemicellulose (10%–50%), and lignin (5%–35%), and its biodegradability is highly affected by its composition [9]. Consequently, fuels derived from it are regarded as GHG neutral because the amount of Carbon dioxide (CO_2) released on combustion equals the amount adsorbed from the atmosphere and sequestered by the plant through photosynthesis [8]. Consequently, emissions emanating from biomass farming, harvesting, processing, transportation, and other segments along the value chain, inevitably give rise to what may be termed as nearly GHG-neutral fuels, rather than achieving a state of absolute neutrality [10]. As GHG generation rises, fossil fuel reservoirs are limited, and energy security is under threat, governments and organizations are increasing support for fuels from biomass[8].
Despite the suitability of woody biomass for energy production purposes through combustion, several studies have focused on converting this raw material into a series of value-added products through the biorefinery concept. Nevertheless, most of these studies have addressed converting the cellulose and hemicellulose, leaving aside the lignin content of woody biomass [11]. Existing lignocellulose-based biorefineries generate large-quantity side streams (e.g., hemicellulose, lignin, sugar derived condensed polymers) with limited accessibility for further conversion into valuable bio-based products, with the result that parts of these streams are currently burnt for energy recovery. Lignin is the main side product as its complex structure makes it difficult to process it. The challenge is to enable the conversion of lignin-rich residual biorefinery streams into higher-added-value applications with a view to improving the sustainability and cost efficiency of the whole lignocellulose-based biorefinery concept [12].
The overall goal of IDEALFUEL is to enable the utilization of lignin from lignocellulosic biomass and to generate a renewable marine fuel. Woody materials, however, not excluding different agro, herbaceous materials are assessed for being suitable, here. Beyond the technical suitability of these feedstocks, it is crucial to study and discuss several criteria that contribute to their overall sustainability in this report.

1.1 What is Lignin?

Lignin is a natural polymer found in the cell walls of trees and other plants[13]. It is the second most abundant natural polymer on earth, after cellulose [14], and it acts as a glue that holds the cellulose fibers together, providing structural support to the plant [15]. It can be utilized as raw material and processed as a renewable and sustainable alternative to petroleum-based products [12]. It is also a by-product of the pulp and paper industry, which makes it a cost-effective and readily available raw material [16]. Lignin has several unique properties that make it an attractive option for various industries [17].

1.2 Types of feedstocks that can be converted into biofuels.

Dedicated Energy crops are grown specifically for their utilization in energy conversion processes in ways that do not displace food production. These crops are often referred to as cellulosic biomass and are further classified into herbaceous and short-rotation wood crops (fuel wood) [18]. Herbaceous energy crops contain little to no woody material and are exemplified by grasses. Common examples include switchgrass, miscanthus giganteus, and energy cane. Short-rotation woody crops are softwoods and hardwoods with short harvest rotations. Common examples include hybrid poplar and eucalyptus [19].

Oil crops are a wide range of crops produced for oils which are extracted from their fruit and seeds. Many of these crops, notably seed cotton, coconut, sunflower, rapeseed and palm are among the most widely grown crops globally [20,21].

Waste Vegetable Oils (WVOs) are predominantly triglycerides (TGAs) that are no longer suitable for consumption [22]. Processed vegetable oils from sunflower, soybean, rape, and other plants have already been utilized for the generation of biofuels [23].

Waste Animal Fats are obtained from meat processing industries, tanneries, and slaughterhouses seemed like suitable feedstock for biofuel synthesis due to their renewable nature, good calorific value, chemical inertness, and zero corrosivity. The main sources of animal fats are beef, tallow, poultry, and lard fats [24].

Agricultural residues (primary residues) are renewable, chiefly unexploited, and inexpensive [25] feedstocks like rice straw, wheat straw, oilseed husk, rice husk, and corn stover, which are mostly left on the fields after the primary agricultural product has been harvested. Conventionally are used for fodder and landfill material or burnt in many places [26].

Agricultural waste (secondary residues) encompasses unwanted waste generated because of agricultural processing rather harvesting activities [27]. Examples of agricultural waste include cake, peels, seeds, and pulp from fruit and vegetable processing, as well as other non-harvested parts of crops or plants [28]. If not utilized properly, it can lead to ground and water pollution [29].

Two main segments of forestry biomass are **primary and secondary forestry residues** [30]. They are a renewable energy source since new forests can be developed through afforestation and appropriate maintenance [31].

Primary forestry residues refer to the woody material such as tops and limbs that remained/ left after harvesting or thinning of forest management. These leftovers can be utilized either as raw materials for wood-based products or as feedstock for generating energy and biofuels [32].

Secondary forestry residues are defined as residues from forest-based industry feedstocks and includes bark, chips, sawdust, black liquor and tall oil from sawmills and pulp mills, amongst other by-products from processing wood [33]. Processing mill residues are the main secondary sources of forestry biomass [30]. For instance, **sawdust** is a waste from the wood and timber industry. As it possesses a firing capacity, it is normally used as a fuel source in thermal processes (biomass) [34]. Another example is the **Black liquor** is a by-product of the pulping process in the paper industry. It is a liquid waste that contains lignin and other wood components and can be used as a fuel for energy production [35].

Forest residues can be provided in various forms in the market, depending on their intended use and the processing required.

Wood chips are small-to-medium-sized wood fragments created by cutting and chipping big pieces of wood such as trees, logging leftovers, branches, roots, stumps, and wood debris. Residual forest products, such as tree limbs, tree crowns, unsaleable materials, or undersized trees, can also be used to make wood chips. Forestry activities offer the raw materials needed to make wood chips [36].

Wood pellets are small cylindrical pieces 10–20 mm long with diameters varying from 5 to 10 mm produced from fine-ground wood bark. They are usually used as fuel by feeding into burner automatically because of their small and fixed form [37].

2 Sustainability Challenges and Considerations for Biomass Production and Biofuels Utilization

Biomass production involves a chain of activities ranging from the growing of feedstock to final energy conversion. Each step along the way can pose different sustainability challenges that need to be managed [38]. Hence, sustainable production and utilization of biomass are important for a true limitation of the dependency on fossil fuels and to reduce GHG emissions [39].

Current conventional biofuels are produced from food crops, such as sugar, starch, and vegetable oil while advanced (second and third generation) biofuels are produced from feedstock that does not compete directly with food and feed crops, such as wastes and agricultural residues (i.e., wheat straw, municipal waste), non-food crops (i.e. miscanthus and short rotation coppice), forestry residues and algae [40].

Feedstock production and exploitation can plausibly influence numerous aspects positively or negatively based on their management. These aspects are GHG emissions, atmospheric pollution, water consumption/pollution, deforestation, biodiversity loss, rural development, energy security, health, and social conflicts, among several others [41]. According to the Intergovernmental Panel on Climate Change (IPCC), direct land use change (dLUC) is a change in the use or management of land by humans, which may lead to a change in land cover. Whereas indirect land use change (iLUC) refers to shifts in land use induced by a change in the consequence of market mechanisms or political measures inducing additional demand for biomass or land [42]. For instance, LUC around the world was induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels. This phenomenon creates competition with the global food supply chain and leads to socioeconomic impacts e.g., higher food prices and food security [41].
Consequently, to truly have a sustainable biomass is crucial to consider the following: (i) the regeneration rate of biomass, (ii) the renewal of other resources needed for biomass growth, (iii) the availability of land and soil quality (iv) losses of biodiversity and ecosystem services from areas from which resources are extracted [43]. Hence, the environmental, social, and economic impact must be studied and considered before the extensive valorization of certain feedstock [7]. Based on these aspects, the Overview Table of Section 10 collects information related to the sustainability of feedstocks.

3 Environmental impact

In the context of **GHG reduction**, fossil fuel consumption emerges as a leading cause of climate change. To address this pressing issue, biofuels have garnered attention as potential solutions due to the inherent CO_2 circularity within their life cycle [10]. Emissions that are resulted from combustion of fuels fall into the category of **direct emissions** [44]. While fossil fuels release an array of harmful byproducts, including sulfur dioxide, mercury, and particulate matter into the atmosphere, combustion of fuels from biomass yields fewer deleterious emissions, leading to a discernibly cleaner air [45]. Biofuels may emit CO_2 upon combustion, but since the carbon was initially extracted from the atmosphere by plants during photosynthesis, they appear to be an effective solution for reducing emissions; they can be distinguished based on various factors such as the type of feedstock, the conversion process, the technical specifications of the fuel, and its intended use. As a result, the reduction of GHG emissions and their environmental profile can also vary depending on these factors [46]. Regarding the efficacy of biofuels, Jeswani et al. underscore the substantially lower Global Warming Potential of second-generation biofuels when juxtaposed with fossil fuels [44]. Nevertheless, the diverse range of emissions values found in different studies and feedstocks underscores the complexity of the biofuel landscape, with biodiesel emissions varying from -88 to 150 g CO_2 eq. MJ^{-1} [46]. It is noteworthy that exploiting lignocellulosic biomass results in **processing emissions** since it can be energy intensive to convert this natural polymer into biofuels. Every process result in different amounts of direct emissions [44]. Moreover, other emissions are related to the **transportation** of feedstock from farmland to production plants[10].
Non-food feedstocks may spur **indirect emissions** when diverted to produce biofuels instead of using them for their traditional application. Those other uses require substitute inputs, which have their own GHG footprints. For instance, converting inedible tallow to biofuel reduces its availability for soapmaking and livestock feed. Substituting with materials of higher emissions elsewhere may be necessary. In other words, the use of low-emissions secondary materials for biofuels may prompt the use of high-emissions materials elsewhere [47]. Another example, sawmill residues are primarily used in heat and power production and as a low-cost material for the fiber products industry. Diverting them to biofuels might result in substantial indirect emissions due to the high GHG emissions associated with their likely substitutes, pulpwood, and natural gas [47].
Land Use Changes - According International Food Policy Research Institute (IFPRI) MIRAGE 2011 model results, oilseed crops (such as soy, sunflower, rapeseed, and palm) to produce vegetable oils show higher LUC emissions while feedstocks like wheat, maize, sugar beet or cane result in lower LUC emissions *(see Table S1 in Appendix)* [48]. In addition, the Globiom report which was written by IIASA, Ecofys and E4tech and commissioned by the energy directorate-general of the European Commission, only calculates LUC emissions resulting from additional demand for biofuels in Europe and it analyses more feedstocks (see next **Error! Reference source not found.**)[44]. A s a second step, emissions from cultivation, transport, etc., are also taken into account. This leads to the following Figure 1 that is sourced from the Globiom study [44].

Important conclusions drawn from this study are that energy crops for production of vegetable oils have high LUC emissions since are usually grown in the tropics, leading to high risk of tropical deforestation and associated peatland drainage. The Union of Concerned Scientists lists palm and soy as two of the four major drivers of tropical deforestation – together with beef and wood. Globiom highlights the link between palm expansion and deforestation/peat loss. Annually harvested crops store less carbon than land left abandoned, allowing grasses, trees and other vegetation and their carbon-storing roots to develop. Energy from plants that are not harvested annually, i.e., of which the roots are allowed to develop and store carbon (willow, poplar, miscanthus, switchgrass) score far better. According to Globiom, they even have negative LUC emissions, meaning that cultivation of these plants typically stores more carbon than leaving the land untouched [44].

As it has been mentioned before, ILUC is caused when agricultural production is redirected to make room for biofuel expansion, potentially resulting in increased GHG emissions [49]. The low-ILUC risk status for feedstocks involves the cultivation of crops that meet additional conditions and can be produced through smart, sustainable, and low input **agricultural practices**, which in return are expected to contribute to climate change mitigation and soil quality. These include carbon sequestration through carbon farming**. Carbon farming** refers to land practices in agriculture and forestry leading to the storage of carbon from the atmosphere in biomass, organic matter, soils, and vegetation [50].

Table 1: LUC GHG emissions from Globiom [44]**.**

Adapted from Mirage and Globiom studies.

Type of fuel	Feedstock	Emissions from LUC (CO_2eq. per MJ)
1G bio diesel	Rapeseed	65
	Palm	231
	Soy	150
	Sunflower	63
1G bio ethanol	Maize	14
	Wheat	34
	Sugar Beet	15
	Barley	38
	Sugar cane	17
Non-food based	Perennials *(e.g., switchgrass and miscanthus)*	-12
	Short-Rotation Coppice *(e.g., willow and poplar)*	-29
	Forest residues	17

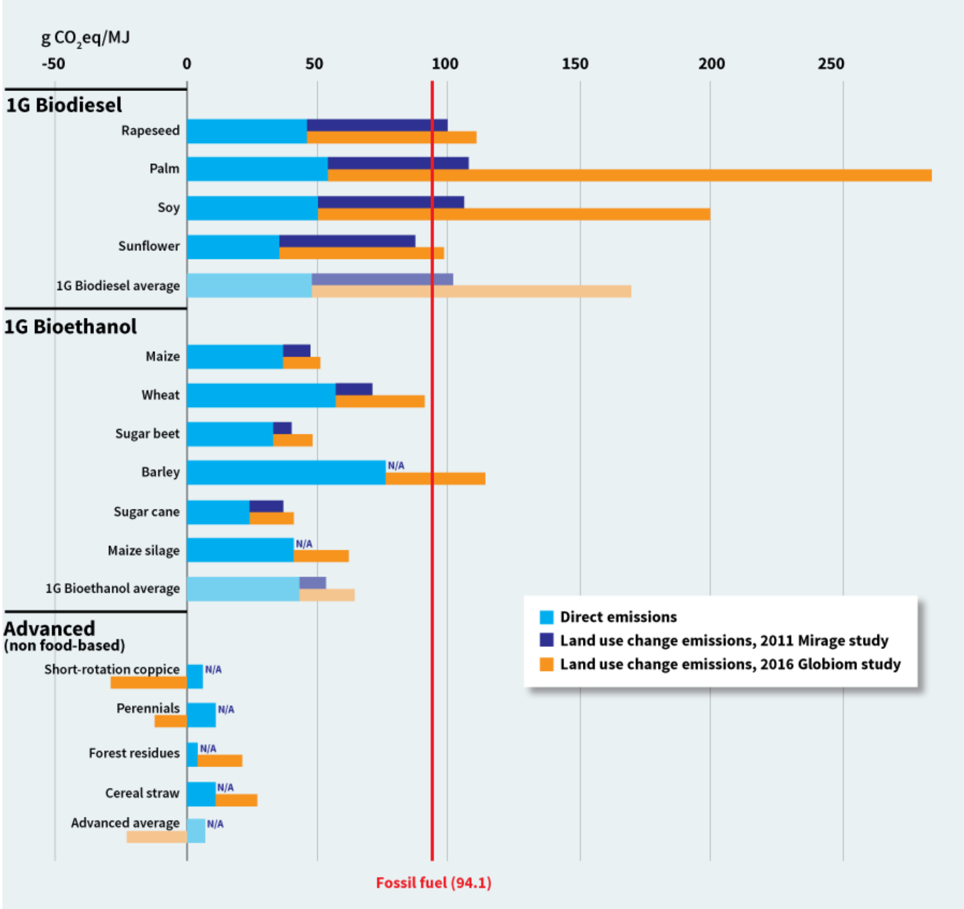

Figure 1 Emissions of biofuels made from different feedstocks, composed of direct emissions (from RED) and land-use change emissions [44]**.**

Extracted from Mirage and Globiom studies

Forest/ Woody biomass removals - An essential practice in **forest management** is leaving a portion of the biomass from felled trees as primary logging residues on the ground, rather than removing it entirely. Excess removal of residues from forest sites implies the removal of nutrients and organic matter, affecting soil and, indirectly, influencing competing vegetation and soil microclimate. As a result, it could change the physical properties of the soil, lower forest productivity and soil carbon, and have negative impacts on biodiversity. However, the outcomes are highly dependent on the location, making it difficult to draw broad conclusions about the potential consequences. For instance, in areas at risk of fires, removing more residues can be a beneficial management practice as it reduces fuel load and mitigates fire hazards [49].

Biodiversity – Exploitation of biomass might contribute to the loss of biodiversity through habitat loss and degradation, excessive nutrient load and other forms of pollution, over-exploitation, and unsustainable use of land, as well as the cultivation of invasive species used as feedstocks [50]. The use of forest and agricultural residues as feedstock is expected to have a lower negative impact on biodiversity than dedicated energy crops [51]. Some of the impact on biodiversity associated with the use of forestry residues includes a reduction in the amount of decaying wood—a niche habitat—and disturbance of wildlife caused by increased forest access. Excessive removal of agricultural residue from fields would also be a concern as it may increase weed growth, which could lead to the increased use of herbicides and thus affect local biodiversity [46]. More specifically, selectively reducing brush can still reduce the risk of wildfires spreading. Exposing underbrush and groundcover to rainfall decreases the change of it drying out and creating optimal, fire spreading conditions [45].

Fertilizer use can result in environmental problems, including contamination of the atmosphere and water sources. Nitrogen runoff and N_2O emissions (which is also GHG) must be reduced to address these issues and avoid the catastrophic consequences of climate change. Additionally, fertilizer byproducts can contaminate water wells in agricultural, forest areas [52]. For instance, woody crops grown on a shorter rotation (e.g., 3–4 years) require frequent fertilizer and herbicide applications, may be more than agricultural production, while woody crops grown on a longer rotation (e.g., >8 years) with less-frequent fertilizer and herbicide applications may be more similar to forestry [53].

Water use in the production of feedstocks can be high, particularly for first-generation biofuels. This is a concern where requirements for irrigation water for certain feedstocks might compete with water used for other purposes, such as food production [50].

To conclude, agricultural and forestry feedstocks can contribute to mitigation of climate change if the right management takes place.

4 Socioeconomic Impact

Economic of forestry and agricultural biomass resources

The valorization of forestry and agricultural biomass resources offers economic benefits, including rural economic stimulation, job creation, and economic diversification [45].

Woody biomass has the potential to generate both direct and indirect employment opportunities, contributing to economic growth in forested or rural regions. This increased employment can lead to higher output, whether woody biomass is part of a broader biomass industry or considered separately [54]. It is noteworthy that the number of direct and indirect jobs in the solid biofuels industry oscillated over the years in the EU amounted to 353 800 in 2021 *(note: this data refers to biofuels made from various feedstocks and not necessarily just from woody biomass)* [55]. However, job destruction occurs in ‘brown’ sectors whose activities get replaced by green sectors [56].

It is noteworthy that forest residues play a crucial role in regulating market prices for agricultural crops that are not used for bioenergy. In areas rich in forests, the relative abundance and low cost of forest residues reduce total production costs for agricultural crops [57].

In addition, by utilizing forestry and agricultural biomass resources, countries can reduce their dependence on foreign fossil fuel providers and improve their local economies. This promotes domestic resource utilization and decreases import costs, benefiting the national economy [45].

The utilization of biomass resources also contributes to economic diversification by creating alternative revenue streams and reducing reliance on traditional industries. This diversification enhances regional resilience and reduces the vulnerability of rural economies to external shocks [58].

Additionally, energy providers can benefit from tax credits and incentives due to the renewable nature of biomass, including residuals and waste. However, eligibility criteria need to be met to determine the suitability of different biomass types for these benefits [45].

Economic impact of other feedstocks

An economic impact related to UCO was recorded. More specifically, the high demand for UCO resulted in higher prices than virgin oil, leading to fraudulent activities like mixing virgin oil. This undermines market fairness and integrity, distorts supply-demand dynamics, and disadvantages legitimate suppliers. Measures have been implemented to prevent such occurrences in the future [59,60]. On the other, if UCO is mismanaged and disposed through sinks instead of recovered, then this leads to damage in the infrastructure and higher operating costs for wastewater treatments [61]. Recovering of WVOS led to a new market: 600 million USD/yr and growing rate of 4%, annually [61].

Low ILUC risk biomass from dedicated energy crops gives European farmers opportunities to diversify their agricultural activities and potentially generate additional income. However, profitability is significantly influenced by additional expenses such as fertilizers, labor, and land rehabilitation [62].

Social impact of exploiting biomass as feedstock

As it has been mentioned before, burning fossil fuels releases sulfur dioxide, mercury and particulate matter into the atmosphere which can cause asthma, cancer, and respiratory problems. Hence, avoiding this means healthier people [45].

Moreover, exploitation of agricultural or industrial waste leads to avoidance of disposal through landfilling and thus, limits health-related problems to the human population and animals [63]. Methane (CH_4) and CO_2 make up 90 to 98% of landfill gas while the remaining 2 to 10% includes nitrogen, oxygen, ammonia, sulfides, hydrogen, and various other gases. Short-term exposures to elevated levels of ammonia and hydrogen sulfide in air can cause coughing, irritation of the eyes, nose, and throat, headache, nausea, and breathing difficulties [64]. Alternatively, combustion of the waste results in smog that mobilizes particulate matter which is also toxic to the environment. Hence, exploiting this waste than disposing leads to limiting health related problems [28]. It is notable, handling forestry waste like sawdust needs to be careful since dust is carcinogenic for humans when it is inhaled [63,65].

Job creation by exploitation of forestry and agricultural residue can contribute to the well-being and livelihoods of local communities [45]. Work is widely recognized as the primary means of generating income, and as a result, the creation of jobs can significantly enhance material well-being, foster family stability, and initiate a positive cycle of reducing poverty. When individuals have access to decent employment that offers adequate income, ensures safe working conditions, and includes social protection coverage, it not only grants them a sense of dignity but also promotes their social integration in the long run [66].

By guaranteeing long-term energy security that is mentioned in the economic impact, the well-being of the local population can also improve [67]. Energy insecurity, characterized by limited energy access, can result in poverty, conflict, financial challenges, unemployment, and environmental exploitation. It exacerbates global inequality, hindering the progress of developing nations and disproportionately impacting individuals from lower-income backgrounds, perpetuating the cycle of poverty. Dependence on foreign energy sources can escalate tensions and lead to conflicts, with far-reaching social consequences such as political instability [68].

Last point to be mentioned in this report is the reduction of forest fires by removal of forestry residuals can indirectly have social benefits, such as protecting communities from the devastating effects of wildfires [45].

5 Legal framework: sustainability criteria

In 2019, bioenergy accounted for around 55% of the renewable energy in the EU, with woody biomass providing the lion’s share (75%) of bioenergy consumption, (followed by agricultural biomass (crops and residues) and biowaste. Energy-and climate policies and strategies foresee a substantial increase in the use of biomass and demand for bioenergy, largely due to policy priorities, GHG accounting rules, and biomass subsidies [6].

Understanding the implications of using biomass to meet EU objectives, and how biomass rests within the EU policy framework requires a look across the nature of biomass itself, the various legislation that influences biomass use and a closer examination of what we understand to be ‘sustainable’ biomass [6].

In the last few years, the European Commission has adopted multiple initiatives that set goals towards decoupling economic growth from resource use; The European Green Deal (EGD), protecting biodiversity (The Biodiversity Strategy), mitigating climate change (Stepping up Europe’s 2030 climate ambition) and, in general, increasing the economy's sustainability and circular use of resources (Bioeconomy Strategy, Farm to Fork Strategy, Circular Economy Action Plan). In all these initiatives, biomass is a key resource [69].

More precisely, the EGD encompasses policy measures aimed at achieving climate neutrality by 2050 through a comprehensive and cross-cutting approach. It includes initiatives covering various areas such as climate change, environment, energy, transport, industry, agriculture, and sustainable finance [30]. Fit for 55, a part of the EGD, is an extensive package of policies and tools that aim for a 55% reduction in emissions across sectors by 2030, as compared to 1990 levels [70].

5.1 RED - Renewable Energy Directive

The EU-RED has been introduced in 2009 and specifies a set of sustainability criteria such as GHG emissions, biodiversity loss, and food security, that must be met before certain biofuel practices can be widely adopted within the EU [71]. The RED was revised in 2018 and is legally binding since June 2021 and the Commission proposed another revision to accelerate the take-up of renewables in the EU and to help reaching the 2030 energy and climate objectives [72]. The revision of RED II that leads to Red III is one of the initiatives of Fit for 55 package which is part of EGD.

The RED II sets a cap for food- and feed-based biofuels that could contribute for a maximum of a 7% share to the total final energy consumption of EU road and rail transport sectors. RED II also defined targets to reduce the consumption of high ILUC-risk feedstock -such as virgin vegetable oils- to produce biofuels, starting in 2023 and reaching a complete phase out by 2030. Today, the main feedstock to produce biofuels for the European market are vegetable oils [73]. According to RED II, an initiative from the EU, the use of fuels produced from feedstocks that do not cope with food security and/or represent a potential risk for land use change, will be gradually phased out by 2030 [74].

According to the directive, advanced biofuels are defined as liquid or gaseous biofuels made from materials listed in Part A of the Annex - mostly produced from residual streams. They have a specific sub-target starting at 0.2% in 2022, at least 1% in 2025, and increasing to at least 3.5% in 2030 [75]. This is the list of feedstocks to produce biogas for transport and advanced biofuels, the contribution of which towards the minimum shares referred to in the first and fourth subparagraphs of Article 25(1) may be twice their energy content:

- Algae - cultivated on land in ponds or photobioreactors.
- Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.
- Biowaste as defined in point (4) of Article 3 of Directive 2008/98/EC from private households subject to separate collection as defined in point (11) of Article 3 of that Directive.
- Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.
- Straw
- Animal manure and sewage sludge
- Palm oil mill effluent and empty palm fruit bunches
- Tall oil pitch
- Crude glycerin
- Bagasse
- Grape marcs and wine lees
- Nut shells
- Husks
- Cobs cleaned of kernels of corn.
- Biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, precommercial thinning, leaves, needles, treetops, saw dust, cutter shavings, black liquor, brown liquor, fiber sludge, lignin and tall oil
- Other non-food cellulosic material
- Other ligno-cellulosic material except saw logs and veneer logs.

Those outside of this list are not considered for advanced fuel production; therefore, the emissions attributed to production phase are accounted [76].

The following are expected to be included in a later stage:

- Alcoholic distillery residues and wastes (fuel oils) are not fit for use in the food or feed chain.
- Raw methanol from kraft pulping stemming from the production of wood pulp.
- Non-food crops grown on severely degraded land, not suitable for food and
- feed crops.

Part B covers UCO and animal fats (category I and II in accordance with Regulation (EC) No 1069/2009) and it is subject to a cap at 1.7% of transport energy. All the biofuels produced from the list may be considered twice their energy content towards the transport of renewable targets. Multipliers are seen as a tool to strengthen support to alternative fuels that are not food and feed-based biofuels, with a view to bringing new fuel technologies to the market [75]. Moreover, on the 14th of February 2023 a draft Delegated Act has been published, which regulates the feedstock and production of Renewable Fuels of Non-Biological Origin (RFNBO), like Green Hydrogen and e-fuels [77].

In addition, the waste hierarchy is a core principle that should guide member states' decisions regarding biofuels. There is a clear reference to it in article 3 (3) of the RED: "Member States shall ensure that their national policies (…) and their support schemes, are designed with due regard to the waste hierarchy as set out in Article 4 of Directive 2008/98/EC to aim to avoid undue distortive effects on the raw material markets." The waste hierarchy indicates the hierarchy that should apply regarding waste prevention and management: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g., energy recovery; and (e) disposal. Hence, the directive gives the possibility to member states to adopt legislation that restricts the use of certain waste streams to a higher priority order [78].Consequently, the development of a coherent legal framework for feedstocks used in biofuel production is crucial for ensuring their sustainability. The EU introduced a number of sustainability criteria such as the RED to be respected by economic operators. The sustainability of most biofuels placed on the EU market is certified by voluntary schemes recognized by the Commission [79].

5.2 Forest and Agricultural management practices and regulations

In addition, sustainable forest management practices are also necessary to be regulated by the EU. For instance, the EU forest strategy for 2030 is one of the flagship initiatives of the EGD. The strategy sets a vision and concrete actions to improve the quantity and quality of EU forests and strengthen their protection, restoration, and resilience [38].

Forest biomass, requiring bioenergy generators to demonstrate that the country of origin has laws in place a) avoiding the risk of unsustainable harvesting and b) accounting of emissions from forest harvesting. If such evidence cannot be provided, bioenergy generators need to demonstrate sustainability compliance at the level of the biomass sourcing area [38].

Moreover, for agriculture waste and residues, requiring evidence of the protection of soil quality and soil carbon, and for agriculture biomass, requiring evidence that the raw material is not sourced from highly biodiverse forests [38].

5.3 Cascading use of biomass

The cascading concept has been emphasized in the EU Bioeconomy Strategy, the EU Circular Economy Package, and the EU Forest Strategy. As of September 2015, the cascading principle is also part of EU legislation as part of the so-called "iLUC Directive" [80]. Cascading use refers to the efficient utilization of biomass resources through the utilization of residues and recycled materials, which extends the availability of biomass within a given system. This concept can be quantified through wood flow analysis, specifically at the market level, considering different sectors and products [81].

The technical aspect of wood cascading involves the processing of wood into a product that is subsequently reused, either for material applications or as a source of energy, ensuring that it is used at least one more time [82].

- In a single stage cascade, wood is processed into a product and this product is used once more for energy purposes [82].
- In a multi-stage cascade, wood is processed into a product and this product is used at least once more in material form before disposal or recovery for energy purposes [82].

An example of cascading wood use is presented in the following figure (Figure 2) and it basically explains the no, single stage, and multi-stage cascading use [83].

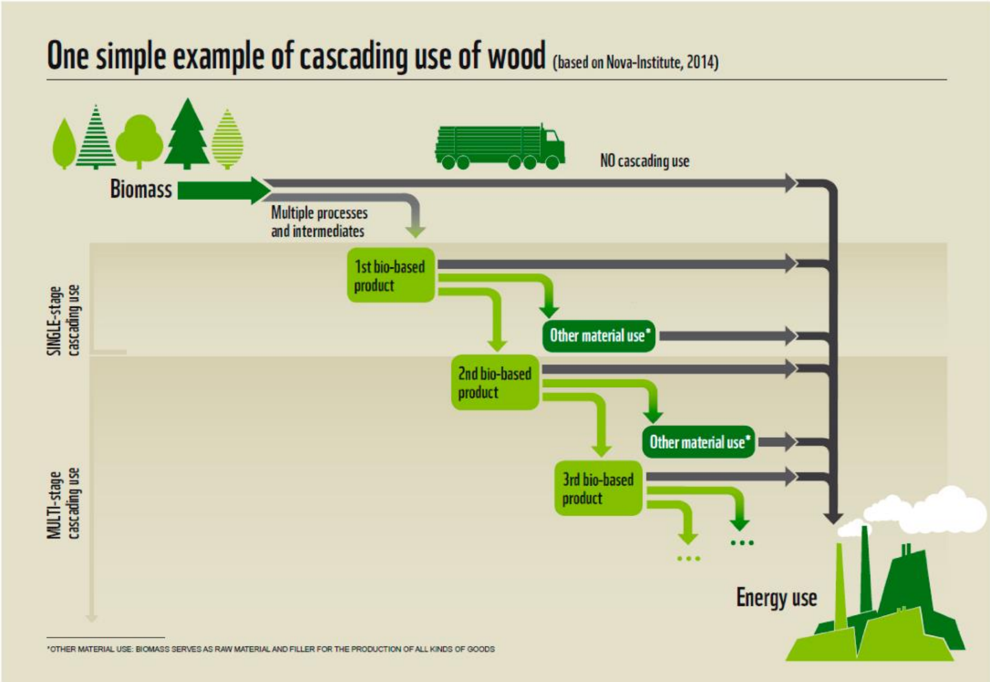

Figure 2 **Cascading use of wood** [83]**.**

Extracted from: Cascade Use of Wood in the Czech Republic

Measures to promote cascading primarily focus on recovering post-consumer wood in alignment with circular economy and resource efficiency initiatives. However, it is crucial to address the current imbalance between material and energy uses of industrial residues to fully capitalize on the significant potential for cascading [81].

6 Certification

The RED II introduced the concept of certified “low ILUC-risk” biofuels, bioliquids, and biomass fuels. These are produced from feedstocks that avoid food/ feed crop displacement through one of two additional pathways: (i) yield increases from improved agronomic practices, or (ii) cultivation of areas not previously used for crop production (including areas with natural constraints, such as unused, abandoned, or severely degraded land) [62,84]. The value proposition for delivering low ILUC-risk certification of other crops is not yet clear, and the creation of value for low ILUC-risk projects may be dependent on Member State policy action [62]. Lignocellulosic material is treated more favorably under the REDII. Biofuels produced from lignocellulosic materials are treated as advanced and are eligible to be counted twice towards RED II targets, and there is no limit on the contribution of fuels from lignocellulosic material [62].

6.1 RSB (*Roundtable on Sustainable Biomaterials)* EU RED FUEL CERTIFICATION

The RSB EU RED Fuel Certification is intended for companies involved in the production, trade, processing, or transport of biofuels from biomass in the EU. It has been acknowledged by the European Commission as a means of demonstrating compliance with the RED and the RSB's rigorous sustainability principles. The certification encompasses primary biomass such as oil or sugar crops, as well as biomass derived from end-of-life products and industrial/ processing residues such as UCO, agricultural and forestry residues, and animal fats. Its objective is to ensure that biofuels are produced in a manner that promotes positive long-term environmental and social impacts and that meets the EU's sustainability criteria and traceability requirements for biofuels and bioliquids. Currently, RSB is in the process of obtaining recognition under the revised RED II requirements [85,86]. The RSB Standard has

12 sustainability principles and criteria to address environmental and social issues with fuels from bio-based and advanced feedstocks [86];

- Principle 1: Legality.
- Principle 2: Planning, Monitoring and Continuous Improvement.
- Principle 3: Greenhouse Gas Emissions.
- Principle 4: Human & Labour Rights.
- Principle 5: Rural and Social Development.
- Principle 6: Local Food Security.
- Principle 7: Conservation.
- Principle 8: Soil
- Principle 9: Water
- Principle 10: Air Quality
- Principle 11: Use of Technology, Inputs and Management of Waste
- Principle 12: Land Rights

It is noteworthy that the following definitions based on RED are described on RSB EU RED Standard for Advanced Fuels (waste and residues) report; Agricultural Processing Residues are directly generated by first processors of agricultural crops (e.g., husks, shells), and that do not include residues produced on-farm (defined instead as agricultural residues) or from further downstream processing (defined instead as industrial processing residues). Waste is defined in point (1) of Article 3 of Directive 2008/98/EC as any substance or object which the holder discards or intends or is required to discard, excluding substances that have been intentionally modified or contaminated in order to meet this definition [87].

6.2 ISCC (International Sustainability and Carbon Certification) – certified biomass and bioenergy

The ISCC EU is the first and leading voluntary scheme also based on the RED, covering the environmental and social aspects of biomass production. Their certification's scheme covers the assessment of sustainable production criteria, management criteria, traceability documentation and an assessment of GHGs saving calculations. The ISCC certification scopes distinguish the following supply chain actors [88]:

- Primary producers, certification not mandatory (farm, plantations, points of origin of waste and residues).
- First gathering points/collecting points.
- Conversion units (output intermediate products or final fuel).
- Traders of raw/intermediate materials or final fuel [88].

7 Current consumption of biomass and future availability in the EU

7.1 The European agricultural biomass supply

In 2013, the overall supply of agricultural biomass in Europe was around 818 million tons (Mt) of dry matter of vegetal biomass equivalents, which includes crop economic production, collected crop residues, grazed biomass, and bio-based product imports [49].

Monforti et al. 2015 have estimated the availability of agricultural residues in EU and suggested an optimal collection rate for ensuring sustainable use of this type of biomass. More specifically, Figure 3 (left panel) shows the amount of residues available for energy uses in EU-27 with a 1×1 km resolution. The right panel reports the optimal collection rates as a percentage of produced residues to avoid negative impact on soil fertility [89,90].

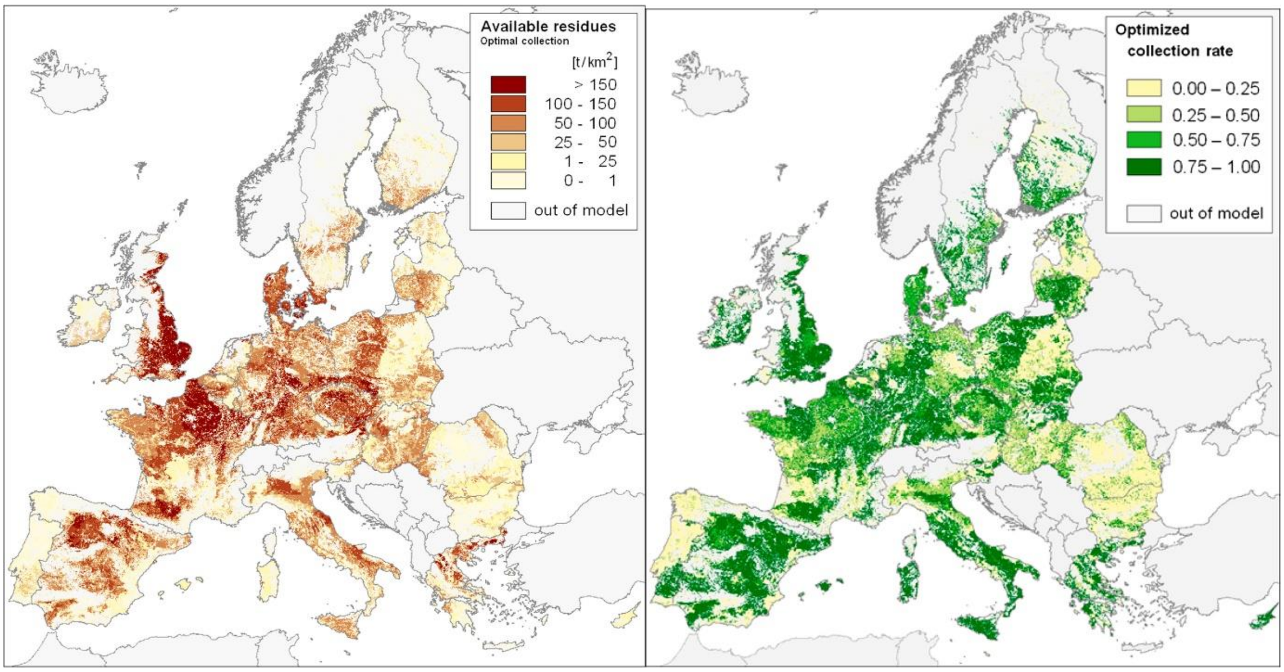

Figure 3 **Agricultural residues available for energy use in EU-27 in the assumption of optimal collection in t/km² (left) and Soil organic carbon (SOC) rates in terms of maximum fraction of residues available for collection (right). The resolution of both maps is 1×1 km** [89,90]**.**

Extracted from: Optimal energy use of agricultural crop residues preserving soil organic carbon stocks in Europe.

Residue management practices on agricultural lands need to be occurred since the residues have many positive impacts on soil quality. They can improve soil structure, increase organic matter content in the soil, reduce evaporation, and help fix CO_2 in the soil [91]. For instance, crop residue is an effective material that minimizes the erosion of soil by wind and water. They reduce the forces of wind and water that would otherwise act upon loose particles at the soil surface. They also provide thermal protection to plants from winter temperature extremes and insulate the soil surface from both winter and summer atmospheric extremes by impeding the movement of heat and water vapor between the soil and atmosphere. Crop residue, therefore, retards heat loss from the soil during winter as well as hinders warming of soil during summer [92].

7.2 Applications of Agricultural biomass

Agricultural biomass is mainly used as animal feed and food (around75% in vegetal biomass equivalents) and around 12% is exported. The conversion of animal-based food in vegetal biomass equivalents emphasizes their importance in the total food uses: animal-based food accounts for nearly one quarter of the food uses if not converted into vegetal biomass equivalents (i.e., feed eq.) but it accounts to approximately 80% of food use when expressed in vegetal biomass equivalents (note that food uses include food waste). The other 20% is made of plant-based and aquatic-based food consumed and wasted [49].

7.3 Current flows of residual wood within Europe

From a biophysical perspective, woody biomass resources are large enough to cover a substantial share of the world's primary energy consumption in 2050. However, these resources have alternative uses and their accessibility is limited, which tends to decrease their competitiveness with respect to other forms of energy [93]. The main importers of wood waste are Germany and Sweden with a yearly import of 600+ kilotons (kt). The Netherlands also imports non-hazardous wood waste from UK and Belgium for the feedstock of its bioenergy plants. The main exporters of non-hazardous wood waste are UK, the Netherlands and Norway. The combined exports exceed 1200 kt in recent years. The major exporter for hazardous wood waste is the Netherlands with a yearly average of 100 kt to Germany [94]. The availability and utilization potential of forest biomass depends on the annual increment in forest volume and the annual demand of stem wood for building and other applied industrial purposes [32].

7.4 EU forests and trends for wood demand

The forest sector can significantly contribute to mitigating climate change by sequestering carbon in forests and exploiting residuals for energy and materials [95].

Forest Area - Over 30% of the world's land area is covered by forests. Approximately 761 million m^3 of wood is harvested annually in Europe (2017) [96]. Forests are an important source of terrestrial carbon on land and play a crucial role in the environment [97]. In 2015, the total forest area in the EU-28 was 161 million hectares, which accounted for 38% of the land [49].

Forest expansion and management - In the EU-28, the forest area increased by about 413,000 hectares per year from 2000 to 2015. However, the expansion rate slowed down to 339,000 hectares per year from 2010 to 2015 [49]. Changes in management practices can lead to substantial (> 50%) increases in forest growth, which would increase the long-term future potential of biomass harvest [98].

Sustainable Wood Availability - The problem of wood availability and over-exploitation of resources is a common theme in the history of all European countries [95]. Hence, one crucial aspect related to the use of forest biomass is the time gap that usually exists between the release of carbon into the atmosphere and its subsequent sequestration [97]. Similarly, to agricultural residues, the constant addition of decaying tree residues in forest ecosystems might represent the primary source of SOC and nutrients to the soil which are utilized by trees for their regeneration and establishment processes. Consequently, managing forest residues according to the carbon content of the soil helps to minimize the ecological footprint of their removal [91].

Utilization of Forest Biomass - The growth of forests was significantly higher compared with removals between 1990 and 2010 in Europe, resulting in an annual average net carbon sink in the standing biomass [99]. According to a study from 2008, traditional high-value forest products such as lumber, plywood, and building products were in high demand. However, significant amounts of low value, undervalued, or unused woody residues, wood waste were underutilized [100]. Over the past few years, the utilization of forest biomass for generating heat and power has started growing due to the targets set by the RED. However, the present suggestions to modify RED, along with the significant policy ambiguity concerning the time after 2020, create difficulties in predicting how these patterns will develop in the future [101].

Forest-Based Industries - The EU forest-based industries are being impacted by various ongoing trends. The substitution of electronic information and communication technology instead of printed media is causing a reduced demand for graphic paper, while growing trade and e-commerce have increased demand for packaging paper. Engineered wood products and prefabrication have enhanced the competitiveness of wood in large-scale construction projects. New developments, such as forest biorefineries, are planned to be integrated with existing pulp and paper mills and companies or will be dependent on the side streams of production, and thus not expected to be economically attractive without the integration or collaboration with pulp and paper mills [102].

7.5 Applications of Woody Biomass in Various Industries

At present, there is a great demand for conventional high-value forest products such as timber, plywood, and various construction and consumer goods [100]. Wood waste is being used for producing energy in modern bioenergy plants in Germany, the Netherlands and Sweden [94]. Some experts believe biomass resources should be targeted for biofuel production rather than electricity generation. According to them, the electricity sector can eventually be decarbonized without biomass and by using solar, wind, geothermal, etc. Diverting biomass from power generation will have indirect consequences. While solar and wind electrification are still scaling up, relying solely on biomass for power may result in increased petroleum consumption in the short term due to the limited availability of alternative energy sources [101].

However, a significant quantity of low-value, no-value, or underappreciated woody residues and biomass remains unused. Common examples of currently undervalued, and often underutilized, lignocellulosic resources include suppressed growth small diameter timber from overstocked stands, forest residues (i.e., slash—tree tops, branches, and leaves), invasive species (e.g., saltcedar, oneseed western juniper, and eastern red cedar), woody landfill debris, construction and demolition wood waste, comingled postconsumer recovered paper, lumber and composites, paper mill residues, and both woody and agricultural crop residues [100].

7.6 Lignin application

Significant amounts of lignin are delivered to the market by pulp mills and biorefineries, and there have been many efforts to develop routes for its valorization. Over the years, lignin has been used to produce biobased chemicals, materials, and advanced biofuels based on its variable functionalities and physicochemical properties. It is noteworthy that several companies that are exploring the production of biofuels from lignin, either as a standalone product or as a co-product alongside other biofuels or bioproducts [103].
Today, lignin's applications are still limited by its heterogeneity, variability, and low reactivity. Thus, modification technologies have been developed to allow lignin to be suitable for a wider range of attractive industrial applications. The most common modifications used for this purpose include amination, methylation, demethylation, phenolation, sulfomethylation, oxyalkylation, acylation or esterification, epoxidation, phosphorylation, nitration, and sulfonation [104]
There are several companies that are exploring the production of biofuels from lignin, either as a standalone product or as a co-product alongside other biofuels or bioproducts [105]. For instance, the Dutch company Avantium, is also exploring the potential of lignin to produce bioasphalt [106]. Moreover, Vertoro has patented thermal solvolytic process (WO2019/053287) of lignin [107]. Bloom produces lignin based cosmetic and health care products [108].

7.7 Current and Future sustainable supply of biomass for materials and energy use in the EU

Biomass is currently the largest source of renewable energy in the EU, providing heat, electricity, and transport fuels. Its availability, competition between alternative uses of biomass, as well as sustainability issues, are major concerns for policy development and bioenergy deployment [109].
According to the Biomass Future project, the biomass sustainable potential is estimated to reach 351 million Tons of Oil Equivalent (Mtoe), of which 163 Mtoe from forestry, 143 Mtoe from agriculture, and 45 Mtoe from waste [110]. Solar's study also estimates the potential of sustainable biomass. The figure below shows projected total biomass potentials (RED II Annex IX, Parts A and B) for bioenergy production (transport, heat, and power) in 2030 and 2050. The estimated potentials for 2030 range from 520–860 million dry tons (208–344 Mtoe). For 2050, the range is similar, from 539-915 million dry tons (215-366 Mtoe). The potential remains stable due to sustainable land and water resource use, slow forest management improvements, and increased waste reduction and recycling commitments, including a 30% reduction in arable land by 2050 [111]. Hence, the availability and potential of biomass is only valuable when it is collected responsively, distributed wisely, and exploited from sectors like bioenergy.

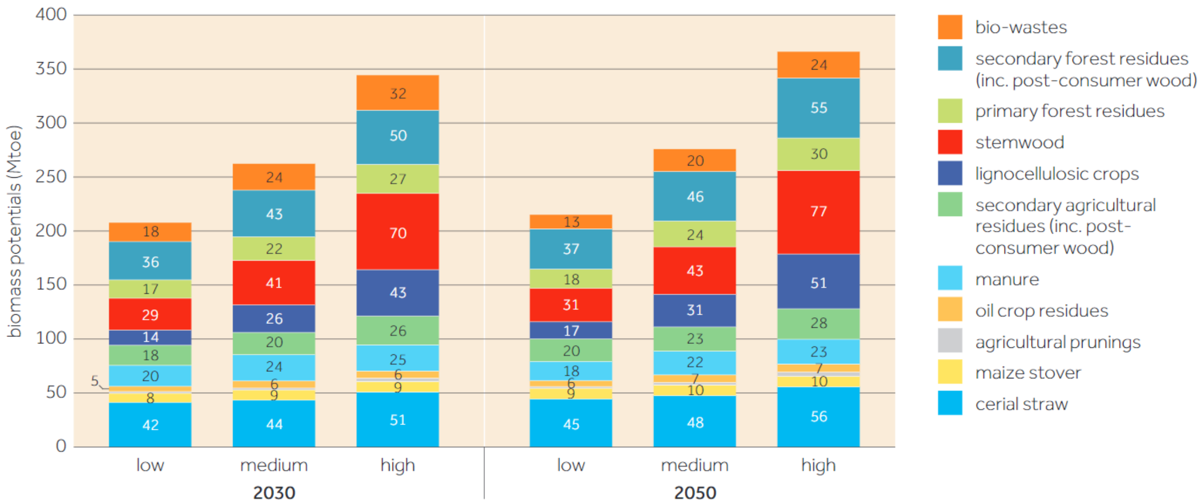

Figure 4 Estimated total sustainable biomass potentials (RED II Annex IX, Parts A and B) that can be dedicated for bioenergy in 2030 and 2050; bioenergy consists of transport, heat, and power [111].

Extracted from: Sustainable biomass availability in the EU towards 2050 (RED II Annex IX, Parts A and B)

A study from Material Economy examines current biomass utilization for biobased materials and energy and this together with the potential available supply in 2050 are presented in Figure 5. Currently, EU biomass comes from forestry, agriculture, and waste streams supply stands at 10.2 EJ per year. It is noteworthy that this is mainly used for heating, power, industry, and road but not for marine or aviation sector [112]. Primary forest residues (residue removals) amount to 0.6 EJ, while secondary forest residues from wood-processing industries account for 1.8 EJ. Agriculture occupies 39% of the EU's land and generates around 7.1 EJ of residues. A quarter of these residues are extracted for animal bedding (1 EJ) and energy production (0.7 EJ). Dedicated energy crops amount to 0.8 EJ annually, with most being food crops like wheat or sugar beet. Non-food or 'second-generation' energy crops represent only 0.1 EJ. Waste and recycled biomass contribute approximately 1.4 EJ or 14% of the total supply, mainly comprising paper and cardboard waste, wood waste, and municipal waste [112].

The future supply of biomass contains uncertainties in literature. First reason is that there is significant uncertainty even about current supply and consequently, there is high intrinsic uncertainty about the evolution of highly complex natural systems. Second, there are various views on what is required to achieve sustainability. Finally, high assessments tend to be for 'potentials' that do not consider the cost of supply which often rises steeply for hard-to-get resources. Especially for waste and residues, these are often very significant barriers. As a result, scenarios differ between almost no increase beyond current levels if summing conservative assessments across all categories, to as much as an additional 10 EJ if summing all the most optimistic or least constrained estimates. The analysis carried out for this study suggests a potential of 1–3 EJ additional supply from forests, waste and residues, and energy crops [112].

	CATEGORY	CURRENT SUPPLY	POTENTIALLY AVAILABLE SUPPLY 2050[1]	RANGE OF VALUES BASED ON EXISTING STUDIES[2]	*Comments*
WOODY BIOMASS	WOOD REMOVALS[4]	4.9	4.9-5.1	4.8-5.6	*Outtakes can rise by harvesting more of the forest growth. Sustainable supply is limited by biodiversity and soil health. The upper limit of 5.6 EJ is the total technical and sustainable potential without any economic considerations.*
	RESIDUE REMOVALS	0.6	0.6-0.7	0.4-0.8	*Supply from primary forest residues can increase with higher removal rates. Currently, 1/3 of the net annual increment of residues is harvested/ removed from forests. Changing the removal rate to 50% would increase the supply to 0.8 EJ, but this might create risks (carbon cycle, biodiversity).*
	INDUSTRIAL BY-PRODUCTS	1.8	1.7	1.6-1.7	*The supply of biomass from industrial by-products and residues is estimated to marginally decrease over time.*
AGRICULTURAL BIOMASS	AGRICULTURAL CROPS (ENERGY CROPS)	0.8	1.0-1.8	0.2-5.6	*The potential from energy crops varies by source and is dependent on land used for growing the crops. Currently 5-6 million hectares of land is used to grow energy crops in the EU – and the supply could increase 0.2 EJ per year if switching from the current food-crops to more efficient energy crops. Other studies estimate 5.6 EJ of crops in a sustainable manner, but this would require 35 Mha (nearly the size of Germany).*
	AGRICULTURAL RESIDUES	0.7	1.0-1.5	0.8-3.	*Harvest rates of agricultural residues can sustainably increase to 30%- 50% which would mean a supply of 2.1 to 3.5 EJ. The supply for materials and energy is lower than this as some of the residues will be used for food and feed (currently this value is 0.9 EJ). It will moreover be infeasible to harvest all these residues as mobilisation often requires changes in farming practices and because of the cost of harvesting and handling the biomass.*
RECYCLING AND WASTE	PAPER WASTE	0.6	0.8-0.9	0.5-1.0	*Available paper and cardboard waste will increase as the EU tries to minimize the amount of waste sent to landfill, and instead recycle or incinerate the paper that has reached its end of life.*
	WOOD WASTE	0.3	0.4	0.3-0.5	*Waste from wood is likely to increase modestly over time. Lower levels of landfill will increase the share of post-consumer wood that is either recycled or incinerated for energy. Today, 0.15 EJ of wood waste is permanently disposed to landfills or incinerated without using the energy.*
	OTHER WASTE[3]	0.5	0.8-1.0	0.5-1.2	*The supply from other waste streams will rise from better collection and better use of the waste generated.*
	TOTAL:	10.2	11-13	9-20	

Figure 5 Current and Future sustainable supply of biomass for materials and energy use in the EU - EJ per year [112].

Adapted from Material Economics: EU Biomass use in a net-zero economy.

8 Sustainability Risk Indication and Recommendation

The following sustainability risk indication offers an overview of various feedstocks used in biofuel production, with a focus on their environmental impact, feedstock availability, and socioeconomic implications. These factors play a crucial role in determining the sustainability risk of feedstocks. Table 2 presents one main positive and negative driver within each factor for every feedstock, with color-coded indicators representing the sustainability risk associated with each factor.

Approach

It is important to note that the color coding takes into account not only the main drivers mentioned but also the overall information provided in the entire report and the Overview Table in Section 10. The information and data were collected from multiple articles and reports. Based on the finding in the Overview Table and the main drivers, a score has been concluded per factor which is translated into a color based on a scale. Hence, the color (score) is not only based on the drivers mentioned here but on all the information collected.
A comprehensive definition of the various types of feedstocks has already been given in section 1.2. Brief definitions are also provided here to make the risk indication easier to interpret:
Oil crops are extracted oils from fruits or seeds and are usually edible [20,21].
WVOs mainly consist of TGAs that are no longer suitable for consumption [22].
Waste Animal Fats are obtained as byproduct from meat processing industries [24].
Dedicated Energy crops are grown specifically for utilization in energy conversion processes without displacing food production [18].
Primary forest residues are the woody material that remains after harvesting or thinning of the forest, prevenient from forestry management [32].
Agricultural waste is unwanted waste generated because of agricultural processing activities [27].
Secondary forest residues are residues from forest-based industry feedstocks, from the processing of woody material[33].
Agricultural residues are unexploited feedstocks, mostly left on the fields after harvesting [25].
The environmental impact considers aspects such as carbon sequestration, emissions, strain on water and food resources, and potential effects on biodiversity. Feedstock availability evaluates current supply and future uncertainties, while the socioeconomic impact examines the potential benefits and drawbacks in terms of energy security, job creation, and economic growth. By examining these aspects, stakeholders can make decisions regarding the selection and utilization of feedstocks for sustainable biofuel production. The feedstocks are listed in ascending sort from the more to less risky feedstocks for the sustainable production of biofuels.

Insights based on the Table 2

The insights drawn from Table 2 reveal a comprehensive perspective on sustainability risks associated with various feedstock sources. In general, it is evident that oil crops, waste vegetable oils (WVOs), and waste animal fats exhibit higher sustainability risk when compared to lignocellulosic biomass. Notably, oil crops stand out as having the highest level of risk, aligning with the EU's strategy to phase them out in favor of promoting waste and residue utilization. The limited availability of waste vegetable oils and animal fats contributes significantly to their elevated sustainability risk scores and is the main constraint.
Conversely, primary forest residues indicate a lower sustainability risk, benefiting from the ample forested areas within the EU capable of generating this resource. However, there is also a limitation on the number of residues that can be responsibly removed to preserve soil health. The sustainability risk associated with dedicated energy crops are heavily contingent on factors such as cultivation location (e.g., marginal lands without biophysical limitations) and appropriate crop selection based on geographic and climatic considerations, in addition to sound agricultural management practices. Further legislative clarity is essential to facilitate the growth of dedicated energy crops. Successful management in this regard could lead to increased availability of this feedstock.
Agricultural and forestry waste (secondary residues) can achieve a high level of sustainability performance when transformed into biofuels rather than being discarded in landfills, thereby mitigating greenhouse gas emissions. Finally, agricultural residues demonstrate the lowest sustainability risk in the context of biofuel production, and their availability can be increased through more efficient removal practices, especially if dedicated energy crop production expands.

Table 2 **Risk Indication on the Sustainability of Feedstocks to produce Biofuels.**

Note: *The color (score))per factor is not only based on the drivers mentioned here but, on all information/ data, collected in the Overview Table Section 10*

Feedstock	Environmental Impact		Feedstock Availability		Socioeconomic Impact	
	Positive driver	*Negative driver*	*Positive driver*	*Negative driver*	*Positive driver*	*Negative driver*
Oil Crops (edible)		Land Use Change Risk	Already used for biofuel production	EU is phasing out them out and boost wastes, residues	Energy security	Risk of causing food price increases, water use strain, potential shortage of food resources
Waste Vegetable Oils (e.g., UCO)	Avoids waste disposal env. Issues	Indirect promotion of waste generation	Already used for biofuel production	Availability is limited	limiting health-related problems (non-disposal)	UCO fraud in the past – higher prices than virgin oil
Waste Animal Fats	Avoids waste disposal env. issues	Indirect emissions in case of feedstock displacement **See overview Table*	Currently: 1.8 billion L of animal fat for biofuel prod.	Feedstock competition *e.g., soaps, cosmetics, lubricants*	limiting health-related problems (non-disposal)	High demand --> less affordable for traditional uses
Primary Forest Residues	Lower GHG emissions compared to fossils	Excessive removal may reduce soil fertility and impact biodiversity	Potential of higher removal rates	Max estimated supply in EU: 0.8 EJ	Job creation/ Economic growth in EU area with forestry activities	
Dedicated Energy Crops	Carbon Sequestration	Requires water, fertilizers	Supply could increase 0.2 EJ per year *(If energy crop will be grown in marginal land)*	Uncertainty on the availability of these crops due to land use policy/recommendation	Improvement of the communities' well-being due to jobs creation	Water security implications
Agricultural Waste **After processing*	Avoids waste disposal env. issues		Processing stage has high valorization potential	Improvements in processing technologies can lead to higher yields and reduced waste	Waste exploitation can generate revenue streams	
Secondary Forest Residues	Avoids waste disposal env. issues	Indirect emissions in case of feedstock displacement **See overview Table*	Current supply: 1,8 EJ	The supply will marginally decrease. *(EU strategies for reducing waste)*	Job creation/ Economic growth in EU area	
Agricultural Residues **After harvesting*	Lower GHG emissions compared to fossils	Excessive removal: soil erosion	Harvest rates can sustainably increase to 30%- 50%	There is a max. harvest rate	Job creation/ Economic growth in EU area	

High Risk

Low Risk

Recommendation

Based on the findings of this report, we offer the following recommendations to guide decision-makers and stakeholders in the biofuel industry. In the context of bioenergy production, it is crucial to diversify feedstocks by utilizing a range of biomass sources rather than relying solely on one. Diversification offers numerous benefits, including mitigating risks associated with supply disruptions and ensuring a reliable and stable biomass supply. It also optimizes the utilization of available biomass resources, leading to improved resource efficiency and economic opportunities in rural areas.

To achieve feedstock diversification, emphasis should be placed on utilizing non-food feedstocks, particularly lignocellulosic biomass such as forest residues, agricultural residues, and dedicated energy crops (especially in marginal and degraded land) such as willow, poplar, miscanthus, and switchgrass and waste resulted from agricultural and forestry practices. According to the previous assessment, these feedstocks indicate lower sustainability risk if managed well.

Supply of biomass from primary forest residues can increase with higher removal rates in the EU but currently are limited/ capped by directives. Similarly, harvest rates of agricultural residues can be sustainably increased to 30%-50%. It's also crucial to stress that responsible management of forestry and agricultural waste is paramount. By doing so, we can not only prevent environmental harm but also ensure that these valuable resources are utilized effectively in biofuel production rather than dispose. In addition to these practices, we recommend the cultivation of dedicated energy crops to meet future energy demands. Responsible forest, rural, and waste management practices are the bedrock upon which the valorization of these feedstocks' rests.

In conclusion, feedstock diversification is critical in alleviating commercial pressure along the biofuels value-chain. It is the key to achieve a more resilient and environmentally friendly bioenergy sector while supporting responsible land management practices and healthier progress. When selecting feedstocks for energy production, it is imperative to consider regional potential and prioritize the use of residue and waste materials.

9 Conclusion

In conclusion, this report has highlighted critical findings and insights regarding the sustainability of feedstocks to produce biofuels. The report emphasizes the importance of responsible management of forestry and agricultural resources to minimize adverse environmental effects on land use, water resources, biodiversity, and air quality. Therefore, lignocellulosic feedstocks, such as forestry and agricultural residues and dedicated energy crops can be considered sustainable and thus, they can play a critical role in achieving energy security, meeting GHG reduction goals.

Besides the GHG reduction contributions and energy security that these feedstocks can offer, they can also result significant economic and social benefits such as job creation, rural development, improving the well-being of humans and the establishment of a circular bioeconomy in EU.

In addition, the biomass supply used for bioenergy in the EU and that is currently sourced from forestry, agriculture, and waste streams, amounting to 10.2 EJ per year (note: this includes primary wood for power/ heat generation and the contribution of residues/ waste used for biofuels to the maritime sector is minimal at the moment). Availability of forestry and agricultural residue and waste in Europe presents promising opportunities for biofuel production. However, uncertainties persist regarding the future biomass supply due to the complexity of natural systems, varying perspectives on sustainability, and cost-related barriers, particularly for waste and residues.

EU legislation, such as the Renewable Energy Directive (RED) and certification schemes such as RSB and ISCC provide a framework that are essential for promoting sustainable sourcing and production practices. Compliance with these certifications and directives demonstrates a commitment to environmental and social standards, supporting the overall sustainability of the biofuel production process.

In conclusion, these findings highlight the significance of adopting a holistic approach to sustainable feedstock sourcing and production to ensure energy security, GHG reduction, and a sustainable future for the biofuel industry. Sourcing should be accompanied by data collection and traceability.

10 Overview Table

FEEDSTOCK	ENVIRONMENTAL IMPACT	FEEDSTOCK AVAILABILITY					SOCIOECONOMIC IMPACT		REGULATORY FRAMEWORK
Type	*GHG, Water use, deforestation etc.*	*Source*	*Prod. capacity in EU per year*	*Market demand for other application*	*Consumption of feedstock per year in EU*	*Relevant Notes*	*Economic*	*Social*	*Relevant regulations in EU*
Forest residues Primary	Forest residues: ~ 20% of carbon emissions compared to fossil fuel (fossil fuel = 100%) [44] LUC: 17 g CO_2 equivalent/MJ [44] **Not specified for primary or secondary* Excessive removal may reduce soil carbon and nutrients → Effect on the soil fertility, forest productivity on biodiversity. Forest fire risk: lower due to collection [44,49,113]	Leftover after the initial harvest: tops and limbs. [32]	Production capacity is 3 times bigger than the residues harvested and removed from EU forests. ~1.8 EJ of feedstock [112]	Biobased products and energy use [114]	For Biomaterials and energy use = 0.6 EJ of feedstock [112]	Availability depends on the forestry and logging activity in the region [114] The removal rate can increase from 33.3% to 50% [112]	Employment opportunities [45] Fostering economic growth [45] Economic diversification [58] Decreased dependence on foreign fossil fuels [115] Energy providers can benefit from tax credits and incentives [45]	By (a) job creation and economic growth (b) guaranteeing long-term energy security → improvement of the well-being of the local population [45,67]	<u>Directive 2009/28/EC</u> Included in RED II - Part A, Annex IX → eligible for advanced fuels. Biomass from forests should comply with the principles of sustainable forest management (SFM) <u>EU forest strategy for 2030</u> (EGD) [85,111]
Forest residues Secondary	Forest residues: ~ 20% of carbon emissions compared to fossil fuel (fossil fuel = 100%)[44] LUC: 17 g CO_2 equivalent/MJ [44] **Not specified for primary or secondary* Sawmill residues are used for heat/ power production and fiber products. Diverting them to biofuels might result in indirect emissions due to the high GHG emissions of substitutes (pulpwood, and natural gas) [47]	Forest-based industry: bark, chips, cutter shavings sawdust, black liquor, etc. [33]	222 Mm^3 (2015) (Bark and cutter shavings = 82.2 Mm^3) [114,117]	Power, heat generation, fiber products <u>Sawdust:</u> is utilized by pulp/ paper. <u>Bark:</u> combusted in boilers <u>Cutter shavings:</u> heat, construction material [117]	For Biomaterials and energy use = 1.8 EJ of feedstock [112]	The supply of these residues is estimated to marginally decrease over time. [112]	Economic diversification [58] Decreased dependence on foreign fossil fuels [115] Energy providers can benefit from tax credits and incentives [45]	Exploitation of waste → avoidance of disposal through landfilling or burning → limits health-related problems Wood dust is carcinogenic for humans (handling) [63,65]	<u>Directive 2009/28/EC</u> Included in RED II - Part A, Annex IX → eligible for advanced fuels. [111]

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	Reduced Env. Impact due to the exploitation of waste disposal [44,47,116]							Improvement of the well-being of the local population [45,67]	
Agricultural Residues	Cereal straw = ~25% of carbon emissions compared to fossil fuel (fossil fuel = 100%)[44] LUC: ~30 g CO_2 equivalent/MJ **Not specified for primary or secondary* [44] Present of residues in the field: Important for maintaining soil organic carbon levels in the soil or preventing soil erosion [44,91]	Field residues: cereal, straw, maize stover, leaves, husks, from oilseed, rice husk, [111]	Residues production = 7.1 EJ [112]	Animal feed, bedding, or bioenergy production [117]	For animal feeding = 1 EJ of feedstock Biomaterials and energy use = 0.7 EJ of feedstock [112]	FR, GE, SP, IT, ES: generate the highest amounts [118] Harvest rates of these residues can sustainably increase to 30-50% [112]	Employment opportunities [45] Fostering economic growth [45] Economic diversification [58] Energy autonomy: by reducing reliance on foreign fossil fuels [45,115] Energy providers can benefit from tax credits and incentives [45]	By (a) job creation and economic growth (b) guaranteeing long-term energy security → improvement of the well-being of the local population [45,67]	Directive 2009/28/EC Included in RED II - Part A, Annex IX → eligible for advanced fuels [111]
Agricultural waste	Waste causes env. Issues → waste management and exploitation are important. Avoidance of waste's combustions or landfilling that releases GHG [28]	Harvesting/ food processing byproduct: Cake, peels, seeds, and pulp from fruit and vegetable processing [28]	Waste production capacity from: Primary production = 32.2 Mt Processing/manufacturing = 30.5 Mt Distribution/ Retail = 6.6 Mt [119]	Biogas, bioelectricity, bio-bricks, fertilizer, and biochar [28]	For Biomaterials and energy use = 0.5 EJ of feedstock **Includes animal and mixed food waste, vegetal waste, household waste, and sludges* [112]	EU strategies for reducing waste. Processing stage has high valorization potential. [119]	Energy autonomy: enhance local economies by reducing reliance on foreign fossil fuels [45,115] Energy providers can benefit from tax credits and incentives. [45]	Exploitation waste → avoidance of disposal through landfilling or combusting → limits health-related problems [28,63] → improvement of the well-being of the local population [45,67]	Directive 2009/28/EC Included in RED II - Part A, Annex IX → eligible for advanced fuels [111]

Waste Vegetable Oils (WVOS)/ Used Cooking Oil (UCO)	Low ILUC LCA of Biodiesel from UCO = 12 - 19 g of CO_2e/MJ [120] Waste is exploited instead of dispose → avoiding pollution [61]	Resulted after consumption - From households, hotels, restaurants, and food businesses that utilize frying operations. [121]	4 million tons of WVOs (Not necessarily collected) 1/7 of the available amount is collected. [121]	Animal feed, industrial lubricants, soap, energy generation, composting, fertilizers 90% of WVOs collected are for energy purposes. [121,122]	1.6 billion litters of UCO for Biofuel production Current demand is very high. [121,123]	UCO in EU is mainly supplied from CN (34%), MY, ID Availability is limited. Max capacity to be reach by 2030 [123]	Recovering of WVOS led to a new market: 600 million USD/yr [61] High demand in EU resulted higher prices of UCO than virgin oil (fraud: mixing virgin oil) → improvements to avoid this [59] WVOS disposed through sinks → costly damage to infrastructure, higher operating costs for wastewater treatments [61] Energy security (limits dependency on fossil fuels) [59]	Mismanagement WVOS disposed through sinks → impacts public health [61] By (a) job creation and economic growth (b) guaranteeing long-term energy security → improvement of the well-being of the local population [45,67]	Directive 2009/28/EC Included in RED II - Part A, Annex IX – biowaste Waste edible oils at the end of their life cycle, must be valorized through their use as raw materials to produce added value products. Regulation (EC) No 1069/2009, deals with the processing of several raw materials, including catering wastes. [111]
Waste animal fats	LCA raw material → biofuel: −8.7 and 47.2 g CO_2 equivalent/MJ Animal fat is used for soapmaking vS biofuel- Indirect emissions may arise due to the need for displacement. Substituting with materials of higher emissions Water pollution - if not managed well: fat can contain nitrogen, phosphorus. Reduce/ exploitation of waste. [124]	From animal by-products [124]	20 million tons of Animal byproducts [125]	Food, soap/ cosmetics, animal feed, fertilizers Lubricants, plastics [126]	1.8 billion liters of animal fat for biofuel prod. Demand: ↑ [127]	DE - processes the highest volume of all 3 categories in EU—118,000* metric ton [127]	Employment opportunities New market [126]	Exploitation waste → avoidance of disposal through landfilling or combusting them → limits health-related problems to human [126] By (a) job creation and economic growth (b) guaranteeing long-term energy security → improvement of the well-being of the local	Categorization - Regulation (EC) No 1069/2009 Categories 1 and 2 fats are not fit for human food, oleochemicals or animal feed due to the high risk of contamination → in part B of Annex IX Category 3 are high-quality fats derived from animal by-products -> non eligible for biofuels. Commission Regulation (EU) No 142/2011 of 25 February 2011 implementing Regulation (EC) No 1069/2009: health rules as regards animal by-products and implementing Council Directive 97/78/EC as

								population [45,67]	regards certain samples and items exempt from veterinary checks at the border under that Directive. [111,125,128]
Dedicated energy crops (Nonfood, cellulosic)	Short rotation coppice =-25% of carbon emissions compared to fossil fuel (fossil fuel = 100%)[44] LUC: -29 – (-12) gr of CO_2eq per MJ Energy crops: low energy density → require large areas of land per kilowatt hour produced Effects with respect to water quality, carbon (C) fluxes, soil quality, watershed hydrology [18,19,44,53]	Herbaceous crops: switchgrass, *M iscanthus giganteus* Short rotation woody crops: hybrid poplar and eucalyptus [19]	Production: 0.8 EJ of dedicated energy crops uses 5.5 million ha **Almost all current energy crops are food crops refined to transport fuels* 60 million hectares of such land is available and 'surpluses. [112]	Traditional forest products and energy products (cellulosic ethanol and power generation) through direct firing, co-firing, or wood pellet systems [129]	Biomaterials and energy use = 0.1 EJ (Nonfood energy crops) [112]	The supply could increase 0.2 EJ per year if switching to non-food-crops and manage/ exploit marginal land [112]	Job creation for growing, cultivating, harvesting etc. (lands that anyways weren't exploited) Higher cost compared to agric. Residues. Economy/ Energy security for countries that can produce energy crops [4,130]	By (a) job creation and economic growth (b) guaranteeing long-term energy security → improvement of the well-being of the local population [45,67]	Cross-compliance: EU income support to farmers – Farmers must respect a set of basic rules. -Statutory management requirements Directives on the use of (1) hormones (Council Directive 96/22/EC) (2) nitrates (Council Directive 91/676/EEC) Regulations on: (1) prevention, control and eradication of transmissible spongiform encephalopathies (EU Regulation 999/2001) (2) Plant protection products (EU Regulation 1107/2009) [111,131,132]
Oil crops **Associated with LUC*	Some studies indicate NO GHG reduction compared to fossil fuels. Cultivating oil crops on previously uncultivated or high carbon stock land results in significant GHG emissions from LUC Cultivating oil crops on existing agricultural land without LUC may lead to lower GHG emissions during the cultivation phase. HIGH LUC: 65-231 CO_2 eq. per MJ Use of fertilizers → eutrophication or N_2O-emissions [44]	Oil extraction: Palm, soy, rapeseed oil etc. [20,21]	Production volume of vegetable oils was 1,474.2 thousand metric tons (2020) Production volume estimation: 17.5 million metric tons (2031) [133]	Biofuels, Food: frying, baking etc., soaps, skin products, candles, perfume, paints, lubricants [134]	For Biofuel production: Rapeseed oil: 1.1 billion litters Soy oil: 0.2 billion litters Palm oil: -2.5 billion litters [135]	EU is phasing out the use of palm oil to boost wastes, residues and rapeseed oil. ID produce/ uses palm oil. BR relies on soybean oil. [135]	Risk for causing food prices increase. Economy security for countries that can produce energy crops since not every country has fossil fuels. [130]	It can cause shortage of food. Requires water use → strain on water and food resources for communities [130]	Not certified as advanced biofuels RED – limits the number of crop-based biofuels that can be counted towards the EU's renewable targets. Article 30 (2-4) of Directive (EU) 2018/2001, EU countries must provide reports/ listing areas where GHG from farming may be lower than to the emissions reported under the heading 'Disaggregated default values for cultivation' in part D of Annex V [111]

11 Appendix

Table S1. **IFPRI MIRAGE 2011 model results for use of feedstocks and iLUC emissions (incl. with revised peat emissions from Page et al. (2011))** [44]

Feedstock	Percentage con-tribution to the modelled mandate	iLUC emissions	iLUC with revised peat emissions	Total emissions including typical direct (with revised peat)
Wheat	6%	14	16	56
Maize	4%	10	11	43
Sugar beet	5%	7	9	36
Sugar cane	13%	15	15	36
Soy	11%	56	71	116
Sunflower	4%	54	63	101
Rapeseed	41%	55	68	108
Palm	17%	54	85	130

Table S2. **Sustainability criteria on material present in RED II (Adapted from: Mai-Moulin et al., 2021 & European Commission, 2018)**

Sustainability criteria		Article
GHG Emission savings	Biofuels and biogas consumed in the transport sector must achieve at least 65% reduction for Bioliquids produced in installations in operation from January 1, 2021. Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) of the RED II. The Commission can revise and update the default values of GHG emissions when technological developments make it necessary. Economic operators have the option to either use default GHG intensity values provided in RED II or to calculate actual values for their pathway.	Article 25 — Mainstreaming renewable energy in the transport sector 1. Each Member State shall set an obligation on fuel suppliers to ensure that the share of renewable energy within the final consumption of energy in the transport sector is at least 14 % by 2030 (minimum share) in accordance with an indicative trajectory set by the Member State. Within the minimum share referred to in the first subparagraph, the contribution of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX as a share of final consumption of energy in the transport sector shall be at least 0,2 % in 2022, at least 1 % in 2025 and at least 3,5 % in 2030. Article 26 — Specific rules for biofuels, bioliquids and biomass fuels produced from food and feed crops Does not apply to second generation biomass

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		Article 27 — Calculation rules with regard to the minimum shares of renewable energy in the transport sector Article 28 — Other provisions on renewable energy in the transport sector The Commission shall adopt delegated acts to supplement this Directive by specifying the methodology to determine the share of biofuel, and biogas for transport, resulting from biomass being processed with fossil fuels in a common process, and by specifying the methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels, which shall ensure that credit for avoided emissions is not given for CO_2 the capture of which has already received an emission credit under other provisions of law. The Commission shall review the list of feedstock set out in Parts A and B of Annex IX with a view to adding feedstock in accordance with the principles set out in the third subparagraph Article 28 — Other provisions on renewable energy in the transport sector The analysis of the potential of the raw material as feedstock for the production of biofuels and biogas for transport, shall take into account all of the following: 1. the principles of the circular economy and of the waste hierarchy established in Directive 2008/98/EC; 2. the Union sustainability criteria laid down in Article 29(2) to (7); 3. the need to avoid significant distortive effects on markets for (by-)products, wastes or residues; 4. the potential for delivering substantial greenhouse gas emissions savings compared to fossil fuels based on a life-cycle assessment of emissions; 5. the need to avoid negative impacts on the environment and biodiversity; 6. the need to avoid creating an additional demand for land. Article 29- Sustainability and greenhouse gas emissions saving criteria for biofuels, bioliquids and biomass fuels: The greenhouse gas emission savings from the use of biofuels, bioliquids and biomass fuels taken into account for the purposes referred to in paragraph 1 shall be: a) at least 50 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations in operation on or before 5 October 2015; b) at least 60 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 6 October 2015 until 31 December 2020; c) at least 65 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 1 January 2021; d) at least 70 % for electricity, heating and cooling production from biomass fuels used in installations starting operation from 1 January 2021 until 31 December 2025, and 80 % for installations starting operation from 1 January 2026.
Waste and residues	These need to fulfil GHG emission savings and address impacts on soil quality and soil organic carbon	Article 29- Sustainability and greenhouse gas emissions saving criteria for biofuels, bioliquids and biomass fuels: However, biofuels, bioliquids and biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, are required to fulfil only the greenhouse gas emissions saving criteria laid down in paragraph 10 in order to be taken into account for the purposes referred to in points (a), (b) and (c) of the first subparagraph. This subparagraph shall also apply to waste and residues that are first processed into a product before being further processed into biofuels, bioliquids and biomass fuels.

Working with RSB standards - *Risk-based approach*: not every requirement applies to every producer and by completing the self-risk assessment and screening exercise during the certification process, your context-specific sustainability requirements will be set out. Depending on your certification scope and the type of operator you are, you will only need to work with some of these documents. The specific sustainability requirements that apply to your operation will be clarified when you complete your Screening Exercise [86].

Table S3. **Requirements applies to every producer**

Extracted from RSB's website.

	RSB PRINCIPLES & CRITERIA [RSB-STD-01-001]	RSB STANDARD FOR EU MARKET ACCESS [RSB-STD-11-001]	RSB PROCEDURE FOR PARTICIPATING OPERATORS [RSB-PRO-30-001]	RSB EU RED PROCEDURE FOR TRACEABILITY (CHAIN OF CUSTODY) [RSB-STD-11-001-20-001]	RSB EU RED STANDARD FOR ADVANCED FUELS [RSB-STD-11-001-01-010]	RSB PROCEDURE FOR COMMUNICATION & CLAIMS [RSB-PRO-50-001]	RSB PROCEDURE FOR RISK MANAGEMENT [RSB-PRO-60-001]
BIOMASS PRODUCERS	√ √*	√ √	√ √	√ √		√ √	√ √
POINT OF ORIGIN		√ √			√ √		
FIRST COLLECTOR		√ √	√ √	√ √	√ √	√ √	√ √
INDUSTRIAL OPERATOR	√ √*	√ √	√ √	√ √	√ √	√ √	√ √
MECHANICAL OPERATOR		√ √	√ √	√ √	√ √	√ √	√ √
TRADER		√ √	√ √	√ √	√ √	√ √	√ √

Please note: In the event of any inconsistency between the *RSB Principles & Criteria* and the *RSB EU Market Access Standard,* the *RSB EU Market Access Standard* shall prevail

√: Main audit, √: Surveillance audit, √: The surveillance audit shall focus on the implementation of the ESMP, the correction of non-conformities and compliance with progress requirements*

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Project partners:

#	Partner short name	Partner Full Name
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2	VERT	Vertoro BV
3	T4F	Tec4Fuels
4	BLOOM	Bloom Biorenewables Ltd
5	UNR	Uniresearch B.V.
6	WinGD	Winterthur Gas & Diesel AG
7		(Formerly SeaNRG, is now GOODFUELS #12)
8	TKMS	Thyssenkrupp Marine Systems GMBH
9	OWI	OWI – Science for Fuels gGmbH
10	CSIC	Agencia Estatal Consejo Superior De Investigaciones Cientificas
11	VARO	Varo Energy Netherlands BV
12	GOOD	GoodFuels B.V.

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