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Biomass Resources: Agriculture

Ingeborg N. Kluts, Marnix L. J. Brinkman, Sierk A. de Jong, and H. Martin Junginger

Abstract Bioenergy is the single largest source of renewable energy in the European Union (EU-28); of this, 14% was produced from agricultural feedstocks in 2012. This chapter provides an overview of the current use (for bioenergy) and future potential of agricultural feedstocks for (amongst others) biorefinery purposes in the European Union. The main application of these feedstocks is currently the production of biofuels for road transport. Biodiesel makes up 80% of the European biofuel production, mainly from rapeseed oil, and the remaining part is bioethanol from wheat and sugar beet. Dedicated woody and grassy crops (mainly miscanthus and switchgrass) are currently only used in very small quantities for heat and electricity generation. There is great potential for primary agricultural residues (mainly straw) but currently only part of this is for heat and electricity generation. Agricultural land currently in use for energy crop cultivation in the EU-28 is 4.4 Mio ha, although the land area technically available in 2030 is estimated to be 16–43 Mio ha, or 15–40% of the current arable land in the EU-28. There is, however, great uncertainty on the location and quality of that land. It is expected that woody and grassy crops together with primary agricultural residues should become more important as agricultural feedstocks.

I.N. Kluts, M.L.J. Brinkman (✉), S.A. de Jong, and H.M. Junginger
Copernicus Institute of Sustainable Development, P.O. Box 80115, 3508 TC Utrecht, The Netherlands
e-mail: I.N.Kluts@uu.nl; M.L.J.Brinkman@uu.nl; S.A.deJong@uu.nl; H.M.Junginger@uu.nl

Keywords Agricultural feedstock, Energy crops, Energy potential, Primary agricultural residues, Straw

Contents

1 Introduction

Two-thirds of renewable primary energy production in the European Union (EU-28) in 2012 was derived from biomass and renewable wastes [1]. In 2012, bioenergy accounted for 12.4, 4.1, and 5.3% of the renewable energy share in heat and cooling, electricity, and transport sectors, respectively [2]. The share of bioenergy produced from agricultural feedstocks is small compared to bioenergy produced from forestry feedstocks, but increased from approximately 7% in 2007 to 14% or 720 petajoule(PJ) in 2012 [3]. Agricultural feedstocks include conventional food crops such as rapeseed, wheat, and maize (i.e., first-generation feedstock), and crops specially cultivated for energy purposes, such as miscanthus, switchgrass, willow, and poplar (i.e., second-generation feedstock). In addition, agricultural residues in the form of straw, cuttings, and prunings are used for bioenergy production. Agricultural feedstocks are mostly used for the production of biofuels and biogas, whereas heat and electricity are mostly produced from forestry feedstocks, although straw and other crop residues are increasingly used as well [4, 5].

This chapter discusses the current use of agricultural feedstocks for bioenergy production and future agricultural potentials as feedstock for (amongst others) biorefineries. The chapter also considers constraints and focuses on the European Union.

This chapter is structured as follows. Section 2 covers the current use of agricultural feedstock in the EU, including energy crops (Sect. 2.1) and agricultural residues (Sect. 2.2). Section 3 focuses on the future potential in Europe. This section first gives an estimation of the land potentially available for energy crop cultivation (Sect. 3.1), and continues with the energy potential from this land and from agricultural residues (Sect. 3.2). A synthesis is provided in Sect. 4.

2 Current Bioenergy Production from Agricultural Feedstocks

2.1 Energy Crops

Currently, sugarcane, maize, oil palm, rapeseed, and soybean are globally the major crops for biofuel production [4]. Although, globally, bioethanol represents the largest share of biofuel production, biodiesel represents more than 80% of total biofuel production in Europe, mainly from rapeseed oil [6, 7]. Sugarcane and maize are the predominant crops for bioethanol production in Brazil and the USA, respectively, although wheat and sugar beet are mainly used in Europe for bioethanol production [4, 6].

European liquid biofuel production increased from 50 PJ in 2002 to 485 PJ in 2012, whereas biofuel gross consumption increased from 47 PJ in 2002 to 658 PJ in 2012 [1]. Hamelinck et al. [8] estimated the agricultural land within Europe required to meet the biofuel consumption in 2012 as approximately 4.4 Mio ha; this is 3.9% of the total arable land. An additional 3.5 Mio ha of agricultural land was required outside Europe to produce the biofuels consumed in the EU-28 in 2012. The authors consider the actual acreage required for biofuel production to be lower because conservative data were used for conversion efficiencies and yields [8].

Besides conventional crops, grassy and woody crops are used for bioenergy production. Currently, this only concerns small quantities, mainly for heat and electricity generation. A synthesis of different data sources by AEBIOM [6] shows approximately 0.16 Mio ha grassy energy crop cultivation in the EU-28 in 2014, of which 32% is switchgrass and 25% is miscanthus. Switchgrass is solely produced in Romania, whereas miscanthus is produced in various countries, including the United Kingdom (17,000 ha), Germany (15,000 ha), France (3,500 ha), and Ireland (2,200 ha). Countries with the highest cultivation of lignocellulosic energy crop cultivation are Romania, Germany, the United Kingdom, and Finland [6].

2.2 Primary Agricultural Residues

Primary agricultural residues include crop residues remaining in the field after harvest, whereas secondary agricultural residues are generated from processing the primary crops. The most important primary agricultural residue in Europe is wheat straw followed by barley straw and maize stover [9]. Conventional uses for straw include animal feed and bedding, mushroom cultivation, surface mulching in horticulture, and industrial uses, such as in the pulp and paper industry [10]. Straw can also be used to produce bioenergy, including fuels, electricity and heat, and biochemicals.

Only part of primary crop residues is potentially available for energy or biorefineries. A certain proportion of the crop residues needs to be left on the field to maintain soil quality, prevent soil erosion, and improve water retention [11]. A sustainable removal rate should therefore be considered when removing crop residues from the field. This removal rate is site-specific and is affected by crop type, farming practices, harvesting equipment, and local soil and climate conditions [9], and is estimated to be in the range of 30–70% [9, 11–16]. The yearly use of crop residues for non-energypurposes, expressed in dry matter (dm), isestimated to be around 28 Mt_{dm} in Europe (also excluding use for soil quality maintenance) [9].

Excluding the crop residues used for soil incorporation and other competitive uses, currently approximately 53–204 Mt_{dm}/year crop residues are available in Europe for energy or biorefinery purposes, equalling 960–3,700 PJ/year [5, 9, 14, 15, 17]. However, crop residue availability varies greatly from year to year [9]. Countries with high crop residue availability are France, Germany, Romania, Spain, Italy, Hungary, and Poland. The agricultural sector is large in these countries and the existing demand for crop residues is relatively low [9, 15].

Across Europe, straw is used to produce heat, power, and, more recently, biofuels. Denmark, the frontrunner in Europe, uses approximately 1.8 million tons of straw each year for energy purposes [18]. In recent years, multiple biofuel plants converting straw to ethanol have come online. European plants include the Abengoa plant in Salamanca, Spain (35,000 tonnes/year input), the Inbicon plant in Kalundborg, Denmark (30,000 tonnes/year input), Beta Renewables/Chemtex in Crescentino (180,000 tonnes/year input), and Chempolis, Oulu, Finland (25,000 tonnes/year input) [10, 19], but not all of these plants are yet operating at full capacity.

Several barriers still exist to extensive mobilization of straw for bioenergy purposes. Barriers include immature markets and lack of market information, competition with traditional uses of straw, lack of infrastructure, lack of experience with straw extraction and mobilization, and varying straw quality and availability over time because of changing weather conditions [10]. Moreover, average straw prices tend to be higher than forestry residue prices (on a mass and energy basis) [20]. Large geographical differences between straw prices also exist as prices are mainly determined by local scarcity [5]. In 2014, straw prices ranged from 14 €/tonne in Lithuania to 169 €/tonne in Greece [21]. Transport costs of straw tend to be high because of the low energy density of the feedstock.

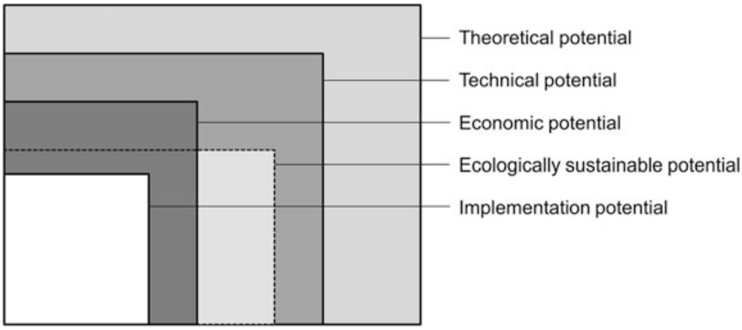

Fig. 1 Overlap between different potential types [23]

3 Future Potential of Agricultural Feedstocks

The sustainable potential from agriculture that could be utilized by, amongst others, biorefineries is constrained by the amount and suitability of the land available for energy[1] crop cultivation and various constraints related to, among others, available technologies, sustainability (e.g., greenhouse gas (GHG) emission mitigation targets, prevention of biodiversity loss), and market conditions defining economic profitability. A distinction between different types of biomass potentials is often made according to the type of constraints as shown in Fig. 1; see [22, 23]. The theoretical potential is defined as the maximum biomass supply constrained only by biophysical limits. The technical potential is the fraction of the theoretical potential available under current available technologies, and limited by other land uses including food, feed and fiber production, and urban areas. The ecologically sustainable potential is the technical potential further constrained by environmental criteria such as biodiversity conservation and soil and water preservation The share of the technical potential meeting certain economic criteria within given conditions is referred to as the market or economic potential. Some studies also estimate the implementation potential, the economic potential that can be implemented within a certain timeframe and socio-political framework.

3.1 Land Potential for Biomass Feedstock Production

Future land potentially available for energy crop cultivation is constrained by the land required for food, feed and fiber production, forests, biodiversity protection,

[1]As scientific literature mainly focuses specifically on the potential for *energy* crops, we also use this terminology throughout this chapter, although energy crops can also be used as feedstock for material/biorefinery purposes.

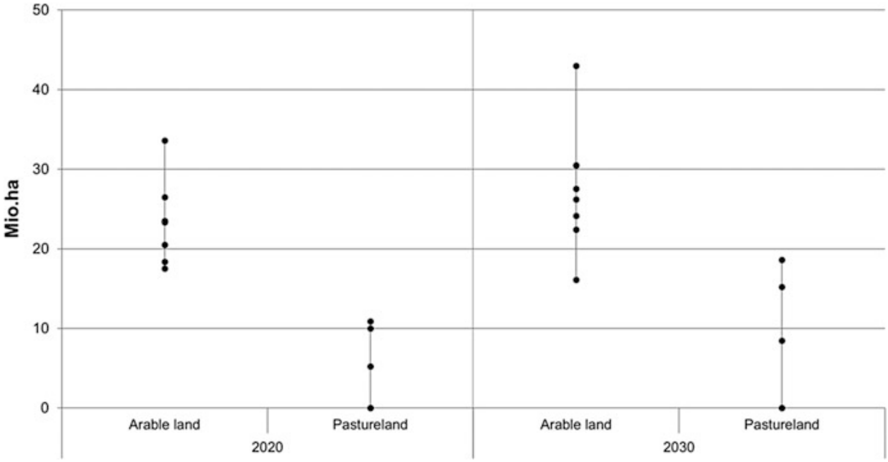

Fig. 2 Estimated land potentially available for energy cropping in the EU-27 in 2020 and 2030 based on [5, 14, 24, 25]

and urban and recreational areas. Projections on European cropland technically available for energy crop production are 6–22 Mio ha currently, 18–34 Mio ha in 2020, and 16–43 Mio ha in 2030 (Fig. 2) [5, 14, 24, 25]. Total arable land in the EU-27 was 66 Mio ha in 2012, so the above numbers correspond with 5–20%, 17–31%, and 15–40% of current arable land, respectively [5, 14, 24, 25]. In addition, pasture land technically available for lignocellulosic energy crop production in Europe is projected to be 0–4 Mio ha currently, 0–10 Mio ha in 2020, and 0–19 Mio ha in 2030 (Fig. 2), corresponding with around 0–6%, 0–16%, and 0–28% of current pasture land [14, 24].

The studies estimating the land availability for energy cropping apply a "food first" paradigm, that is, agricultural land required for food and feed production is never included in the land availability estimates for energy crops. Two key factors in determining the amount of land required for food and feed production are the projected food demand and production intensity. Production intensity is, in turn, related to the level of agricultural intensification and rationalization. Although the demand for agricultural land for food production is projected to increase globally, large differences exist between developing countries (further expansion of agricultural land) and developed countries (further decline of agricultural land) [26]. Although an increase in European agricultural output is projected, the utilized agricultural land area is projected to continue to decline; from 180 Mio ha in 2009 to 173 Mio ha in 2024 [27].

Differences in the projections of future land potential between studies are caused by different methods, approaches, and assumptions being applied. Assumptions on the interaction between land use for food and biomass feedstock production are central in different ways. First, biomass feedstock production may act as an additional driver for intensification of food and feed production as competition for land increases [28, 29]. Assumptions on intensification rates of food and feed crops are critical in the estimation of land availability. In addition, many studies neglect the role of pastureland in biomass feedstock provision. Woods et al. [29] emphasize the role of pastureland in biomass feedstock provision. Pastureland occupies a large area of global agricultural land (i.e., twice the area of cropland) although only providing a small share of the food supply (i.e., about 3% of human dietary protein consumption) [29]. Woods et al. [29] argue that pasture intensification is likely to be larger in the presence of a robust bioenergy industry than without. Second, competition for resources may alter prices of land and therefore the competitive position of food and feed commodities [14]. Third, by-products produced during bioenergy production may substitute animal feed sources and are therefore interacting with the animal feed sector [30].

Differences in future land potentials between studies are also caused by the application of different sustainability criteria. Stricter criteria on sustainability, related to nature and biodiversity conservation and GHG emissions, lead to less land being available for biomass feedstock production as a higher share of agricultural land is reserved for nature conservation and there are less regions where the GHG mitigation requirements are reached [14, 31, 32].

3.1.1 Land Categories

In addition to land that can be made available for bioenergy production by intensification of current agricultural systems, there is also land available that is currently not used to its full potential. This under-utilized land can be divided into two types: low productive land that is not suitable for conventional crop production and unused agricultural land [22].

Low productive lands are known under various names: marginal, degraded, or contaminated lands. The amount and suitability of these lands are difficult to assess as many reasons for the low productivity exist, including economic, environmental, and agronomic limitations or a combination of these [33]. Agricultural production might no longer be economic with current agricultural practices, salinized lands might arise where the salt content has risen to a level where food production is no longer possible, and manufacturing or mining can also have detrimental effects on the quality of the soil [33, 34]. Improved management and technological development can make these lands productive again [34], although productivity could be lower than average.

Despite the resemblance in the unused lands category between fallow land and abandoned land, the reasons for the land to be out of use are very different; fallow land is set aside in the crop rotation, whereas abandoned land is land that has been used for agriculture but has fallen out of use in recent years. The amount of fallow land in Europe has for many years been connected to the requirements of the Common Agricultural Policy (CAP), in which a certain amount of fallow land was mandated. This requirement has been abolished in the CAP 2014–2020 reform, which means that fallow land has been included for agricultural production again and the available fallow land is now diminishing rapidly [33]. In addition, fallowing of land is important in maintaining soil fertility and energy crop cultivation on fallow land should therefore be considered carefully. Abandoned crop or pastureland, on the other hand, can be used for energy crop production, as it is not in use for food, feed, or fiber production and under the condition that this land is not constrained by the sustainability criteria of the Renewable Energy Directive (RED) of the European Union [35]. See [36] on sustainability evaluation for more details on sustainability criteria in the RED. The use of pastureland for energy crop cultivation should also be carefully considered and limited to perennial crops only to minimize tillage practices and related environmental impacts.

As Allen et al. [33] note, there are no official statistics on the different land categories, which makes it difficult to estimate directly the amount of land that can be used for energy crops. A first estimate shows there can be great potential as the agricultural area in Eastern Europe (Belarus, Bulgaria, Czech Republic, Hungary, Poland, Moldova, Romania, Russia, Slovakia, and Ukraine) has declined by over 16 Mio ha in the period 1992–2012 [37]. This decline can be attributed to the decrease in demand for agricultural products from the former Soviet Union after the collapse and economic decline in the beginning of the 1990s.

However, not the whole area is available for energy crop production, as not all land complies with the current sustainability criteria for liquid biofuels. If we assume that these criteria are to apply for all future uses in a biobased economy, existing carbon stocks in particular may be a critical factor limiting land conversion to energy crops. Carbon stocks slowly increase after abandonment [38] and are released when taking the land into production for agricultural energy cropping, thereby possibly negatively affecting the carbon balance of biofuels. The effect on the biofuel's carbon balance depends on the type of crop used with lignocellulosic (perennial) crops in general performing better. Perennial crops sequester more carbon because of the deeper rooting systems and have lower tillage and fertilizer requirements compared to annual crops [39]. The FAO statistics show an increase of 3.2 Mio ha in forest areas in Eastern Europe in the period 1992–2012, the same period in which the agricultural area declined significantly. This trend was also recently confirmed by data from satellite images by Potapov et al. [40]. Schierhorn et al. [41] identified that, in the 20 years after the large-scale abandonment in European parts of the former Soviet Union, carbon stocks have increased on average by 15 tonnes/ha. These ongoing increases make abandoned agricultural land for energy crops increasingly unavailable.

3.2 Future Feedstock Potential

3.2.1 Energy Crops

Many studies projected the future bioenergy potential from energy crops and agricultural residues; an overview is shown in Fig. 3 for the years 2020 and 2030.

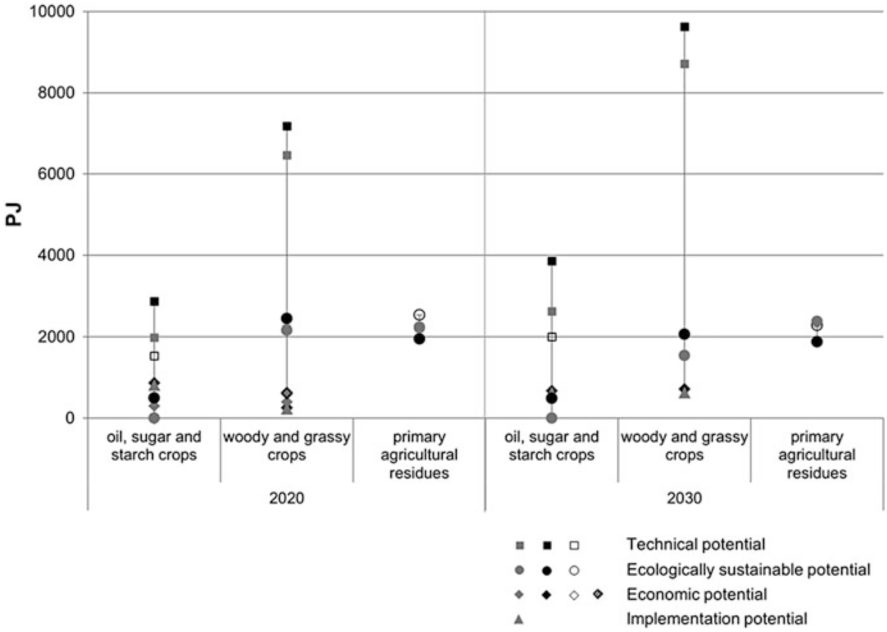

Fig. 3 Estimated bioenergy potentials from energy crops and agricultural residues in 2020 and 2030 in the EU-27 based on [5, 14, 24, 25]

The technical potential is estimated to be in the range of 1,530–2,860 PJ in 2020 and 2,000–3,860 PJ in 2030 for first-generation crops, and 6,470–7,180 PJ in 2020 and 8,720–9,630 PJ in 2030 for second-generation crops [24]. These potentials are calculated based on cropping the total available land with crops from one specific crop group (i.e., oil, sugar, starch, woody, or grassy crops). Considering sustainability criteria, other than food security, but considering both annual and perennial crops, gives a potential of 2,160–3,160 PJ/year in 2020 and 1,540–2,500 PJ/year in 2030 [5]. The economic potential of energy crops is projected to be 600–1,100 PJ in 2020 and around 1,400 PJ in 2030 [12, 31].

Sustainability constraints are considered to a varying extent in the ecologically sustainable and economic potentials. Stricter sustainability constraints lead to a lower potential from energy crops for two main reasons. First, less land is available as more land is reserved for nature protection. Second, the GHG emission mitigation requirements as set in the EU's RED [35] for the production of liquid transport fuels are not met by all energy crops for different production pathways. Considering the GHG emissions from indirect land use change (ILUC) in the GHG emission mitigation requirement lowers the energy potential from energy crops further, as is shown by, for example, Elbersen et al. [32]. However, large variations are found in land use change-related GHG emissions for the different energy crops [34] and the use of default ILUC factors is debatable. Generally, the calculated ILUC-induced GHG emissions are lowest for woody and grassy crops, followed by sugar and starch crops, and highest for oil crops [42]. More on land use change induced by energy crops can be found in [36]. It remains to be seen whether similar sustainability criteria are also applicable for the use of biomass feedstocks in biorefineries for the production of, for example, biochemicals and plastics, but this could ultimately become a limiting factor for these applications as well.

The type of energy crops cultivated on the available land determines to a large extent the final potential (in terms of energy content/dry matter). Woody and grassy crops are expected to play a key role in the future sustainable bioenergy potential. The results of De Wit and Faaij [24] show the importance of crop selection on the total potential as they estimate the potentials by dedicating the whole land area available to one specific crop group. The highest potential is from grassy crops, followed by woody crops, because these crops reach high yields with relatively extensive agriculture management practices, leading to lower costs [24].

A shift from oil, sugar, and starch crops to woody and grassy crops is also foreseen by the European Environment Agency (EEA). The EEA [31] used a demand-driven approach to estimate the amount of land needed to reach the targets on bioenergy set in the National Renewable Energy Action Plans in 2020. They projected land demand for energy crops to be between 7 and 17 Mio ha, depending on the assumptions regarding the bioenergy mix, the use of different bioenergy feedstocks, and conversion pathways. Less land is required in the scenarios that emphasize sustainable biomass feedstock production, the avoidance of ILUC impacts, and with a higher price support. These assumptions lead to a higher availability of woody and grassy crops with higher yields and thus a more efficient use of the land. If these feedstocks are also to be used for biorefineries, the specific type and feedstock requirements of the biorefinery plays a crucial role with regard to the land availability.

3.2.2 Agricultural Residues

Agricultural residues are also expected to play a role in supplying bioenergy potential as well as woody and grassy energy crops. The sustainable potential of primary agricultural residues remains fairly constant over time and is estimated at 115–150 Mt_{dm}/year (2,000–2,500 PJ/year) and 110–135 Mt_{dm}/year (2.000–2,300 PJ/year) for the EU in 2020 and 2030, respectively [5, 14, 24]. Including non-EU Member States in the supply potential for Europe raises the sustainable potential to 4,000 PJ/year in 2020 and 4,100 PJ/year in 2030 [13]. Overall, wheat straw contributes most to the total share of primary agricultural residues, followed by barley and maize.

The amount of crop residues is affected by crop yield. Crop breeding aims at improving yields by increasing the share of the harvestable component of the crop, thereby reducing the residues to product ratio (RPR). However, as the use of straw for soil protection is proportional to land use, intensification of crop production leads to a higher sustainable supply potential as less land is required to produce the same amount of crops in intensive production systems than extensive production systems [13]. However, when taking a global (rather than European) perspective, Daioglou et al. [13] found the residue supply to be more sensitive to developments in competitive uses, including livestock feed and fuel use for poor households, than to the rate of intensification. Bentsen et al. [17] also estimate an increase in the theoretical potential of crop residues through agricultural intensification. This increase is estimated to be high for Africa (93% of current theoretical residue availability), Oceania (155%), and Eastern Europe (61%), whereas the increase in agricultural residue supply through agricultural intensification is low (12%) for Northern, Western, and Southern Europe, because high input agriculture is already applied [17].

4 Synthesis

This chapter provided an overview of the current use and future potentials of agricultural feedstocks for energy and biomaterial purposes in the European Union. Agricultural land currently in use to produce energy crops in the European Union is 4.4 Mio ha, and land technically available in 2030 is estimated to be in the range of 16–43 Mio ha, which is 15–40% of the current arable land in the EU-28. Abandoned lands offer a good opportunity for energy crop production without competing with other uses such as food and feed production and nature protection. The availability of abandoned lands is, however, uncertain as statistics do not separately report this land type. Furthermore, it can be expected that productivity on these lands is lower than average. To add these lands to the land potential estimates, better maps are required to expand the knowledge on the location of these lands.

Agricultural feedstocks are used to produce approximately 14% of the bioenergy in the EU-28 in 2012. Oil seed biodiesel forms the majority of biofuel production in Europe, whereas wheat and sugar beet for bioethanol are used in smaller amounts. The future energy potential from crops is estimated to vary between 1,530 and 7,180 PJ in 2020 to 2,000 and 9,630 PJ in 2030, depending on crop type and sustainability constraints considered. Stricter sustainability constraints on nature protection and GHG emissions lead to an overall lower potential from crops and causes a shift from annual to perennial crops.

Primary agricultural residues are a large resource for bioenergy and biomaterial production that is not used to its fullest extent, mainly for cost and logistic reasons. The low energy density of straw makes transport costly. Besides, average straw prices are higher than forestry residues and a high variation in straw prices is observed from region to region, as prices are mainly determined by local scarcity. The availability of crop residues is estimated to stay rather stable (i.e., 115–150 Mt_{dm}/year (2,000–2,500 PJ/year) and 110–135 Mt_{dm}/year (2.000–2,300 PJ/year) in 2020 and 2030, respectively). Crop management practices, influencing crop yields and the amount of crop residues that need to be left on the land, influence the amount of crop residues bioenergy and biomaterial production available. It can be concluded that primary agricultural residues, together with woody and grassy energy crops, should become more important as agricultural feedstocks, although the share of oil, starch, and sugar crops should decrease. This effect is reinforced if sustainability criteria become more stringent and/or if they are applied for all energy uses and material application.

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