Can we know how much biomass will be available for BECCS and bioenergy?

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Summary and key Drax take-aways undertaken by:
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Summary

Drax commissioned the University of Surrey to perform a rapid literature synthesis assessing the range of estimates of biomass availability in existing literature as of January 2024. The synthesis identifies estimates of current potential for production as well as projections for potential availability in 2030 and 2050. Availability was assessed for energy crops, woody biomass, and agricultural residues.

Key Drax take-aways

1. There does not appear to be widespread consensus on estimates for either current production or the current potential for production at a global level. The best available estimate for current production is 55 EJ/yr, with a commonly cited value for current potential for production of 104 EJ/yr.
   a. Barriers to improving production estimates include a lack of standardised terminology and a lack of consistency in reporting at both the regional and local level.
   b. Uncertainties in estimates of current potential production largely centre around the definition of degraded and marginal lands and the ability to rapidly access these lands for the production of additional biomass.
2. There is generally agreement among model simulations that the availability of biomass will increase in both 2030 and through 2050. However, the magnitude of this increase varies dramatically depending on the model assumptions used. Projections for biomass availability in 2050 span four orders of magnitude.
   a. The greatest variance occurs in energy crops; this variance is attributable to model assumptions around the dedication of land to energy crops vs food crops, anticipated changes in dietary preferences, the ability to access marginal or degraded lands for energy crops, and expectations around the prioritisation of land use.
   b. The impacts of climate change on the viability of energy crops, forests, and agriculture also create uncertainties within modelled availability of biomass.
3. It is difficult to impossible to remove many of the uncertainties surrounding estimates of biomass availability. Moreover, there remains disagreement on probability distributions ideal system models, and the range of probable outcomes. This level of uncertainty is characterised as deep uncertainty.
   a. Level four uncertainty occurs when there is a range of plausible outcomes, but it is impossible to distinguish between the likelihoods of each outcome occurring.
   b. The presence of level four uncertainty indicates that there is a requirement to use decision making under deep uncertainty (DMDU) approaches when assessing future biomass availability.
4. Despite the presence of deep uncertainty in projections of future availability, if even half of the current potential for biomass production was mobilised and utilised for BECCS, it would be sufficient to support 800 to 4,000 1 Mt/yr plants, depending on the BECCS pathway deployed.

Extended summary

Carbon removals through bioenergy with carbon capture and storage (BECCS) feature heavily in most IPCC and other climate mitigation scenarios through 2050, with estimates ranging from ~500 to 16,000 Mt CO_2 per year. However, there is considerable debate within the scientific community as to whether there is sufficient biomass available to support such a deployment of BECCS, particularly at the higher end of the scale. In particular, concerns focus on whether such a massive deployment could have consequences for food production or would lead to conversion of natural ecosystems. Literature estimates of biomass availability vary over several orders of magnitude, with no clear consensus emerging.

Drax therefore commissioned a report to identify the range of estimates for biomass availability from now to 2050 available in the published literature and what factors underlie the wide variation in estimates. The rapid literature review was performed by Sophie Tudge and Professor Zoe Harris at the University of Surrey in January 2024; their analysis is presented in tables 1-3.

The literature review yielded 30 studies containing 131 estimates of global biomass availability at any of the three timepoints. In the 22 studies containing multiple global estimates, separate estimates were most commonly provided for different biomass source types (namely dedicated energy crops, forest residues, and agricultural residues), land use scenarios, climate scenarios and/or timepoints. Six further studies considered only regional availability (without global estimates). There were 199 estimates of biomass availability overall.

Although the publication dates were distributed throughout the reviewed range, among the ten that include a current global estimate, the most recent two datasets were collected in 2015 (Scarlat et al., 2019) and 2010 (Daioglou et al., 2015). This highlights not only the age of these specific estimates, but also that some biomass availability estimates use data that are already several years old at time of publication.

In January 2025, Oak Ridge National Laboratories (Jacobson et al., 2025) published an assessment of current biomass production based on publicly available data for 62 countries. They identified 2030 potential for a subset of 41 of those countries. We include the summary findings here for comparison. Overall, Tudge and Harris report a current potential of 104 EJ/yr; if all this biomass were dedicated to BECCS, it would represent removals on the order of 1.6 to 8 Gt CO_2 per year, depending on the BECCS pathway. Jacobson and colleagues (2025) reported actual production from responding countries of 2.83 billion dry metric tonnes, on the order of 55 EJ/yr, which would be equivalent to removals on the order of 0.84 to 4.2 Gt CO_2 per year. These values are well in line with estimates of sustainable levels of removals through BECCS of 2-3 Gt CO_2 per year (Ives & Smith, 2024).

Biomass type and availability

For biomass to be suitable for bioenergy and BECCS, it must be energy rich and, for direct power generation, combustible. Each form of bioenergy will have its own requirements for biomass, including around feedstock chemical composition and the consistency of that composition through time. For large scale bioenergy, biomass will also need to have the potential to scale and to do so sustainably. Estimates of biomass availability through time will typically use sustainability criteria including potential conflicts with other land use as well as other uses for that particular type of biomass. Global estimates typically focus on energy crops, agricultural residues, and forestry residues, also known as woody biomass. Other types such as municipal waste may be included, noting these sources are typically used locally for combined heat and power plants, though we did not specifically seek estimates of municipal waste availability in the scope of this literature review.

Energy crops

Energy crops tend to dominate estimates of biomass availability in 2030 and 2050. Such crops include grasses (such as miscanthus and sugar cane), herbs (mostly oil crops such as soybeans and sunflowers), and longer-lived woody species (such as willows and poplars). Most are perennial, limiting the need for significant disturbances such as tilling and potentially promoting biodiversity (Pedroli et al., 2013). Sustainability considerations for energy crops include limiting direct competition for other agricultural land uses such as food crops and avoiding the conversion of natural grasslands or other ecosystems. Many studies seek to assign energy crops to so-called marginal lands, although the definition of marginal tends to vary between studies (Khanna et al., 2021).

The literature review identified 21 studies that separately reported global energy crop availability. The current global estimates (9 estimates from 5 studies) ranged from 2 EJ/yr for an explicitly conservative estimate (Sims et al., 2006) to 83–91 EJ/yr for a theoretical estimate (Hakala et al., 2009) assuming a global vegetarian diet and energy crop production that does not conflict with food production. The three estimates for 2030 were of a similar magnitude, i.e., tens of EJ/yr.

Estimates in 2050 showed no such consistency, ranging from 8 EJ/yr (Hoogwijk et al., 2003) to 1272 EJ/yr (Smeets et al., 2007), the latter assuming globally very advanced agricultural technology. As above, other estimates were distributed throughout this range, but even within individual studies, predicted yields from energy crops showed enormous variability depending on the underlying assumptions (e.g., Hoogwijk et al., 2003). Among the eleven estimates scored highest for applicability, estimates ranged from 19 to 455 EJ/yr; eight of these estimates were between 172 and 313 EJ/yr.

Agricultural residues

Distinct to purpose grown energy crops, agricultural residues such as straw, husks, and sugarcane bagasse can also be used for bioenergy. Indeed, such materials that are surplus to uses such as animal fodder or as a soil amendment are frequently used today for bioenergy.

In the reviewed studies, global bioenergy availability from agricultural residues was often grouped with that from energy crops or forestry residues, not reported separately. One estimate suggests current availability of 39–42 EJ/yr (Hakala et al., 2009), with an estimate of 17 EJ/yr for straw alone (Parikka, 2004), and two at 2030 (an apparently conservative estimate of 30 EJ/yr in the year 2035 and a supply potential estimate of 50 EJ/yr (World Bioenergy Association, 2016). For 2050, there were five estimates from three studies, all in the range 3–55 EJ/yr (Hakala et al., 2009).

Woody biomass

Forests cover 31% of the world's land, and of that forested area, 30% (1.15 billion ha) is managed – i.e., primarily designated for the production of timber, fibre, and/or non-wood forest products (FAO, 2020). In managed forests, timber is typically the highest value output. The production of timber results in the creation of other co-products and by products that can be used by other sectors, namely pulp and paper, with additional uses such as bioenergy. Bioenergy will typically use materials such as thinnings, low grade roundwood, and sawmill residuals and shavings. For some forms of bioenergy, paper mill byproducts such as black liquor (waste water containing both wood waste and processing chemicals) can also be used.

Forestry residues can be utilised without processing in some contexts, particularly when used for onsite energy at sawmills and pulp and paper plants, but for power generation they are generally processed into pellets first. Compared with raw forestry residues such as wood chips, pellets have much higher energy density (11 GJ/m^3 vs 3 GJ/m^3) and lower moisture content (8% vs 20-25% for air-dried wood chips; IRENA, 2019), hence higher combustion efficiency. This transformation is critical for their use as a replacement for coal.

Again, the literature review identified few separate global bioenergy availability estimates for woody biomass and forestry residues. The only current estimate was 42 EJ/yr (Parikka, 2004), and the two estimates for 2030 were 72–84 EJ (World Bioenergy Association, 2016 for 2035) and 24–43 EJ/yr (IRENA, 2014). Of the 14 estimates for 2050, three were <10 EJ/yr (Smeets & Faaij, 2006) and the remainder were distributed evenly between 24 and 103 EJ/yr. Additionally, Lauri et al. (2014) estimated a range of 0–165 EJ/yr depending on the simulated wood bioenergy prices.

Current and future biomass potential

Only one identified study reported total potential biomass availability for today, estimating 104 EJ/yr excluding municipal waste (Parikka, 2004). This value is broadly consistent with the combined estimates for individual source types, suggesting a degree of corroboration from the source-specific literature estimates. The three global biomass availability estimates for 2030 ranged from 97 to 166 EJ/yr (IRENA, 2014; World Bioenergy Association, 2016). Jacobson et al (2025) found a planned 60% increase in biomass production in the 41 countries that reported data for both current and projected 2030 production. However, these results are not likely to be comparable due to the different methodologies and scopes involved in all studies. Estimates for 2050 showed more variation, from 33 to 1,548 EJ/yr (Hoogwijk et al., 2003; Smeets et al., 2007. That said, 13 of the estimates fell between 120 and 610 EJ/yr, suggesting a consensus at least in terms of order of magnitude).

To help rationalise the complexity of the assumptions underlying the estimates, Tudge and Harris subjectively scored (out of three, with three the most believable) the perceived applicability of each estimate related to data timeliness, whether an estimate was described within the source text as unfeasible or highly conservative/unconservative, or whether it relied on less probable external conditions. These ratings are available in Tables 1-3. Estimates from sources that ranked well, tended to fall within the range of 120 to 610 EJ/yr.

Reasons for variations

Estimates for biomass availability in 2030 and in 2050 span four orders of magnitude, with the bulk of variation due to widely varying estimates of energy crop growth and yield. These variations link back to several core assumptions within model scenarios and modelling choices. Considering growing and farming conditions, variations in scenarios assumptions related to crop choice, the use of marginal and degraded land, the magnitude of marginal or degraded land available, and assumptions around food and dietary choices all impact the amount of land available for energy crops in each scenario. Policy and economic choices governing land use also impacted the amount of land available, particularly the relative prioritisation of forest conservation, re/ afforestation, and the protection of arable farmland for food crops. Prices of woody biomass for use in bioenergy also had an impact in one study (Lauri et al. 2014). Moreover, assumptions around future climate change and state also impacts the simulated viability and yield of crops in different regions.

Next steps

Although the future modelling efforts could potentially constrain options for several of these variables, for others it will be impossible to reduce, or in some cases even quantify the associated uncertainty. There is also disagreement about the relationship between variables and the ability to influence outcomes through the use of different strategies or levers as well as disagreements over what the most desirable outcome is for the availability and use of biomass for energy. Thus the question of "how much biomass will be available for BECCS and bioenergy" is impossible to answer and meets the definition of deep uncertainty.

When faced with deep uncertainty, so-called predict-then-act models are insufficient and cannot support effective decision making (Stanton & Roelich, 2021). Instead, methods appropriate to decision making under deep uncertainty (DMDU) must be applied. Such methods have proven effective in assessing options to reach net zero at country and regional scale (Mendez et al., 2024; Workman et al., 2024). In the case of biomass, these methods could be applied to support policy development at appropriate regional scales so as to ensure biomass is sourced and utilised in a manner that delivers robust and sustainable outcomes as agreed by core stakeholders.

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Table 1

Estimates of the current potential for production for major biomass types. Analysis by Dr Zoe Harris and Sophie Tudge, University of Surrey.

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Agricultural (harvest & process) & forestry (logging & process) residues	33 EJ/yr	Current available potential estimate that is used in scenarios of agriculture and forestry production, livestock production and fuel use from the spatially explicit integrated assessment model IMAGE, based on 3 scenarios from the Shared Socioeconomic Pathways.	Residue production is related to agricultural and forestry production and intensification, and the limiting effect of ecological and alternative uses of residues are accounted for. Forestry harvest residue generation factors are calculated per biome & management type based on estimates within the literature. Agricultural yields are inevitably uncertain. Estimate is for the available potential.	NA	3	Daioglou et al. (2015)
Global	Energy crops	86 EJ/yr	Based on geographically explicit data for the global land reserve & the biophysical crop model LPJmL for the year 2000.	Potential biomass from non-agricultural land. Data has a spatial resolution of 0.5°. Assumes that plantations are EU RED-compliant. Approach relies on relatively aggregated data. Biomass potentials are concurrent with EU sustainability criteria, thus believability on a global scale is uncertain. Also unclear what land types are considered as suitable for energy crops & what crops are included; the assumption is that the study includes all land that is theoretically productive.	431 Mha	2	Schueler et al. (2016)
North America	Energy crops	11.3 EJ/yr	Based on geographically explicit data for the global land reserve & the biophysical crop model LPJmL for the year 2000.	Potential biomass from non-agricultural land. Data has a spatial resolution of 0.5°. Assumes that plantations are EU RED-compliant. Approach relies on relatively aggregated data. Biomass potentials are concurrent with EU sustainability criteria, thus believability on a global scale is uncertain. Also unclear what land types are considered as suitable for energy crops & what crops are included; the assumption is that the study includes all land that is theoretically productive.	NA	2	Schueler et al. (2016)
Europe	Energy crops	3 EJ/yr	Based on geographically explicit data for the global land reserve & the biophysical crop model LPJmL for the year 2000.	Potential biomass from non-agricultural land. The area & productivity are based on the biophysical crop model LPJmL. Assumes that plantations are EU RED-compliant. Approach relies on relatively aggregated data. Biomass potentials are concurrent with EU sustainability criteria, thus believability on a global scale is uncertain. Also unclear what land types are considered as suitable for energy crops & what crops are included; the assumption is that the study includes all land that is theoretically productive.	NA	2	Schueler et al. (2016)
Europe	Forest biomass	166 Mm3	Reviews and compares the estimated current potentials for wood biomass production in 25 countries, based on previous models & estimations.	Includes forest biomass currently available considering increased utilisation of current forests. Each study included considers different expansion factors and restrictors for availability. The use of harvest records may underestimate the wood potentials for energy.	NA	3	Mola-Yudego et al. (2016)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Europe	Fast-growing plantations (Salix sp. & Populus sp)	98 Mm3	Reviews and compares the estimated current potentials for wood biomass production in 25 countries, based on previous models & estimations.	Fast-growing, dedicated biomass plantations (mainly willow & poplar). Fast-growing plantations are established on 5% of current agricultural land, based on trends in agricultural productivity & realistic estimates in the literature. Short-rotation forestry plantations are currently very limited, thus there are extrapolations of estimations from small plots.	At least 56,049 ha of fast-growing woody biomass crops currently exist. The estimate of biomass availability includes a larger area (5% of current agricultural land).	3	Mola-Yudego et al. (2016)
Europe	Agricultural residues	149 Mt DM/yr	The amount of residues potentially obtainable from the main crops cultivated in Europe, namely wheat, rye, barley, oats, maize, rice, rapeseed and sunflower was assessed. Data are from multiple sources, considering local soil, climate, and farming practices across Europe.	36 European countries. 1km spatial resolution. Values represent the average sustainable potential considering both technical and environmental constraints, which is less than the theoretical potential (ie. it is the most restrictive condition for removal of crop residues). However, there is uncertainty in the literature about how much residue needs to remain on the soil for sustainability. The potential of crop residues estimated in this study could be used for different purposes: fodder, bedding, horticulture, bio-based materials, not only for bioenergy production. Thefore, the result could be an overstimation of biomass available for bioenergy.	NA	1	Scarlat et al. (2019)
Global	Energy crops (first- & second-generation) & crop residues	122–133 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	327 Mha available for energy crops	1	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (first- & second-generation) & crop residues	86–93 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	166 Mha available for energy crops	2	Hakala et al. (2009)
Global	Energy crops (first- & second-generation) & crop residues	47–50 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	34 Mha available for energy crops	1	Hakala et al. (2009)
Global	Energy crops (first- & second-generation)	47–51 EJ/yr	FAO production statistics for 1997–2006.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	166 Mha available for energy crops	2	Hakala et al. (2009)
Global	Crop residues	39–42 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. The estimation does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability.	NA	1	Hakala et al. (2009)
Global	Energy crops (first- & second-generation)	83–91 EJ/yr	FAO production statistics for 1997–2006.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	327 Mha available for energy crops	1	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (first- & second-generation)	8–8.7 EJ/yr	FAO production statistics for 1997–2006.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	34 Mha available for energy crops	1	Hakala et al. (2009)
USA	Energy crops (first- & second-generation) & crop residues	36–41 EJ/yr	FAO production statistics for 1997–2006. Harevestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)
USA	Energy crops (first- & second-generation) & crop residues	23–26 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)
USA	Energy crops (first- & second-generation) & crop residues	5.4–5.7 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Canada	Energy crops (first- & second-generation) & crop residues	4.1–4.4 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)
Canada	Energy crops (first- & second-generation) & crop residues	3.0–3.3 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)
Canada	Energy crops (first- & second-generation) & crop residues	1.2–1.3 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. Energy crops included conventional grain/seed crops, sugarcane, Miscanthus, reed canary grass & switchgrass. The estimation for crop residues does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability. Energy crops are assumed to be grown at the same intensity as crops. Technological improvements could change this estimate dramatically.	NA	1	Hakala et al. (2009)
USA	Crop residues	5.4–5.7 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. The estimation does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability.	NA	1	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Canada	Crop residues	0.8–0.9 EJ/yr	FAO production statistics for 1997–2006. Harvestable crop residue is based on estimations of technical residue potentials.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Set values are used to reduce theoretical crop residue potentials to technical residue potentials, based on previous literature estimates e.g. a reduction of 30% is used for cereals. The estimation does not include a reduction for the amount of residue needed to remain on the soil for soil sustainability.	NA	1	Hakala et al. (2009)
Global	Biomass (woody biomass, energy crops, residues & other)	103.8 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessmens of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Global	Woody biomass	41.6 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Global	Energy crops	37.4 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT).	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Global	Straw	17.2 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
North America	Biomass (woody biomass, energy crops, residues & other)	19.9 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
North America	Woody biomass	12.8 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
North America	Energy crops	4.1 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT) for 2000.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Straw	2.2 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Europe	Biomass (woody biomass, energy crops, residues & other)	8.9 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Europe	Woody biomass	4 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessmens of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Europe	Energy crops	2.6 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT) for 2000.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Europe	Straw	1.6 EJ/yr	Literature review based on FAO statistics (FAO database & FAOSTAT). Estimates of % of woody biomass available as residues is based on previous assessments of different forestry processes.	Sustainable biomass energy potential. Based on relatively old statistics. Doesn't explicitly account for environmental constraints e.g. with residues or technological improvements.	NA	2	Parikka (2004)
Global	Energy crops	11 EJ/yr	Scenario analysis with 3 different land-use scenarios (sustainable land use, business as usual and environment and health). Calculated potentials of cultivable land for energy crop production. The results presented reflect predictions for 2020.	Analysis includes 133 countries. Energy crops are grown on surplus agricultural land. Scenario includes changes in food consumption, population growth, urban expansion & increases in agricultural yields. Value is for sustainable land-use scenario.	NA	1	Thrän et al. (2010)
Global	Energy crops	40 EJ/yr	Scenario analysis with 3 different land-use scenarios (sustainable land use, business as usual and environment and health). Calculated potentials of cultivable land for energy crop production. The results presented reflect predictions for 2020.	Analysis includes 133 countries. Energy crops are grown on surplus agricultural land. Scenario includes changes in food consumption, population growth, urban expansion & increases in agricultural yields. Value is for environment and health scenario.	NA	1	Thrän et al. (2010)
Global	Energy crops	2 EJ/yr	Analysis based on energy crop areas given in each of the IPCC SRES scenarios in 2025 (as projected by the IMAGE 2.2 integrated assessment model). B1 scenario.	A prediction for the year 2025. More conservative dry matter and energy yield estimates were used to estimate the realistically achievable potential for energy crops. Result strongly depends on yield, which is estimated based on regional averages. Estimate is a little outdated.	58 Mha	2	Sims et al. (2006)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops	22 EJ/yr	Analysis based on energy crop areas given in each of the IPCC SRES scenarios in 2025 (as projected by the IMAGE 2.2 integrated assessment model). B2 scenario.	A prediction for the year 2025. More conservative dry matter and energy yield estimates were used to estimate the realistically achievable potential for energy crops. Result strongly depends on yield, which is estimated based on regional averages. Estimate is a little outdated.	141 Mha	2	Sims et al. (2006)
Global	Wasted crops (corn, barley, oat, rice, wheat, sorghum & sugar cane) & crop residues (corn stover, crop straws & sugar cane bagasse)	1623.28 Tg	Data for biomass (e.g. crop production, yield, harvested area) are averages from 1997-2001 from FAOSTAT.	Wasted crops are defined as crops lost during the year at all stages between the farm and the household level during handling, storage, and transport. Data in FAOSTAT may not be accurate for every crop in every country. There are differences in FAOSTAT data and national statistics in some cases. The fraction of crop residues collectable for biofuel is not easily quantified; 60% ground cover by crop residues is assumed in this study to reduce soil erosion by water, which is a conservative estimate.	NA	2	Kim & Dale (2004)
Global	Crop residues (corn, barley, oat, rice, wheat, sorghum & sugar cane)	1549.42 Tg	Data for biomass (e.g. crop production, yield, harvested area) are averages from 1997-2001 from FAOSTAT.	Data in FAOSTAT may not be accurate for every crop in every country. There are differences in FAOSTAT data and national statistics in some cases. The fraction of crop residues collectable for biofuel is not easily quantified; 60% ground cover by crop residues is assumed in this study to reduce soil erosion by water, which is a conservative estimate.	NA	2	Kim & Dale (2004)
Europe	Crop residues (corn, barley, oat, rice, wheat, sorghum & sugar cane)	216.56 Tg	Data for biomass (e.g. crop production, yield, harvested area) are averages from 1997-2001 from FAOSTAT.	Data in FAOSTAT may not be accurate for every crop in every country. There are differences in FAOSTAT data and national statistics in some cases. The fraction of crop residues collectable for biofuel is not easily quantified; 60% ground cover by crop residues is assumed in this study to reduce soil erosion by water, which is a conservative estimate.	NA	2	Kim & Dale (2004)
North America	Crop residues (corn, barley, oat, rice, wheat, sorghum & sugar cane)	218.90 Tg	Data for biomass (e.g. crop production, yield, harvested area) are averages from 1997-2001 from FAOSTAT.	Data in FAOSTAT may not be accurate for every crop in every country. There are differences in FAOSTAT data and national statistics in some cases. The fraction of crop residues collectable for biofuel is not easily quantified; 60% ground cover by crop residues is assumed in this study to reduce soil erosion by water, which is a conservative estimate.	NA	2	Kim & Dale (2004)
Global	Agricultural & forestry residues	48.71 EJ/yr	Estimate the maximum sustainable amount of energy potentially available from agricultural and forestry residues by converting crop production statistics from FAOSTAT into associated residue, while allocating some of this resource to remain on the field to mitigate erosion and maintain soil nutrients.	For the year 2005 thus estimate is old. Based on reported statistics, which might not be accurate. The principal source of uncertainty in this estimate is the amount of residue that needs to be left behind to reduce soil erosion.	NA	1	Gregg & Smith (2010)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
USA	Agricultural & forestry residues	5.44 EJ/yr	Estimate the maximum sustainable amount of energy potentially available from agricultural and forestry residues by converting crop production statistics from FAOSTAT into associated residue, while allocating some of this resource to remain on the field to mitigate erosion and maintain soil nutrients.	For the year 2005 thus estimate is old. Based on reported statistics, which might not be accurate. The principal source of uncertainty in this estimate is the amount of residue that needs to be left behind to reduce soil erosion.	NA	1	Gregg & Smith (2010)
Canada	Agricultural & forestry residues	1.36 EJ/yr	Estimate the maximum sustainable amount of energy potentially available from agricultural and forestry residues by converting crop production statistics from FAOSTAT into associated residue, while allocating some of this resource to remain on the field to mitigate erosion and maintain soil nutrients.	For the year 2005 thus estimate is old. Based on reported statistics, which might not be accurate. The principal source of uncertainty in this estimate is the amount of residue that needs to be left behind to reduce soil erosion.	NA	1	Gregg & Smith (2010)

Table 2

Availability estimates for 2030 for all major biomass types.

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Europe	Miscanthus	80.7–89.7 Mt/yr, 1.2–1.3 EJ/yr	Biomass growth simulation model (MiscanFor) used to project the biomass potentials of new market-ready hybrids. The model uses soil properties and meteorological data to predict crop growth. Field measurements of crop growth were taken from crop trials taking place on marginal agricultural land and used for model calibration.	10% land-use conversion of the least (productive) grassland and arable for farm diversification. Projections for new Miscanthus biomass crop hybrids. However, less productive sites may produce lower yields. The result is conservative, with values based on growth on marginal (less productive) land. Used the RCP2.6 future climate scenario from the HADGEM 3 model from the UK Met Office to predict future climate. Upscaling of Miscanthus in Europe has been slow so far, and the future scale of planting is still relatively unknown. The model is focused on crop growth and doesn't consider practical limitations to the expansion of miscanthus. Miscanthus may not be the best crop to plant throughout Europe.	15.7 Mha (10% pasture & 10% arable land converted to miscanthus plantations)	2	Shepherd et al. (2023)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
EU & UK	Energy crops (woody & herbaceous lignocellulosic crops: Miscanthus, switchgrass, giant reed, reed canary grass, cardoon, poplar, willow & eucalyptus)	1951 PJ/yr	Marginal land availability is assessed based on sustainability criteria & biomass potential from energy crops is determined in each location, based on the best crop for each area.	Includes the EU & UK. 1km spatial resolution of biophysical conditions. The largest share of available marginal land corresponds to shrubland, followed by open space. Agricultural land is excluded from the analysis, whereas most studies assume that agricultural land is where energy crops will be planted. Thus, this estimate is potentially one of the more ecologically damaging predictions. Economic constraints were not considered.	7.9–8.9 Mha of marginal land (20.5 Mha is available but less is actually suitable for energy crop cultivation).	1	Vera et al. (2021)
Global	Biomass (energy crops, processing residue, fuel wood, harvesting residue, animal and household waste & wood residue)	97 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Future land demand is based on FAO estimates, and data for potentially available land are drawn from the Global Agro-ecological Zone Assessment (AEZ) model. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic). Low supply scenario.	NA	2	IRENA (2014)
Global	Biomass (energy crops, processing residue, fuel wood, harvesting residue, animal and household waste & wood residue)	147 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Future land demand is based on FAO estimates, and data for potentially available land are drawn from the Global Agro-ecological Zone Assessment (AEZ) model. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic). High supply scenario.	NA	2	IRENA (2014)
Global	Agricultural residues (harvesting residue, processing residue and food waste) & waste	37–66 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic).	NA	2	IRENA (2014)
Global	Energy crops (including food crops)	33 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Future land demand is based on FAO estimates, and data for potentially available land are drawn from the Global Agro-ecological Zone Assessment (AEZ) model. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic). Low supply scenario.	NA	2	IRENA (2014)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (including food crops)	39 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Future land demand is based on FAO estimates, and data for potentially available land are drawn from the Global Agro-ecological Zone Assessment (AEZ) model. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic). High supply scenario.	NA	2	IRENA (2014)
Global	Forest products (fuelwood, residues and processing, and post-consumer waste)	24–43 EJ/yr	International Renewable Energy Agency (IRENA) Remap 2030 analysis that projects the potential for bioenergy with different technologies & scale-up of bioenergy.	Supply potential. Realising the potential depends on a range of assumptions including policy developments and technology advancements. The roadmap depicts a future with implementation of all the realisable potential of renewable energy, which is unlikely to be the case (the scenario is optimistic).	NA	2	IRENA (2014)
Global	Biomass (agriculture, forestry & waste)	134–136 EJ	Projections based on current biomass use (2012) & potential changes in agricultural yields, innovation & policy.	World Bioenergy Association fact sheet, assumed to be fairly reliable. Conservative estimate. Results depend on land area available for energy crops, innovation in agriculture & supportive policies.	240 Mha agricultural land for energy crops	2	World Bioenergy Association (2016)
Global	Energy crops (including food crops & solid biomass crops i.e. Miscanthus and SRF) & residues	56–72 EJ	Projections based on current biomass use (2012) & potential changes in agricultural yields, innovation & policy.	World Bioenergy Association fact sheet, assumed to be fairly reliable. Conservative estimate. Results depend on land area available for energy crops, innovation in agriculture & supportive policies.	240 Mha agricultural land	2	World Bioenergy Association (2016)
Global	Forestry (main products e.g. stems and wood fuel and residues)	72–84 EJ	Projections based on current biomass use (2012) & potential changes in agricultural yields, innovation & policy.	World Bioenergy Association fact sheet, assumed to be fairly reliable. Conservative estimate. Results depend on having supportive policies for the industry.	NA	2	World Bioenergy Association (2016)
Global	Organic waste	6–10 EJ	Projections based on current biomass use (2012) & potential changes in agricultural yields, innovation & policy.	World Bioenergy Association fact sheet, assumed to be fairly reliable. Conservative estimate. Results depend on having supportive policies for the industry.	NA	2	World Bioenergy Association (2016)
Global	Energy crops (food crops & solid biomass crops i.e. Miscanthus & SRF)	26–34 EJ	Projections based on current biomass use (2012) & potential changes in agricultural yields, innovation & policy.	World Bioenergy Association fact sheet, assumed to be fairly reliable. Conservative estimate. Results depend on land area available for energy crops, innovation in agriculture & supportive policies.	240 Mha agricultural land	2	World Bioenergy Association (2016)
UK	Biomass (agriculture, forestry & waste)	0.58 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report. Minimum estimate.	NA	3	Bates (2017)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
UK	Biomass (agriculture, forestry & waste)	0.67 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report. Maximum estimate.	NA	3	Bates (2017)
UK	Forestry residues	0.01 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report.	NA	3	Bates (2017)
UK	Stemwood	0.02 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report.	NA	3	Bates (2017)
UK	Waste wood	0.1 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report.	NA	3	Bates (2017)
UK	Energy crops (perennial)	0.07–0.08 EJ	Model based on a variety of data including sustainability data, land availability, UK crop yields & global demand.	Accessible resource (less than total resource). Source is a UK government-commissioned report.	NA	3	Bates (2017)
Global	Biomass	74 EJ	Projections for achieving net zero by 2050.	IEA Net Zero Roadmap that projects pathways to net zero by 2050. Updated in 2023 & a reliable source. Estimate assume net zero in 2050, which may not be achieved (could be an optimistic assumption).	NA	2	IEA (2023)
UK	Energy crops (short rotation forestry, short rotation coppice willow, short rotation coppice poplar, Miscanthus, cereal crops, oil-based crops & sugar-based crops)	4.3 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Population growth, crop productivity and land use are key drivers. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)
UK	Agricultural residues	17.86 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Population growth, crop productivity and land use are key drivers. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)
UK	Dedicated forestry resources	4.3 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
UK	Forestry residues	2.55 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)

Table 3

Availability estimates for 2050 for all major biomass types.

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
UK	Energy crops (short rotation forestry, short rotation coppice willow, short rotation coppice poplar, Miscanthus, cereal crops, oil-based crops & sugar-based crops)	31.3 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Population growth, crop productivity and land use are key drivers. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)
UK	Agricultural residues	26.3 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Population growth, crop productivity and land use are key drivers. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)
UK	Dedicated forestry resources	1.98 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)
UK	Forestry residues	2.55 Mt	Biomass Resource Model that includes economic, infrastructure, industry, environmental, food, policy & resource demand drivers. Bottom-up approach that estimates practical availability of biomass. Literature review was used to get baseline estimates.	Model is based on numerous forecasts e.g. of future crop yields. Policy changes and financial support are required to achieve the full biomass potential.	NA	3	Welfle et al. (2014)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Primary biomass (energy crops, agricultural residues, forestry residues, animal manure & biomaterials)	33 EJ/yr	Update existing estimates using data from the literature.	Includes energy crops grown on surplus & degraded agricultural land, agricultural residues, forestry residues, animal manure & organic waste, accounting for biomass used for biomaterials. Depends on future demand for food, population growth, future diet, the type of food production systems in place, crop productivity, use of biomaterials, availability of degraded land, policy development & competing land uses. Estimate is the upper limit, or geographic potential availability. Estimates of surplus/degraded agricultural land are highly uncertain. Low estimate caused by low numbers for energy crop potential and high figures for biomaterials.	0 surplus agricultural land + 430 Mha degraded land used for energy crops	2	Hoogwijk et al. (2003)
Global	Primary biomass (energy crops, agricultural residues, forestry residues, animal manure & biomaterials)	1,135 EJ/yr	Update existing estimates using data from the literature.	Includes energy crops grown on surplus & degraded agricultural land, agricultural residues, forestry residues, animal manure & organic waste, accounting for biomass used for biomaterials. Depends on future demand for food, population growth, future diet, the type of food production systems in place, crop productivity, use of biomaterials, availability of degraded land, policy development & competing land uses. Estimate is the upper limit, or geographic potential availability. Estimates of surplus/degraded agricultural land are highly uncertain. High estimate due to high potential of energy crops on surplus & degraded land	2.6 Gha of surplus agricultural land + 580 Mha degraded land used for energy crops	2	Hoogwijk et al. (2003)
Global	Energy crops	8 EJ/yr	Update existing estimates using data from the literature.	Surplus and degraded agricultural land is used to grow energy crops, after the demand for food and fodder is satisfied. Depends on future demand for food, population growth, future diet, the type of food production systems in place, crop productivity, use of biomaterials, availability of degraded land, policy development & competing land uses. Estimate is the upper limit, or geographic potential availability. Estimates of surplus/degraded agricultural land are highly uncertain.	0 surplus agricultural land + 430 Mha degraded land used for energy crops	2	Hoogwijk et al. (2003)
Global	Energy crops	1,098 EJ/yr	Update existing estimates using data from the literature.	Surplus and degraded agricultural land is used to grow energy crops, after the demand for food and fodder is satisfied. Depends on future demand for food, population growth, future diet, the type of food production systems in place, crop productivity, use of biomaterials, availability of degraded land, policy development & competing land uses. Estimate is the upper limit, or geographic potential availability. Estimates of surplus/degraded agricultural land are highly uncertain.	2.6 Gha of surplus agricultural land + 580 Mha degraded land used for energy crops	2	Hoogwijk et al. (2003)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	All biomass sources	130 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Land availability for biomass plantations could be different from the 4 scenarios modelled, which account for food production, nature conservation & emissions reductions. Future yields are uncertain. Estimates are on lower end of previous estimates. Lower estimate.	NA	2	Beringer et al. (2011)
Global	All biomass sources	270 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Land availability for biomass plantations could be different from the 4 scenarios modelled, which account for food production, nature conservation & emissions reductions. Future yields are uncertain. Estimates are on lower end of previous estimates. Higher estimate.	NA	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	26 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations only and F1C1 scenario (cropland expansion & higher nature conservation).	142 Mha plantation expansion into natural areas	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	52 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations with additional renewable surface runoff for irrigation. F1C1 scenario (cropland expansion & higher nature conservation).	NA	2	Beringer et al. (2011)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (lignocellulosic biomass plantations)	65 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations only and F1C2 scenario (cropland expansion & lower nature conservation).	NA	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	111 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations with additional renewable surface runoff for irrigation. F1C2 scenario (cropland expansion & lower nature conservation).	NA	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	68 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations only and F2C1 scenario (no cropland expansion & higher nature conservation).	NA	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	105 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations with additional renewable surface runoff for irrigation. F2C1 scenario (no cropland expansion & higher nature conservation).	NA	2	Beringer et al. (2011)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (lignocellulosic biomass plantations)	116 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations only and F2C2 scenario (no cropland expansion & lower nature conservation).	NA	2	Beringer et al. (2011)
Global	Energy crops (lignocellulosic biomass plantations)	174 EJ/yr	Global biogeochemical model of plant growth, carbon exchange & water limitations (LPJmL), validated with observations from test plantations. Climate scenarios from the IPCC are used to simulate future yields. Land use scenarios have various combinations of cropland expansion, no cropland expansion, higher nature conservation and lower nature conservation.	Estimate is for rainfed plantations with additional renewable surface runoff for irrigation. F2C2 scenario (no cropland expansion & lower nature conservation).	454 Mha plantation expansion into natural areas	2	Beringer et al. (2011)
Global	Energy crops	40 EJ/yr	Revise 10 existing estimates in the literature based on updated assumptions e.g. about crop yields & land availability.	Results represent the maximum plausible energy crop production, allowing for the conversion of virtually all 'unused' grassland and savannah (referred to as marginal land). Food crops & forests are set aside. The assumptions made are optimistic but reasonable. Lower estimate.	0.1 Gha	2	Searle & Malins (2014)
Global	Energy crops	110 EJ/yr	Revise 10 existing estimates in the literature based on updated assumptions e.g. about crop yields & land availability.	Results represent the maximum plausible energy crop production, allowing for the conversion of virtually all 'unused' grassland and savannah (referred to as marginal land). Food crops & forests are set aside. The assumptions made are optimistic but reasonable. Upper estimate.	3.7 Gha	2	Searle & Malins (2014)
Global	Energy crops & residues (forestry, agriculture & waste)	60 EJ/yr	Revise 10 existing estimates in the literature based on updated assumptions e.g. about crop yields & land availability. Lower estimate.	Results represent the maximum plausible energy crop production, allowing for the conversion of virtually all 'unused' grassland and savannah (referred to as marginal land). Food crops & forests are set aside. Food crops & forests are set aside. The assumptions made are optimistic but reasonable. The actual energy output will likely be lower.	0.1 Gha for energy crops	1	Searle & Malins (2014)
Global	Energy crops & residues (forestry, agriculture & waste)	120 EJ/yr	Revise 10 existing estimates in the literature based on updated assumptions e.g. about crop yields & land availability.	Results represent the maximum plausible energy crop production, allowing for the conversion of virtually all 'unused' grassland and savannah (referred to as marginal land). Food crops & forests are set aside. Food crops & forests are set aside. The assumptions made are optimistic but reasonable. The actual energy output will likely be lower. Upper estimate.	3.7 Gha for energy crops	1	Searle & Malins (2014)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	"Energy crops (short-rotation woody biomass crops e.g. willow, poplar or eucalyptus) "	311 EJ/yr	4 development and land-use scenarios from the IPCC and simulations by the IMAGE 2.2 model were conducted for the time frame 1970–2100.	Assumes that energy crops are grown on abandoned agricultural land, low-productivity land and 'rest land', i.e. remaining non-productive land/the remaining area further corrected for the grassland area, the forest land, the urban area and the bioreserves. Rest land area is assumed to be partly available. Estimates are for technical potential. Energy from low-productivity land is negligible. Land area available for energy crops is high compared to other studies. Estimates don't consider practical implementation limitations. A2 scenario (economic oriented).	Abandoned agricultural land is 0.6 Gha, rest land is 2.3 Gha.	2	Hoogwijk et al. (2005)
Global	"Energy crops (short-rotation woody biomass crops e.g. willow, poplar or eucalyptus) "	451 EJ/yr	4 development and land-use scenarios from the IPCC and simulations by the IMAGE 2.2 model were conducted for the time frame 1970–2100.	Assumes that energy crops are grown on abandoned agricultural land, low-productivity land and 'rest land', i.e. remaining non-productive land/the remaining area further corrected for the grassland area, the forest land, the urban area and the bioreserves. Rest land area is assumed to be partly available. Estimates are for technical potential. Energy from low-productivity land is negligible. Land area available for energy crops is high compared to other studies. Estimates don't consider practical implementation limitations. B1 scenario (global oriented).	NA	2	Hoogwijk et al. (2005)
Global	"Energy crops (short-rotation woody biomass crops e.g. willow, poplar or eucalyptus) "	322 EJ/yr	4 development and land-use scenarios from the IPCC and simulations by the IMAGE 2.2 model were conducted for the time frame 1970–2100.	Assumes that energy crops are grown on abandoned agricultural land, low-productivity land and 'rest land', i.e. remaining non-productive land/the remaining area further corrected for the grassland area, the forest land, the urban area and the bioreserves. Rest land area is assumed to be partly available. Estimates are for technical potential. Energy from low-productivity land is negligible. Land area available for energy crops is high compared to other studies. Estimates don't consider practical implementation limitations. B2 scenario (regional oriented).	NA	2	Hoogwijk et al. (2005)
Global	"Energy crops (short-rotation woody biomass crops e.g. willow, poplar or eucalyptus) "	657 EJ/yr	4 development and land-use scenarios from the IPCC and simulations by the IMAGE 2.2 model were conducted for the time frame 1970–2100.	Assumes that energy crops are grown on abandoned agricultural land, low-productivity land and 'rest land', i.e. remaining non-productive land/the remaining area further corrected for the grassland area, the forest land, the urban area and the bioreserves. Rest land area is assumed to be partly available. Estimates are for technical potential. Energy from low-productivity land is negligible. Land area available for energy crops is high compared to other studies. Estimates don't consider practical implementation limitations. A1 scenario (material oriented).	Abandoned agricultural land is 1.3 Gha, rest land is 2.3 Gha.	2	Hoogwijk et al. (2005)
Global	Biomass	200 EJ/yr	Literature review with an additional sensitivity analysis that accounts for water availability, soil quality and protected areas, and thus reduces previous estimates.	Constraints due to biodiversity protection, water limitations & food demand are included. Crop type & yield are uncertain. Estimate is for bioenergy potential. Detailed methodology is not provided. Lower estimate.	NA	1	Dornburg et al. (2010)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Biomass	500 EJ/yr	Literature review with an additional sensitivity analysis that accounts for water availability, soil quality and protected areas, and thus reduces previous estimates.	Constraints due to biodiversity protection, water limitations & food demand are included. Crop type & yield are uncertain. Estimate is for bioenergy potential. Detailed methodology is not provided. Upper estimate.	NA	1	Dornburg et al. (2010)
Global	Energy crops	120 EJ/yr	Literature review with an additional sensitivity analysis that reduces previous estimates.	Constraints due to biodiversity protection, water limitations & food demand are included. Crop type & yield are uncertain. Estimate is for bioenergy potential. Assumes exclusion of areas due to water scarcity, land degradation and expansion of protected areas. Detailed methodology is not provided.	NA	1	Dornburg et al. (2010)
Global	Energy crops	330 EJ/yr	Literature review with an additional sensitivity analysis that reduces previous estimates.	Constraints due to biodiversity protection, water limitations & food demand are included. Crop type & yield are uncertain. Estimate is for bioenergy potential. Includes an additional 70 EJ from water-scarce, marginal and degraded land, and an additional 140 EJ due to agricultural management improvements. Detailed methodology is not provided.	NA	1	Dornburg et al. (2010)
Global	Energy crops (first- & second-generation) & crop residues	101–110 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	282 Mha of set-aside arable land used for energy crops	2	Hakala et al. (2009)
Global	Energy crops (first- & second-generation) & crop residues	57–61 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	81 Mha of set-aside arable land used for energy crops	2	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (first- & second-generation) & crop residues	44–47 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	24 Mha of set-aside arable land used for energy crops	2	Hakala et al. (2009)
Global	Crop residues	38–41 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Irrigation could change the figures dramatically. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
Global	Energy crops (first- & second-generation)	64–70 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	282 Mha of set-aside arable land	1	Hakala et al. (2009)
Global	Energy crops (first- & second-generation)	19–21 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	81 Mha of set-aside arable land	3	Hakala et al. (2009)
Global	Energy crops (first- & second-generation)	6.3–6.8 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 ºC increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	24 Mha of set-aside arable land	2	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
USA	Energy crops (first- & second-generation) & crop residues	28–32 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
USA	Energy crops (first- & second-generation) & crop residues	11–13 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
USA	Energy crops (first- & second-generation) & crop residues	5.2–5.4 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
Canada	Energy crops (first- & second-generation) & crop residues	4.2–4.5 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a vegetarian diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Canada	Energy crops (first- & second-generation) & crop residues	2.9–3.1 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & a moderate diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
Canada	Energy crops (first- & second-generation) & crop residues	0.9–1.0 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Energy crops are grown on fields set aside from food production & an affluent diet is followed. Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. The residue potential depends also on local climate, and may be considerably lower than the technically harvestable potential when soil quality and sustainable development are considered. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
USA	Crop residues	5.2–5.4 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)
Canada	Crop residues	0.9–1.0 EJ/yr	FAO production statistics for 1997–2006 & estimations of climate change impacts on agriculture based on IPCC scenario B1 were used to estimate future bioenergy potential. B1 assumes reduced emissions and only about 2 °C increase in global average temperature by 2100.	Result reflects the technically harvestable residue energy potential, thus is in overestimation (some of the crop residue, in addition to the stubble, has to be ploughed in or left on the ground for better organic matter content and functionality of the soil). Irrigation could change the figures dramatically. The climate change scenario is optimistic. Crop residue potential was based on harvest indexes per crop that were based on the literature and the authors' results. Does not take into account international trade or land degradation or urbanisation that might occur in the meantime.	NA	2	Hakala et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops	16 EJ/yr	Scenario analysis with 3 different land-use scenarios (sustainable, business as usual and environment & health). 133 countries included.	Energy crops are grown on fallow (disused) land. Sustainable land-use scenario. No deforestation takes place. Food demand takes priority over energy crops. Estimate for the environment & health pathway is 40 EJ/yr. In all scenarios the analysis shows that no areas are available for producing energy crops in Central America, Asia and Africa. However, the EU, North America and Australia have relatively stable potentials. The assumptions may be conservative.	NA	2	Thrän et al. (2010)
Global	Energy crops	40 EJ/yr	Scenario analysis with 3 different land-use scenarios (sustainable, business as usual and environment & health). 133 countries included.	Energy crops are grown on fallow (disused) land. Food demand takes priority over energy crops. Environment & health pathway. Slow increase of land productivity. This development is based on a trend towards lower crop growth rates. Growth rates on arable land will decrease until 2050. There is a global reduction in food consumption. In all scenarios the analysis shows that no areas are available for producing energy crops in Central America, Asia and Africa. However, the EU, North America and Australia have relatively stable potentials.	NA	1	Thrän et al. (2010)
Global	Energy crops	96 EJ/yr	Scenario analysis with 3 different land-use scenarios (sustainable, business as usual and environment & health). 133 countries included.	Energy crops are grown on fallow (disused) land. Business as usual scenario. Development of food demand and agricultural conditions as existing since 1989 are analysed from time series, estimated as regression and applied to the future, after plausibility check and modification of variables if reasonable. Food demand takes priority over energy crops. Estimate for the environment & health pathway is 40 EJ/yr. In all scenarios the analysis shows that no areas are available for producing energy crops in Central America, Asia and Africa. However, the EU, North America and Australia have relatively stable potentials. The assumptions may be conservative.	NA	2	Thrän et al. (2010)
Global	Biomass (energy crops such as woody crops, sugarcane, corn, palm, and elephant grass and residual biosources such as animal-derived wastes, black liquor, wood residue, and municipal solid waste)	64 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Business-as-usual scenario- high population growth, rampant meat consumption etc.	8.8 Mha arable land	3	Errera et al. (2023)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Biomass (energy crops such as woody crops, sugarcane, corn, palm, and elephant grass and residual biosources such as animal-derived wastes, black liquor, wood residue, and municipal solid waste)	313 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Optimistic trends scenario- moderate population growth, reduction in beef consumption etc.	588 Mha arable land	3	Errera et al. (2023)
Global	Biomass (energy crops such as woody crops, sugarcane, corn, palm, and elephant grass and residual biosources such as animal-derived wastes, black liquor, wood residue, and municipal solid waste)	1192 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Full adaptation sceanario that considers dramatic changes in diet to non-beef, vegetarian and insect-based proteins. There is no food waste & large gains in agricultural productivity.	3,170 Mha arable land	1	Errera et al. (2023)
Global	Energy crops (such as woody crops, sugarcane, corn, palm, and elephant grass)	2 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Business-as-usual scenario- high population growth, rampant meat consumption etc.	8.8 Mha arable land	2	Errera et al. (2023)
Global	Energy crops (such as woody crops, sugarcane, corn, palm, and elephant grass)	167.2 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Optimistic trends scenario- moderate population growth, reduction in beef consumption etc.	588 Mha arable land	3	Errera et al. (2023)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (such as woody crops, sugarcane, corn, palm, and elephant grass)	991.7 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Full adaptation scenario that considers dramatic changes in diet to non-beef, vegetarian and insect-based proteins. There is no food waste & large gains in agricultural productivity.	3,170 Mha arable land	1	Errera et al. (2023)
Global	Agricultural residues (livestock & crops)	6.9 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Business-as-usual scenario- high population growth, rampant meat consumption etc.	NA	3	Errera et al. (2023)
Global	Agricultural residues (livestock & crops)	36 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Optimistic trends scenario- moderate population growth, reduction in beef consumption etc.	NA	3	Errera et al. (2023)
Global	Agricultural residues (livestock & crops)	55 EJ/yr	Scenario analysis with 3 scenarios: business-as-usual, full adaptation & optimistic trends. Advance and improve earlier projections of available land area for food crops. Main factors that affect biomass availability are resource availability, the final use energy demand by the population, possible crop productivity gains, expansion in mass and energy valorization of biomass residues and efficiency enhancements due to the advancement of technology.	Projections consider changes in available land for bioenergy and food for the global demand and advancements in yield, productivity, expansion of bio-waste recovery & energy conversion. Transition from mainly firewood today to mainly energy crops & biowastes. Advance earlier projections. Scenarios have different assumptions regarding population growth, food waste, diets, crop yield, land use & technologies. Some arbitrary assumptions needed & there may be previous errors in estimates used from the wider literature. Full adaptation scenario that considers dramatic changes in diet to non-beef, vegetarian and insect-based proteins. There is no food waste & large gains in agricultural productivity.	NA	1	Errera et al. (2023)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (miscanthus and switchgrass)	245 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for technical potential without any environmental protection policy implementation.	NA	1	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	244 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for moderate soil protection scenario.	NA	3	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	229 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for enhanced soil protection scenario.	NA	2	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	172 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for moderate biodiversity protection scenario. Wider coverage of protected and biodiversity sensitive areas.	NA	3	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	160 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for enhanced biodiversity protection scenario. Wider coverage of protected and biodiversity sensitive areas.	NA	2	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	149 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Estimate is for full environmental policy scenario.	NA	1	Wu et al. (2018)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (miscanthus and switchgrass)	167 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Demand-side policy for societal transformation scenario.	NA	2	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	183 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Supply-side policy for societal transformation scenario.	NA	2	Wu et al. (2018)
Global	Energy crops (miscanthus and switchgrass)	186 EJ/yr	AIM/CGE model under different environmental protection & societal transformation measures (e.g. changing diets, trade & technology). Assess global biomass energy potential and production costs under conditions that conserve land quality and biodiversity.	Simulated environmental policies that would meet land-based SDGs. Environmental policies include biodiversity & soil conservation, while societal transformation measures include changes in diet, trade & technology developments. Demand- and supply-side policy for societal transformation scenario.	NA	1	Wu et al. (2018)
Global	Biomass (dedicated energy crops, traditional biomass & residues)	70 EJ/yr	Simulations based on different land-use futures, food diet patterns and climate change mitigation efforts. Business-as-usual, high mitigation & extreme mitigation scenarios tested, based on IEA pathways 6DS, 4DS & 2DS. The 'Global Calculator Land Use Change' model.	Estimate is for business-as-usual scenario. Land area is for dedicated energy crops only. Scenario assumes medium population growth. Bioenergy does not compete with food security or forest conservation. Any expansion of energy crops is directed onto surplus land arising from declining land demand for food/feed, instead of onto areas of natural vegetation (e.g. native forests and natural grasslands).	100 Mha of agricultural land	1	Strapasson et al. (2017)
Global	Biomass (dedicated energy crops, traditional biomass & residues)	170 EJ/yr	Simulations based on different land-use futures, food diet patterns and climate change mitigation efforts. Business-as-usual, high mitigation & extreme mitigation scenarios tested. The 'Global Calculator Land Use Change' model.	Estimate is for high mitigation scenario. Land area is for dedicated energy crops only. Scenario assumes medium population growth. Bioenergy does not compete with food security or forest conservation. Any expansion of energy crops is directed onto surplus land arising from declining land demand for food/feed, instead of onto areas of natural vegetation (e.g. native forests and natural grasslands). A 2 °C scenario.	390 Mha of agricultural land	3	Strapasson et al. (2017)
Global	Biomass (dedicated energy crops, traditional biomass & residues)	360 EJ/yr	Simulations based on different land-use futures, food diet patterns and climate change mitigation efforts. Business-as-usual, high mitigation & extreme mitigation scenarios tested. The 'Global Calculator Land Use Change' model.	Estimate if for extreme GHG mitigation scenario. Land area is for dedicated energy crops only. This scenario is more theoretical and unlikely to occur, requiring 12% of current agricultural land for energy crops. Scenario assumes medium population growth. Extreme mitigation scenario assumes large reduction in meat consumption & very large increases in crop yields. Bioenergy does not compete with without compete with food security or forest conservation. Any expansion of energy crops is directed onto surplus land arising from declining land demand for food/feed, instead of onto areas of natural vegetation (e.g. native forests and natural grasslands).	570 Mha of agricultural land	1	Strapasson et al. (2017)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Biomass (second-generation bioenergy crops, agricultural residues & forestry residues)	40.36–311.72 EJ/yr	IPCC review of 85 1.5 degree pathways.	154.13 is median of all pathways, which is optimistic & assumes large areas of land are available for bioenergy crops. Some biomass is projected to be grown on marginal land. Land for second-generation energy crops (such as Miscanthus or poplar) expands by 2030 and 2050 in all available pathways that assume a cost-effective achievement of a 1.5°C temperature goal in 2100, but the scale depends strongly on underlying socio-economic assumptions. Reliable source.	0–6 Mkm^2 agricultural land for energy crops	3	IPCC (2018)
EU	Energy crops (Miscanthus, switchgrass, giant reed, reed canary grass, cardoon, poplar, willow & eucalyptus)	2265 PJ/yr	Marginal land availability is assessed based on sustainability criteria & biomass potential from energy crops is determined in each location, based on the best crop for each area.	Includes the EU & UK. 1km spatial resolution of biophysical conditions used. The largest share of available marginal land corresponds to shrubland, followed by open space (agricultural land is not presumed to be used for energy crops). Sustainability is unclear due to land-use change away from natural habitats. The best crop is mainly Miscanthus, followed by giant reed. Many uncertainties remain around land availability.	7.9–8.9 Mha	1	Vera et al. (2021)
Global	Woody biomass (roundwood and logging residues from forests & dedicated energy crop wood plantations; Miscanthus, switchgrass, giant reed, reed canary grass, cardoon, poplar, willow and eucalyptus)	0–23 Gm^3/yr, 0–165 EJ/yr	Global Biosphere Management Model (GLOBIOM) baseline scenario, where all forest areas are allowed to be used for harvesting, including primary forests.	The initial period of the model is the year 2000. Deforested biomass is excluded from the available woody biomass resources. Woody biomass includes stemwood, branches and stumps and foliage & roots. Permitted land-cover types for plantations expansion include cropland, grassland, and other natural vegetation areas, and they exclude forest areas. In 2000 energy wood demand is based on IEA data regarding solid biomass use for energy. Increasing amounts of woody biomass/land are available when the price of energy wood increases. Land-use competition between food, wood and energy production is modeled explicitly. Supply of biomass is modeled at 200 km × 200 km resolution. Economic costs are considered. Energy wood price determines the most important source of biomass. Estimate is market potential, which is less than theoretical & technical potential. Scenario assumes energy wood prices vary in a range of 0–30$/GJ.	3,829–3,848 Mha of forest area and 0–315 Mha of plantations and 818–1,939 Mha of managed forest area	2	Lauri et al. (2014)
Global	Crop residues	3.2–21.5 EJ/yr	Using the global biomass balance model BioBaM, this is an assessment of agricultural bioenergy potentials compatible with the FAO's (2018) 'Alternative pathways to 2050' projections.	Moderate GHG costs. Sustainable residue removal rates are given as 40% ('low estimate') and 60% ('high estimate'). Crop yields and the amount of residue removed are key influencing parameters. 20 EJ/yr in all FAO-based scenarios if 60% sustainable removal rate is assumed and less than 4 EJ/yr for a removal rate of 40%.	NA	2	Kalt et al. (2020)
Global	Energy crops (lignocellulosic or 'second generation' energy crops)	69–84.7 EJ/yr	Using the global biomass balance model BioBaM, this is an assessment of agricultural bioenergy potentials compatible with the FAO's (2018) 'Alternative pathways to 2050' projections. Universal grazing intensification scenario.	Energy plantations expand into grazing areas and grazing land is intensified globally. No expansion of agricultural land. The availability of energy crop potentials depends on various socio-economic developments and underlying narratives. Land demand, diet changes and yield changes are main influencing parameters. Forests are not used for energy crop expansion.	4–5 Mkm^2	2	Kalt et al. (2020)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (lignocellulosic or 'second generation' energy crops)	9.9–19.4 EJ/yr	Using the global biomass balance model BioBaM, this is an assessment of agricultural bioenergy potentials compatible with the FAO's (2018) 'Alternative pathways to 2050' projections. No grazing intensification scenario.	Assumes failure in addressing challenges for food access and stability and no grazing intensification. No expansion of agricultural land. The availability of energy crop potentials depends on various socio-economic developments and underlying narratives. Land demand, diet changes and yield changes are main influencing parameters. Forests are not used for energy crop expansion.	580,000 km^2 – 1.1 Mkm^2	2	Kalt et al. (2020)
Global	Energy crops (lignocellulosic or 'second generation' energy crops)	43–57 EJ/yr	Using the global biomass balance model BioBaM, this is an assessment of agricultural bioenergy potentials compatible with the FAO's (2018) 'Alternative pathways to 2050' projections. Grazing intensification on highly productive sites scenario.	Grazing land is only intensified for the most productive sites. No expansion of agricultural land. The availability of energy crop potentials depends on various socio-economic developments and underlying narratives. Land demand, diet changes and yield changes are main influencing parameters. Forests are not used for energy crop expansion.	2.42–3.1 Mkm^2	2	Kalt et al. (2020)
Global	Energy crops (second-generation woody)	215 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 1 estimate- high level of technology, rain-fed agriculture.	729 Mha for dedicated woody bioenergy crops	3	Smeets et al. (2007)
Global	Energy crops (second-generation woody)	455 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	1154 Mha for dedicated woody bioenergy crops	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Energy crops (second-generation woody)	1101 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 3 estimate- very high level of agricultural technology, rain-fed and/or irrigated.	3312 Mha for dedicated woody bioenergy crops	1	Smeets et al. (2007)
Global	Energy crops (second-generation woody)	1,272 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 4 estimate- super high level of advancement of agricultural technology, rain-fed and/or irrigated.	3585 Mha for dedicated woody bioenergy crops	1	Smeets et al. (2007)
North America	Energy crops (second-generation woody)	20 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 1 estimate- high level of technology, rain-fed agriculture.	54 Mha	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Energy crops (second-generation woody)	53 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	105 Mha	3	Smeets et al. (2007)
North America	Energy crops (second-generation woody)	144 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 3 estimate- very high level of agricultural technology, rain-fed and/or irrigated.	307 Mha	1	Smeets et al. (2007)
North America	Energy crops (second-generation woody)	174 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 4 estimate- super high level of advancement of agricultural technology, rain-fed and/or irrigated.	348 Mha	1	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Surplus forest growth	5.1 Gm^3, 59 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential. Surplus forest growth is forest growth not required for the production of industrial roundwood and traditional woodfuel. The technical potential of bioenergy from surplus forest growth is based on the yearly increment, i.e. the maximum amount of wood that can be harvested from forests annually without deforestation or reducing the standing stock (calculated as the supply of wood minus the demand for wood). Estimate represents a low plantation establishment scenario and a high demand. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted.	NA	2	Smeets et al. (2007)
Global	Surplus forest growth	8.9 Gm^3, 103 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential. Surplus forest growth is forest growth not required for the production of industrial roundwood and traditional woodfuel. The technical potential of bioenergy from surplus forest growth is based on the yearly increment, i.e. the maximum amount of wood that can be harvested from forests annually without deforestation or reducing the standing stock (calculated as the supply of wood minus the demand for wood). Estimate is for a high plantation establishment scenario and a low demand. The potential in case of a medium plantation establishment scenario and medium demand is calculated to be 74 EJ/yr. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted.	NA	1	Smeets et al. (2007)
Global	Surplus forest growth	74 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential. Surplus forest growth is forest growth not required for the production of industrial roundwood and traditional woodfuel. The technical potential of bioenergy from surplus forest growth is based on the yearly increment, i.e. the maximum amount of wood that can be harvested from forests annually without deforestation or reducing the standing stock (calculated as the supply of wood minus the demand for wood). Estimate is for a medium plantation establishment scenario and medium demand. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted.	NA	2	Smeets et al. (2007)
Global	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	76 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. System 1 estimate- high level of technology, rain-fed agriculture.	NA	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	79 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	NA	3	Smeets et al. (2007)
Global	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	96 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. Systems 3 & 4 estimates- very high level of agricultural technology, rain-fed and/or irrigated & super high level of advancement of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)
North America	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	14 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. System 1 estimate- high level of technology, rain-fed agriculture.	NA	3	Smeets et al. (2007)
North America	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	17 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	NA	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Agricultural and forestry residues and waste (harvest residues, process residues and biomass waste)	19 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. The reliability of data on land use (changes) varies significantly. Systems 3 & 4 estimates- very high level of agricultural technology, rain-fed and/or irrigated & super high level of advancement of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)
Global	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	367 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 1 estimate- high level of technology, rain-fed agriculture.	NA	3	Smeets et al. (2007)
Global	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	610 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	NA	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	1,273 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 3 estimate- very high level of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)
Global	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	1,548 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 4 estimate- super high level of advancement of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	39 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 1 estimate- high level of technology, rain-fed agriculture.	NA	3	Smeets et al. (2007)
North America	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	75 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 2 estimate- high level of technology, rain-fed and/or irrigated agriculture.	NA	3	Smeets et al. (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	168 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 3 estimate- very high level of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)
North America	Biomass (surplus forest growth, agricultural residues, forestry residues, waste & woody energy crops)	204 EJ/yr	Model for estimating bioenergy production potentials in 2050 called the Quickscan model, in addition to a literature review. Takes into account biological and climatological limitations and the future use of biomass for the production of food, materials and traditional woodfuel as well as the need to maintain existing forests for the protection of biodiversity. Base year (1998) data on harvested areas and yields per country are derived from the FAOSTAT database.	Surplus agricultural land i.e. land not needed for food or feed production is used for bioenergy production, dependent on the level of advancement of agricultural technology. Values represent technical potential, requiring significant increases in the efficiency of food production that may be unrealistically high. Dedicated bioenergy crops are woody bioenergy crop (e.g., eucalyptus, willow, poplar) that are assumed to be grown on surplus agricultural land. Data on the yield of energy crops are derived from the IMAGE model. The technical potential of residues and wastes is based on the technical potential to collect agricultural and forestry residues and wastes and by considering the amount of residues needed as animal feed. Estimates shown are for residues that can be recovered minus residues for animal feed. The reliability of data on land use (changes) varies significantly. The scenarios are based on state-of-the-art outlook studies that are commonly accepted. System 4 estimate- super high level of advancement of agricultural technology, rain-fed and/or irrigated.	NA	1	Smeets et al. (2007)
Global	Short-rotation energy crops	270.6 EJ/yr	Land-use scenarios to estimate the geographic & technical potential of energy crops. Scenarios are based on the IPCC SRES scenarios simulated with the IMAGE 2.2 model. Energy crop yields are from the IMAGE 2.2 model.	Energy crops are assumed to grow on abandoned agricultural land & rest land (rest land includes all the remaining non-productive land that can be used for energy crop production. The rest land category excludes bioreserves, forest, agricultural and urban areas and is calculated after satisfying the demand for food, fodder and forestry products). Estimates shown are less than the geographic potential; they represent the amount of biomass that could be available at costs below $2 GJ/yr. A1 scenario. Quite a large area of productive land may become available.	NA	3	Hoogwijk et al. (2009)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Short-rotation energy crops	129.3 EJ/yr	Land-use scenarios to estimate the geographic & technical potential of energy crops. Scenarios are based on the IPCC SRES scenarios simulated with the IMAGE 2.2 model. Energy crop yields are from the IMAGE 2.2 model.	Energy crops are assumed to grow on abandoned agricultural land & rest land (rest land includes all the remaining non-productive land that can be used for energy crop production. The rest land category excludes bioreserves, forest, agricultural and urban areas and is calculated after satisfying the demand for food, fodder and forestry products). Estimates shown are less than the geographic potential; they represent the amount of biomass that could be available at costs below $2 GJ/yr. A2 scenario.	NA	2	Hoogwijk et al. (2009)
Global	Short-rotation energy crops	271.8 EJ/yr	Land-use scenarios to estimate the geographic & technical potential of energy crops. Scenarios are based on the IPCC SRES scenarios simulated with the IMAGE 2.2 model. Energy crop yields are from the IMAGE 2.2 model.	Energy crops are assumed to grow on abandoned agricultural land & rest land (rest land includes all the remaining non-productive land that can be used for energy crop production. The rest land category excludes bioreserves, forest, agricultural and urban areas and is calculated after satisfying the demand for food, fodder and forestry products). Estimates shown are less than the geographic potential; they represent the amount of biomass that could be available at costs below $2 GJ/yr. B1 scenario. Quite a large area of productive land may become available.	NA	2	Hoogwijk et al. (2009)
Global	Short-rotation energy crops	155.3 EJ/yr	Land-use scenarios to estimate the geographic & technical potential of energy crops. Scenarios are based on the IPCC SRES scenarios simulated with the IMAGE 2.2 model. Energy crop yields are from the IMAGE 2.2 model.	Energy crops are assumed to grow on abandoned agricultural land & rest land (rest land includes all the remaining non-productive land that can be used for energy crop production. The rest land category excludes bioreserves, forest, agricultural and urban areas and is calculated after satisfying the demand for food, fodder and forestry products). Estimates shown are less than the geographic potential; they represent the amount of biomass that could be available at costs below $2 GJ/yr. B2 scenario.	NA	3	Hoogwijk et al. (2009)
Global	Surplus forest growth	5.2 Gm^3/yr, 64 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the technical potential, which is < the theoretical potential but doesn't consider economic or ecological limitations. Includes deforestation of forests.	NA	2	Smeets & Faaij (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Surplus forest growth	1.3 Gm^3/yr, 15 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the economic potential, which is < the theoretical and technical potential but doesn't consider ecological limitations. Includes deforestation of forests.	NA	3	Smeets & Faaij (2007)
Global	Surplus forest growth	0.7 Gm^3/yr, 8 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the ecological potential, which is < the theoretical, technical & economic potential. Includes deforestation of forests.	NA	1	Smeets & Faaij (2007)
Global	Surplus forest growth	0	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the economic-ecological potential, which is < the theoretical, technical & economic potential. The demand for woodfuel and industrial roundwood exceeds the supply by 0.7 Gm^3 (8 EJ/yr). Includes deforestation of forests.	NA	1	Smeets & Faaij (2007)
Global	Logging & processing residues & wastes	2.4 Gm^3/yr, 28 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Woody biomass from forestry was defined as all of the aboveground woody biomass of trees, including all products made from woody biomass. This includes the harvesting, processing and use of woody biomass. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and the technical, economic & ecological potential (these are equal).	NA	3	Smeets & Faaij (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Logging & processing residues & wastes	24 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Woody biomass from forestry was defined as all of the aboveground woody biomass of trees, including all products made from woody biomass. This includes the harvesting, processing and use of woody biomass. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and the economic-ecological potential.	NA	1	Smeets & Faaij (2007)
North America	Surplus forest growth	4.9 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the technical potential, which is < the theoretical potential but doesn't consider economic or ecological limitations.	NA	2	Smeets & Faaij (2007)
North America	Surplus forest growth	0.2 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the economic potential, which is < the theoretical and technical potential but doesn't consider ecological limitations.	NA	3	Smeets & Faaij (2007)
North America	Surplus forest growth	1.1 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the ecological potential.	NA	1	Smeets & Faaij (2007)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
North America	Surplus forest growth	0	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Surplus wood supply is wood left after the demand for woodfuel and industrial roundwood is met, including from forests, plantations and trees outside forests. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and represents the economic-ecological potential, which is < the theoretical, technical & economic potential. The demand for woodfuel and industrial roundwood exceeds the supply by 0.7 Gm^3 (8 EJ/yr).	NA	1	Smeets & Faaij (2007)
North America	Logging & processing residues & wastes	10.7 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Woody biomass from forestry was defined as all of the aboveground woody biomass of trees, including all products made from woody biomass. This includes the harvesting, processing and use of woody biomass. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and the ecological potential.	NA	1	Smeets & Faaij (2007)
North America	Logging & processing residues & wastes	10.6 EJ/yr	Projection based on comparing future demand for woody biomass with future supply of wood, based on existing databases, scenarios, and outlook studies.	Woody biomass from forestry was defined as all of the aboveground woody biomass of trees, including all products made from woody biomass. This includes the harvesting, processing and use of woody biomass. Key variables included the demand for industrial roundwood and woodfuel, the plantation establishment rates, and the various theoretical, technical, economical, and ecological limitations related to the supply of wood from forests. The residues available for energy depend on the demand and the supply of wood. Estimate is for a medium demand and medium plantation scenario and the economic, technical and economic-ecological potential (these are equal).	NA	3	Smeets & Faaij (2007)
Global	Agricultural & forestry residues	20–75 EJ/yr	Estimate the maximum sustainable amount of energy potentially available from agricultural and forestry residues by converting crop production statistics into associated residue, while allocating some of this resource to remain on the field to mitigate erosion and maintain soil nutrients. The Object-Oriented Energy, Climate, and Technology Systems Mini Climate Assessment Model ((OECTS)-E-bj MiniCAM) was used for projections into the future.	Estimate is for mid-to late-century, depending on physical assumptions such as of future crop yields and the amount of residue sustainably harvestable, on the presence of a climate policy and the economics of harvesting, aggregating, and transporting residue. Values represent global use of residue biomass, which is less than residue biomass that is available. To project future scenarios, the price for biomass is computed based on total energy demand and the prices for competing sources of energy. Estimate is for the reference scenario without climate policy.	NA	1	Gregg & Smith (2010)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Agricultural & forestry residues	60–100 EJ/yr	Estimate the maximum sustainable amount of energy potentially available from agricultural and forestry residues by converting crop production statistics into associated residue, while allocating some of this resource to remain on the field to mitigate erosion and maintain soil nutrients. The Object-Oriented Energy, Climate, and Technology Systems Mini Climate Assessment Model ((OECTS)-E-bj MiniCAM) was used for projections into the future.	Estimate is for mid-to late-century, depending on physical assumptions such as of future crop yields and the amount of residue sustainably harvestable, on the presence of a climate policy and the economics of harvesting, aggregating, and transporting residue. Values represent global use of residue biomass, which is less than residue biomass that is available. To project future scenarios, the price for biomass is computed based on total energy demand and the prices for competing sources of energy. Estimate is for the climate policy scenarios, where a premium is paid for carbon-free energy such as residue biomass, and nearly all of the potential residue biomass resource is used for energy.	NA	2	Gregg & Smith (2010)
Global	Biomass	99 EJ	Projections for achieving net zero by 2050.	IEA Net Zero Roadmap that projects pathways to net zero by 2050. Updated in 2023 & a reliable source. Estimate assume net zero in 2050, which may not be achieved (could be an optimistic assumption).	NA	2	IEA (2023)
Global	Energy crops (first- and second-generation)	115 EJ/yr	Supply modelling of bioenergy options based on existing statistics and estimates within the literature, with additional analyses.	Restrict bioenergy cropping to land suitable for rain-fed cultivation of energy crops in order not to require irrigation as an agricultural input. Land for bioenergy cropping excluded land needed for food, feed, biodiversity, high carbon stock forestes, urban areas & marginally suitable land. Estimate is for sustainable bioenergy availability. Energy crops include oil crops, starch and sugar crops and (ligno) cellulosic crops. Estimate of land availability is high; 2.5 Mha may be actually utilised for bioenergy but 6.4 Mha could be available.	6.4 Mha of mostly pasture available	1	Cornelisson et al. (2012)
Global	Surplus forest growth & traditional biomass	38 EJ/yr	Supply modelling of bioenergy options based on existing statistics and estimates within the literature, with additional analyses.	Estimate is for sustainable bioenergy availability. This category consists of woody biomass gained from sustainable harvesting of additional forest growth and of the sustainable share of the biomass currently used in traditional uses.	NA	2	Cornelisson et al. (2012)
Global	Agricultural and forestry residues and waste	101 EJ/yr	Supply modelling of bioenergy options based on existing statistics and estimates within the literature, with additional analyses.	Estimate is for sustainable bioenergy availability. Sustainable residues and waste originating from agriculture, forestry and the food processing industry. Exclusion of residues that are not available due to other uses and sustainability reasons	NA	2	Cornelisson et al. (2012)
Global	Energy crops	110–270 EJ/yr	Multi-regional global-land-use-and-energy model (GLUE-11) which consists of both a food sector and a forest sector.	Energy crops are planted on surplus arable land. The potential of energy crops will be strongly affected by the variation of the parameters of food supply and demand such as animal food demand	NA	2	Yamamoto et al. (2001)
Global	Biomass residues	48–135 EJ/yr	Multi-regional global-land-use-and-energy model (GLUE-11) which consists of both a food sector and a forest sector.	Practical bioenergy supply potential of biomass residues. Bioenergy supply potential of biomass residues will be stable against changes of food demand parameters.	NA	2	Yamamoto et al. (2001)
Global	Biomass	190 EJ/yr	Estimate the maximum physical potential of the world's total land area outside croplands, infrastructure, wilderness and denser forests.	Biophysical maximum biomass production that might be generated from the 4.7 billion hectares of the world's vegetated land outside denser forests, croplands, urban areas and wilderness. Figure is optimistic and does not consider practical, economic, ecological constraints etc.	NA	1	Haberl et al. (2013)

Region	Feedstock	Estimate	Method	Assumptions/limitations	Land area	Believability	Source
Global	Biomass (crop residues, grasslands, forest products, animal waste & municipal waste)	370–450 EJ/yr	Use land-use changes in a global scenario of agricultural development with requirements for arable land and with agricultural production, as projected by IIASA's world food system model. FAO land-use data for 1990 were used. Statistics and estimates are taken from literature.	Estimates account for economic criteria. The bioenergy potential of crop residues was calculated separately for five crop groups: wheat, rice, other grains, protein feed, and other food crops. Forest products are assumed to be sustainable.	NA	1	Fisher & Schrattenholzer (2001)
Global	Biomass	162 EJ/yr	Update existing estimates using data from the literature.	Maximum global production of biomass for energy use. Assumes that only present agricultural areas are used for food and biomass production. Biomass is produced without irrigation. There is a low food requirement.	7 Gha	2	Wolf et al. (2003)
Global	Biomass	360 EJ/yr	Update existing estimates using data from the literature.	Maximum global production of biomass for energy use. Assumes that all potential agricultural areas are used for food and biomass production. Biomass is produced without irrigation. Assumes a large expansion of the agricultural area and a very large area in use for biomass production.	NA	1	Wolf et al. (2003)