HOW MUCH BIOMASS IS AVAILABLE?

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INTRODUCTION

Human beings have always influenced their habitats and the conversion of natural ecosystems to anthropogenic landscapes is perhaps the most evident alteration of the Earth. Human societies have put almost half of the world's land surface to their service, and human land use has caused extensive land degradation and biodiversity loss, and also emissions to air and water contributing to impacts such as eutrophication, acidification, stratospheric ozone depletion and climate change. The substitution of biomass with fossil resources has – together with the intensification of agriculture – saved large areas from deforestation and conversion to agricultural land. However, intensified land management and the use of oil, coal and natural gas cause many of the environmental impacts we see today. Societies therefore take measures to reduce the dependence on fossil resources and return to relying more on biomass and other renewable resources.

Besides that demand for food and conventional forest products such as paper and sawnwood grows around the world, the ambition to replace fossil based products (especially fuels) with biobased products presents considerable opportunities as well as challenges for agriculture and forestry. Figure 4.1 illustrates this by presenting a magnitude comparison of biomass output in forestry and agriculture with prospective biomass demand for energy (see figure caption for more detailed description). One immediate conclusion from this comparison is that the biomass extraction in agriculture and forestry will have to increase substantially in order to provide feedstock for a bioenergy sector large enough to make a significant contribution to the future energy supply. Biomass will also be required as feedstock for the production of new types of biomaterials displacing their fossil based alternatives (e.g., plastics, rubber and bulk chemicals, see Chapter 3), but this materials production only uses on the order 10% of total annual petroleum and gas production.[1] It is the use of fossil fuels in the energy sector that is the main source of society's exploitation of fossil resources and the displacement of fossil fuels with biomass consequently represents that largest prospective use.

A first quantitative understanding of prospects for meeting future biomass demands can be gained from considering the total annual aboveground net primary production (NPP: the net amount of carbon assimilated in a time period by vegetation) on the Earth's terrestrial surface. NPP is estimated to correspond to about 35 billion ton of carbon, or 1260 EJ[2], per year (Haberl et al., 2007), which can be compared to the current world energy use of about 500 EJ per year and the present and prospective biomass demands shown in Figure 4.1. (see numbers in figure caption). This comparison shows that the present and prospective biomass demand is clearly significant compared to global NPP. Establishing bioenergy as a major future contributor to energy supply requires that a significant part of global terrestrial NPP takes place within production systems that

1 Some 10% of the coal is used in steel production.
2 Assuming an average carbon content in biomass of 50% and 18 GJ/ton (dry biomass and average lower heating value, see Chapter 6 for a discussion on heating values and water content of biomass feedstock).

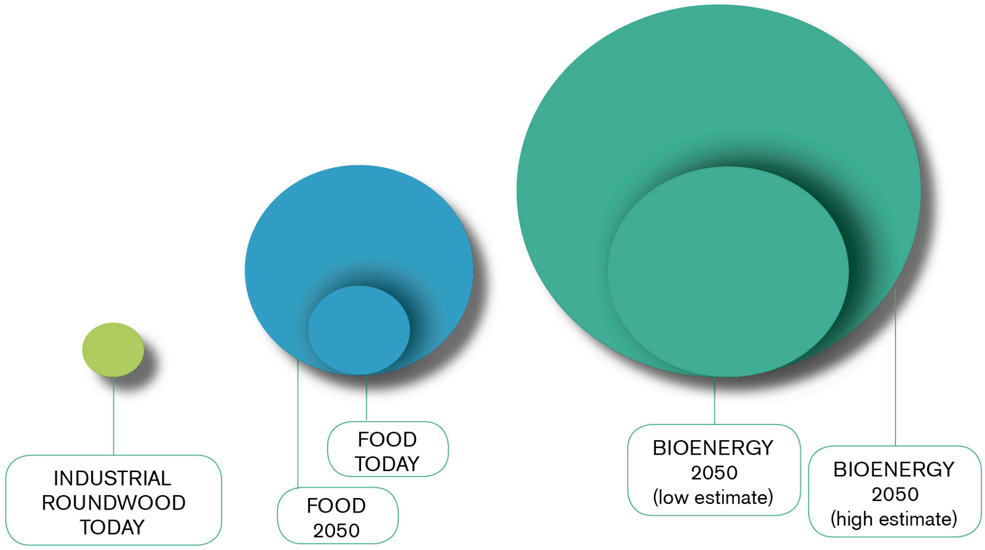

Figure 4.1 Comparison of the food and agriculture sector with a prospective bioenergy sector. The energy content in today's global industrial roundwood production is about 15-20 EJ per year, and the global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers and pulses) corresponds to about 60 EJ per year (FAO 2011). The large green circles show the range (25th and 75th percentiles) in biomass demand for energy found in a recent review by the IPCC of 164 long-term energy scenarios meeting <440 ppm CO2eq concentration targets (118 to 190 EJ per year of primary biomass). Source: IPCC (2011).

provide bioenergy feedstocks. Total terrestrial NPP may also have to be increased through fertilizer, irrigation and other inputs on lands managed for food, fibre and bioenergy production.

Biomass production, to provide feedstocks for bioenergy and new types of biobased products, interacts in complex ways with the production of food and other conventional biobased products. Some biomass flows that earlier were considered to be waste products can find new economic uses, and opportunities for cultivating new types of crops and integrating new biomass production with food and forestry production can help improve overall resource management. However, the growing biomass demand also means increased competition for land, water and other production factors, and can result in overexploitation and degradation of resources.

This chapter discusses long-term biomass resource potentials and how these have been estimated based on considerations of the Earth's biophysical resources (ultimately net primary production, NPP) and restrictions on their use arising from competing requirements, including non-extractive requirements such as soil quality maintenance or improvement and biodiversity protection. The focus is on assessments that are concerned with biomass supply for energy but these are relevant also for those thinking about the prospects for a biobased economy in general. Approaches to assessing biomass potentials – and results from selected studies – are presented with an account of the main determining factors. An account is also given of possible consequences that can follow from a substantially increased use of biomass as feedstock for bioenergy and other bioproducts – and how these consequences can be addressed.

METHODOLOGIES FOR ASSESSING BIOMASS SUPPLY POTENTIALS

Studies have used different approaches to assess how biophysical conditions influence the biomass supply potential. Studies also differ in whether – and how – they consider important additional factors, such as socioeconomic considerations, the character and development of agriculture and forestry, and factors connected to nature conservation and preservation of soil, water and biodiversity.[3] Assessments that only consider biophysical conditions produce so-called *theoretical potentials*. If also limitations imposed by the employed production practices, and the competing demand from other biomass end uses (e.g., food), are considered one commonly refer to *technical potentials*. The term *sustainable potential* is sometimes used when also various limitations connected to nature conservation and soil, water and biodiversity preservation are considered.

There are also studies that quantify *market potentials*, which might be done from both the supply side and the demand side (Figure 4.1 showed results of demand side assessments). Supply side assessments of market potentials aim at estimating how much biomass that can be produced below a given cost limit. They combine data on land availability, yield levels, and production costs to obtain plant- and region-specific cost-supply curves. These are based on projections or scenarios for the development of cost factors, including opportunity cost of land, and can be produced for different contexts (including different policy regimes) and scales. Examples include feasibility studies of supplying individual bioenergy plants, sector-focusing studies, and studies producing comprehensive multi-sector cost-supply curves for countries, larger regions, or for the entire world.[4] The biomass production costs can be combined with technological and economic data for related logistic systems and conversion technologies to derive market potentials for secondary energy carriers such as bioelectricity and biofuels for transport. The cost limits used to derive market potentials are also dependent on policy regime as well as on costs for competing energy technologies and development of the overall energy system.

Most assessments of the biomass resource potential considered in this section are variants of technical and market potentials that employ a "food and fibre first principle" with the objective of quantifying biomass resource potentials under the condition that global requirements of food and conventional forest products such as sawnwood and paper are met with priority. Studies that start out from such principles should not be understood as providing guarantees that a certain level of biomass can be supplied for energy purposes without competing with food or fibre production. They quantify how much bioenergy could be produced at a certain future year based on using resources not required for meeting food and fibre demands, given a specified development in the world or in a region. But they do not analyze how bioenergy expansion towards such a future level of production would – or should – interact with food and fibre production.

RANGES OF ESTIMATED BIOMASS POTENTIALS

Table 4.1 shows ranges in the assessed technical potential for the year 2050 for various biomass categories. The wide ranges shown in Table 4.1 are due to the variety of methodological approaches applied and diverging assumptions about critical factors such as economic and technology development, population growth, dietary changes, nature protection requirements and effects of climate change on agriculture and forestry production. Some studies exclude areas where attainable yields are below a certain minimum level. Other studies exclude biomass resources judged as being too expensive to mobilize, given a certain biomass price level, even if assessment of economic potentials is not the stated aim of the study.

Figure 4.2(a) shows – as an example – estimates of European supply potentials corresponding to certain food sector scenarios for 2030 considering also nature protection requirements and

3 See. e.g., the overview of 17 studies in Berndes et al. (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy, 25(1), pp. 1-28.

4 See, e.g., Hoogwijk et al. (2009). Exploration of regional and global cost-supply curves of biomass energy from short-rotation crops at abandoned cropland and rest land under four IPCC SRES land-use scenarios. Biomass and Bioenergy, 33(1), pp. 26- 43.

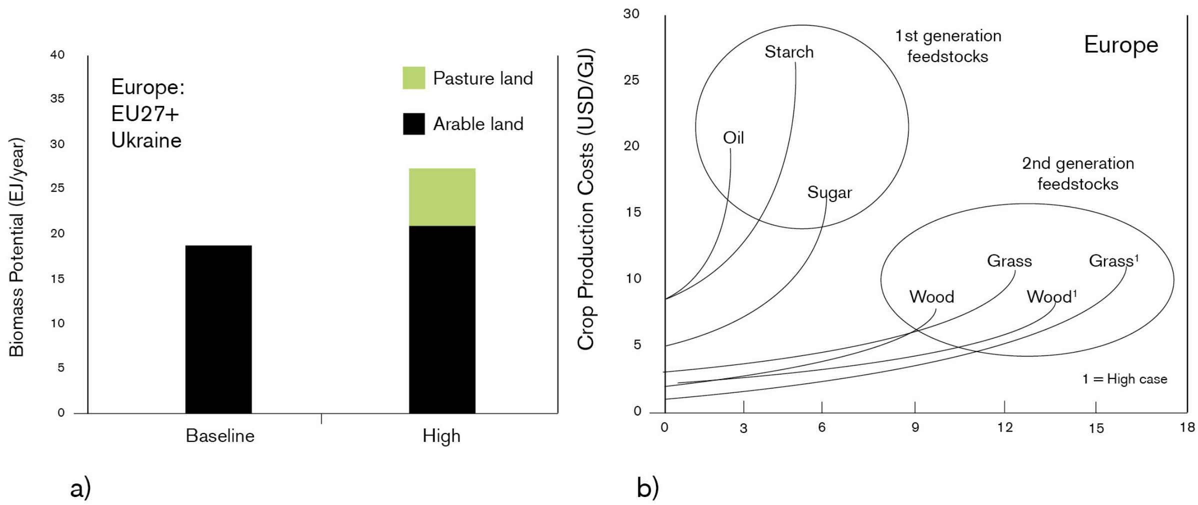

Figure 4.2 Examples of modelled market potentials 2030 (a) based on feedstock cost supply curves shown in (b) for European countries. Sources: (a): Fischer et al., (2010); (b): de Wit and Faaij, 2010

infrastructure development. The cost supply curves shown in Figure 4.2(b) were subsequently produced including biomass plantations and residues from forestry and agriculture. The key factor determining the size of the potential in this case was the pace of land productivity development in pasture production, i.e., the amount of meat and milk that could be produced per unit of pasture land.

Studies that quantify the biomass resource potential consider a range of factors that reduce the potential to lower levels than if they are not included. These factors are also connected to impacts arising from the exploitation of biomass resources. Despite that assessments employing improved data and modelling capacity have not succeeded in narrowing down the uncertainty range of potential future biomass supply, they do indicate the most influential factors that affect the potential. The following sections briefly describe how the potentials of the different categories of biomass in Table 4.1 are estimated and elaborate on the impact of important factors.

ORGANIC WASTE AND RESIDUE FLOWS IN AGRICULTURE

Many factors determine how much organic waste that is produced in society or how much residues that are generated in agriculture and forestry – and also how much of this that can be extracted. First of all, the future volumes of post-consumer organic waste as well as residues in agriculture and forestry production are determined by the future demand for agriculture and forestry products. Assumptions about population growth, economic development, dietary changes and consumption patterns in general thus influence the outcome in studies that quantify the future potential of residues. The way studies characterize materials management strategies (including recycling and cascading use of materials) is also important since it influences how the demand for different types of products translates into demand for basic food commodities and industrial roundwood.

Organic waste is a heterogeneous category that can include, e.g., organic waste from households and restaurants, and discarded wood products such as paper and demolition wood. The availability depends on many factors including consumption patterns, competing uses and implementation of collection systems. Studies use similar approaches to quantification as when assessing primary residue volumes in agriculture and forestry, i.e., production or consumption data are combined with factors that reflect the amount of organic waste that is produced per unit of product output. More rough estimates may simply combine information about per capita production of organic waste with population projections. As there is no global set of agreed definitions of

Table 4.1 Overview of global technical potential of land-based bioenergy supply for a number of categories (primary energy, rounded numbers).

Biomass category	Comment	2050 technical potential (EJ/year)
Organic waste	A heterogeneous category that can include, e.g., organic waste from households and restaurants, and discarded wood products such as paper and demolition wood. The availability depends on future consumption patterns, competing uses and implementation of collection systems.	5 – 50
Residue flows in agriculture	By-products associated with food/fodder production and processing, both primary (e.g., cereal straw from harvesting) and secondary residues (e.g., rice husks from rice milling).	15 – 70
Dung	Population development, diets, and the character of livestock production systems are critical determinants: usually only dung from confined livestock production is assumed to be available.	5 – 50
Forest biomass	Biomass from silvicultural thinning and logging, and wood processing residues such as sawdust and bark. Dead wood from natural disturbances, such as fires and insect outbreaks, represents a second category. Some studies estimate the size of available forest growth that is not required for industrial roundwood production to meet projected demand for conventional forest products such as sawnwood and pulp. "Available forest growth" here refers to growth occurring on lands judged as being available for wood extraction. High forest biomass potentials correspond to a much larger forest biomass extraction for energy than what is presently achieved in industrial wood production. Zero potential indicates that forest biomass requirement to meet the demand for conventional forest products can become larger than the estimated forest supply capacity.	0 – 110
Dedicated biomass production on surplus agricultural land	Includes conventional agriculture crops, tree species (e.g., eucalyptus, and pine) grown in plantations providing pulpwood and other conventional forest products, and new types of plants suitable as feedstock for bioenergy or new types of biomaterials. "Surplus agriculture land" refers to former agriculture land no longer used for food production, but availability of such land needs not imply that less land is needed for food in the future compared to today: land may become excluded from agriculture use in modeling runs due to land degradation processes or climate change making them non-suitable for food crops and food production may then have expanded elsewhere, for instance by converting forests to croplands. Large potential requires global development towards high-yielding agricultural production and low demand for grazing land, making very large areas (similar scale as present global cropland area) available for biomass plantations. Zero potential reflects that studies report that food sector development can be such that no surplus agricultural land will be available.	0 – 700
Dedicated biomass production on marginal lands	Some studies specifically assess the extent of marginally productive land or land that has become degraded due to unsustainable use, but that still could be suitable for some bioenergy schemes, for instance via reforestation. There is no globally established definition of degraded/marginal land and not all studies make a distinction between such land and other land judged as suitable for bioenergy. Adding an estimate of potential biomass supplies from surplus agriculture lands with another estimate of potential biomass supplies from degraded lands may therefore lead to double counting since the studies may actually refer to partly the same land areas. Low potential for this category indicate competing land demand for, e.g., extensive grazing management and/or subsistence agriculture, or that the biomass production on the land is judged to not be viable.	0 – 110
Total		<50 – >1000

The total assessed technical potential can be lower than the present bioenergy supply of about 50 EJ/year in the case of high future food and fiber demand in combination with slow productivity development in land use, leading to strong declines in biomass availability for energetic purposes. Source: IPCC (2011).

different organic waste and residue categories available, it is important to make sure that double counting is avoided if assessments of residue and waste flows are made based on combining results from studies that themselves focus on only one or a few waste streams. Different studies might also be more or less incompatible in the sense that the quantifications are made based on diverging assumptions about population growth, economic development, consumption patterns and character of production systems. This is a challenge also when other biomass categories are studied.[5]

Assessments of the potential contribution of agricultural residue flows to the future biomass supply combine data on future production of agriculture products obtained from food sector scenarios with so-called "residue factors" that account for the amount of residues generated per unit of primary product produced. For example, harvest residue generation in agricultural crops cultivation is commonly estimated based on the harvest index of respective crops, i.e., the ratio of harvested product to total aboveground biomass.[6] The shares of these biomass flows that are available for energy ("recoverability fractions") are then estimated based on consideration of other extractive uses (e.g., animal feeding or bedding) and other requirements such as the need to leave residues on the ground for the purposes of soil conservation. Other recoverable biomass flows in the food sector can be estimated in a similar way. For example, recoverability fractions for dung are set based on the structure of the animal production sector (confined production vs. free grazing) and then used to quantify the bioenergy potential associated with dung management.

Changes in the food industry influence the residue generation per unit product output in different ways: crop breeding leads to improved harvest index reducing residue generation rates; implementation of no-till, or conservation, agriculture requires that harvest residues are left on the fields to maintain soil cover and increase organic matter in soils; shift in livestock production to more confined and intensive systems can increase recoverability of dung but reduce overall dung production at a given level of livestock product output.

In agriculture, overexploitation of harvest residues is one important cause of soil degradation in many places of the world.[7] Fertilizer inputs can compensate for nutrient removals connected to harvest and residue extraction, but maintenance or improvement of soil fertility, structural stability and water holding capacity requires recirculation of organic matter to the soil.[8] Residue recirculation leading to nutrient replenishment and storage of carbon in soils and dead biomass contributes positively to climate change mitigation by withdrawing carbon from the atmosphere and by reducing soil degradation and improving soil productivity leading to less need to convert land to cropland and thereby lowering GHG emissions arising from vegetation removal and ploughing of soils.

RESIDUES AND UNUSED GROWTH IN FORESTS

The generation of logging residues in forestry, and of additional biomass flows such as thinning wood and process by-products, is estimated using similar methods as when residue flows in agriculture are quantified. Again, recoverability fractions are estimated based on consideration of other extractive uses (e.g., fibre board production in the forest sector) and other requirements such as the need to leave dead wood in the forest to promote biodiversity. Changes in the forest industry influence the residue generation per unit product output, e.g. increased occurrence of silvicultural treatments such as early thinning

5 See also Chapter 6 for a discussion on the problems and risks of mixing results from studies that use different definitions and incompatible assumptions.
6 See, e.g., Krausmann et al. (2008). Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. Ecological Economics, 65(3), pp. 471-487.

7 Blanco-Canqui, H., and R. Lal (2009). Corn stover removal for expanded uses reduces soil fertility and structural stability. Soil Science Society of America Journal, 73(2), pp. 418-426.
8 Wilhelm, W.W. et al. (2007). Corn stover to sustain soil organic carbon further constrains biomass supply. Agronomy Journal, 99, pp. 1665-1667.

to improve stand growth will lead to increased availability of small roundwood suitable for energy uses.[9]

Studies indicate that the cost of soil productivity loss may restrict residue removal intensity to much lower levels than the quantity of biomass physically available in forestry.[10] However, the combination of residue harvest and nutrient (including wood ash) input can avoid nutrient depletion and acidification and can in some areas improve environmental conditions due to reduced nutrient leaching from forests. [11]Development of technologies for stump harvesting after felling increases the availability of residues during logging. It can also reduce the cost of site preparation for replanting and reduce damage from insects and spreading of root rot fungus. [12] Yet, again, it can also lead to negative effects including reduced forest soil carbon and nutrient stocks, increased soil erosion and soil compaction.[13] Besides soil sustainability, additional aspects (e.g., biodiversity and water quality) need to be considered. Organic matter at different stages of decay plays an important ecological role in conserving soil quality as well as for promoting biodiversity and thresholds for desirable amounts of dead wood in forest stands are difficult to set.

In addition to the residue flows that are linked to industrial roundwood production and processing to produce conventional forest products, forest growth above what is currently harvested is considered a source of forest wood in some studies. Figure 4.3 shows an example for the case of Europe, where both current wood removals and the unused forest growth are compared to the current gross energy consumption in order to place the forest wood flows in the context of energy systems. The potential of unused forest growth is quantified based on estimating the net annual increment (NAI) of biomass in the parts of forests that are assessed as being available for wood supply and deducting the present biomass removals on the same land.[14] Countries close to the dotted diagonal have a non-used NAI that is roughly equal to the current removals or, in other words, the total NAI is twice as large as the current removals. The further up a country is in the diagram, the larger is the non-used NAI compared to the country's gross energy consumption. A special case that can play a role is forest growth that becomes available after extensive tree mortality from insect outbreaks or fires.[15]

Studies that consider the possibility to exploit unused forestry growth as a feedstock source do not commonly account for the possibilities to intensify conventional long-rotation forestry to increase forest growth over time. Yet, many studies indicate significant potential for intensifying conventional long-rotation forestry to increase forest growth and total biomass output – for instance by fertilizing selected stands and using shorter rotations– especially in regions of the world with large forest areas that currently practice extensive forest management. [16] However, concerns about biodiversity and other undesirable effects might restrict productivity-enhancing measures.

9 See Chapter 5 for an outline of current and potential utilization of residue flows in pulp mills.

10 Gan, J., and C. Smith (2010). Integrating biomass and carbon values with soil productivity loss in determining forest residue removals. Biofuels, 1(4), pp. 539-546; Titus, B.D. et al (2009). Wood energy: Protect local ecosystems. Science, 324(5933), pp. 1389-1390.

11 Börjesson, P. (2000). Economic valuation of the environmental impact of logging residue recovery and nutrient compensation. Biomass and Bioenergy, 19(3), pp. 137-152; Eisenbies, M., E. Vance, W. Aust, and J. Seiler (2009). Intensive utilization of harvest residues in southern pine plantations: Quantities available and implications for nutrient budgets and sustainable site productivity. BioEnergy Research, 2(3), pp. 90-98.

12 Saarinen, V.-M. (2006). The effects of slash and stump removal on productivity and quality of forest regeneration operations – preliminary results. Biomass and Bioenergy, 30(4), pp. 349-356.

13 Walmsley, J.D., and D.L. Godbold (2010). Stump harvesting for bioenergy - A review of the environmental impacts. Forestry, 83(1), pp. 17-38.

14 NAI minus current removals is a rough indication of how much removals can increase in a given country. NAI refers to the average annual volume of increment of all trees, with no minimum diameter, minus the natural losses. Thus, it is equivalent to natural forest growth in a year (minus the natural losses).

15 Dymond, C.C. et al. (2010). Future quantities and spatial distribution of harvesting residue and dead wood from natural disturbances in Canada. Forest Ecology and Management, 260(2), pp. 181-192.

16 Berndes, G et al. (2011). Bioenergy, land use change and climate change mitigation. Background Technical Report. IEA Bioenergy: ExCo:2011:04

There is also the need to consider the net outcome in relation to climate change mitigation, one primary objective of using more biomass as feedstock for fuels and other products. Changed forest management in response to bioenergy demand influences forest carbon flows and can lead to increased or decreased forest carbon stocks.[17] Shortening forest rotation length in order to obtain increased output of timber and biomass fuels leads to decreased carbon stock in living biomass (other things being equal). Intensified biomass extraction in forests, for instance for bioenergy, can lead to a decrease in soil carbon or the dead wood carbon pool compared to existing practice. Conversely, if changed forest management employing intensified extraction also involves growth-enhancing measures, forest carbon stocks may increase. Finally, increasing CO_2 concentrations[18] and associated climate change influence future forest productivity and the potential of utilizing unused forest growth is sensitive to technical and economic aspects of biomass extraction in areas with limited infrastructure and other constraints on access.

PLANTATIONS DEDICATED TO BIOENERGY

The category biomass plantations include many different types of biomass production systems, ranging from the cultivation of conventional food crops to management of tree plantations that are grown in rotations up to several decades. The category differs from the forest category in that the production commonly uses agricultural practices, i.e., employing even aged monocultural stands that are subject to fertilizer, pesticide and other inputs. Certain boreal forest stands might share some of these features but are despite of this usually included in the forest category. The potential biomass supply from dedicated biomass plantations is estimated based on assessments of the availability of land that is suitable for such plantation, and the biomass yields that can be obtained on the available lands. Given that surplus agricultural land is commonly identified as the major land resource for the biomass plantations, food sector development is critical. The rate of intensification in agriculture is consequently a key aspect because it influences both land availability for biomass plantations (indirectly by determining the land requirements in the food sector) and the biomass yield levels obtained. Studies also point to the importance of diets and the food sector's biomass use efficiency in determining land requirements (both cropland and grazing land) for food.[19]

Most earlier assessments of biomass resource potentials used rather simplistic approaches to estimate the technical potential of biomass plantations, but the continuous development of modelling tools that combine databases containing biophysical information (soil, topography, climate) with analytical representations of relevant crops and agronomic systems and the use of economic and full biogeochemical vegetation models has resulted in improvements over time.[20]

As an example, Figure 4.4. shows the modelled global land suitability for both lignocellulosic plants and conventional food and feed crops that are suitable as biofuel or biomaterials feedstock (see caption to Figure 4.4for information about plants included). By overlaying spatial data on global land cover derived from best available remote sensing data combined with statistical information and data on protected areas, it is possible to quantify the extent of suitable land for different land cover types. A suitability index has been used in order to represent both yield

17 Berndes, G et al. (2011). Bioenergy, land use change and climate change mitigation. Background Technical Report. IEA Bioenergy: ExCo:2011:04

18 Elevated CO_2 levels in the ambient air stimulate plant growth. However, plants grown in conditions where other factors (e.g. limitations of rooting volume, light, temperature) restrict growth may not show a sustained response to elevated CO_2.

19 See, e.g., Wirsenius et al. (2010). How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems (2010), doi: 10.1016/j.agsy.2010.07.005

20 See, e.g., Beringer et al. (2011). Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. Global Change Biology Bioenergy, doi:10.1111/j.1757-1707.2010.01088.x; Fischer et al., (2009) Fischer, G., E. Hizsnyik, S. Prieler, M. Shah, and H. van Velthuizen (2009). Biofuels and Food Security. The OPEC Fund for International Development (OFID) and International Institute of Applied Systems Analysis (IIASA), Vienna, Austria, 228 pp

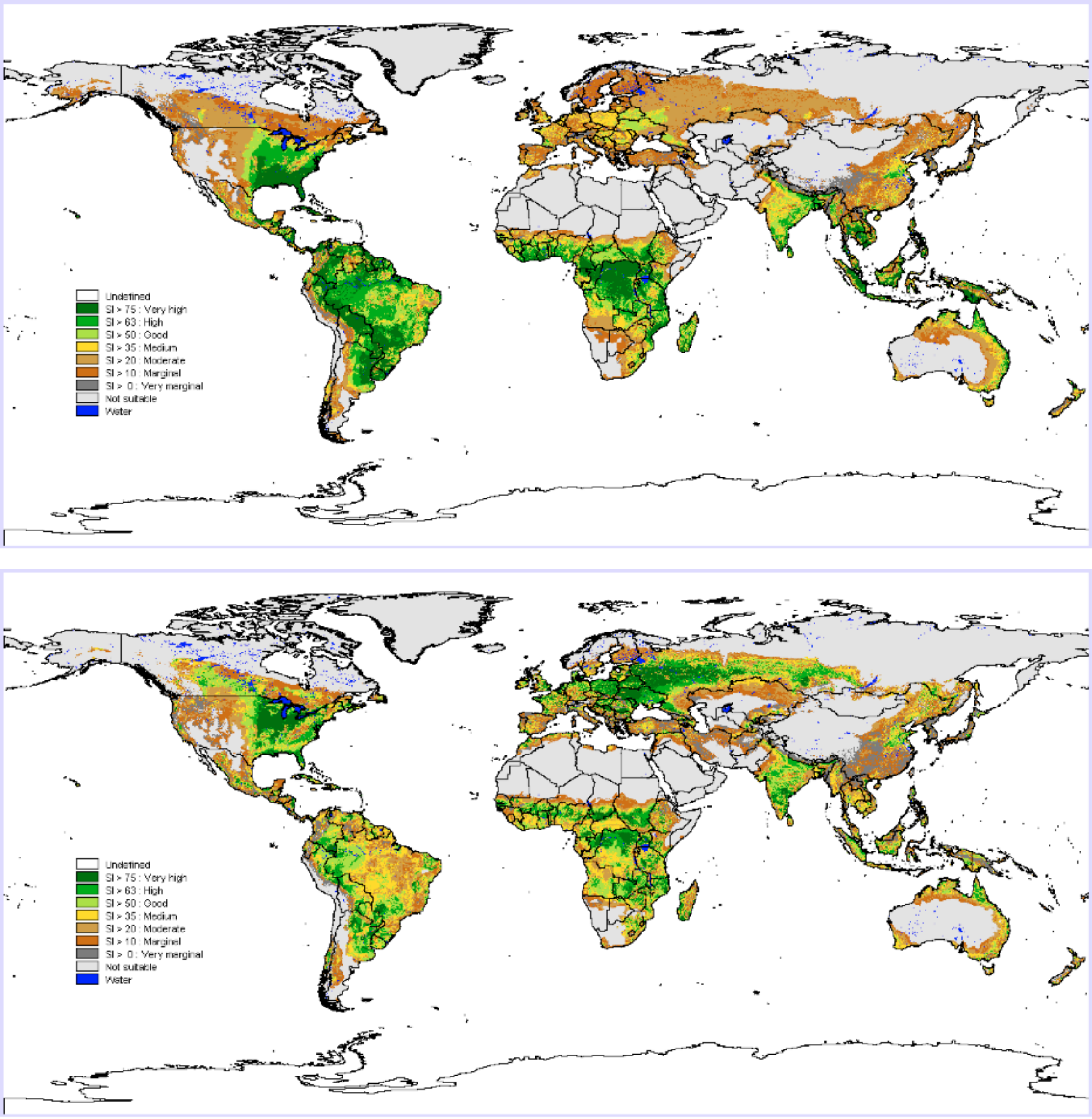

Figure 4.4 Global land suitability for bioenergy plantations. The upper map shows suitability for herbaceous and woody lignocellulosic plants (Miscanthus, switchgrass, reed canary grass, poplar, willow, eucalypt) and the lower map shows suitability for first generation biofuel feedstocks (sugarcane, maize, cassava, rapeseed, soybean, palm oil, jatropha). The suitability index SI describes the spatial suitability of each pixel and reflects the match between crop requirements and prevailing climate, soil and terrain conditions. The map shows suitability under rain-fed cultivation and advanced management systems, which assume availability of sufficient nutrients, adequate pest control and mechanization, and other practices. Results for irrigated conditions or low input management systems would result in different pictures (Fischer et al. 2009).

potentials[21] and suitability (see caption to Figure 4.4).

Considerations concerning biodiversity can limit both intensification and expansion of the agricultural land area. The common way of considering biodiversity requirements as a constraint is by including requirements on land reservation for biodiversity protection. However, the focus is as a rule on forest ecosystems and takes the present level of protection as a basis. Other natural ecosystems also require protection – not least grassland ecosystems – and the present

21 Yield potential is the yield obtained when an adapted cultivar (cultivated variety of a plant) is grown with the minimal possible stress that can be achieved with best management practices.

status of nature protection for biodiversity may not be sufficient. Bioenergy plantations can support biodiversity conservation in human-dominated landscapes, particularly when multiple species (e.g., agroforestry systems) are planted and mosaic landscapes are established in uniform agriculture landscapes and in some currently poor or degraded areas. Biomass resource potential assessments, however, as a rule assume yield levels corresponding to what is achieved in monoculture plantations and therefore provide little insight into how much biomass could be produced if a significant part of the biomass plantation were shaped to contribute to biodiversity preservation.

It is notable that several studies of agricultural development [22] show lower expected yield growth than studies of the biomass resource potential that report very high potentials for biomass plantations.[23] Some observations indicate that it can be a challenge to maintain yield growth in several main producer countries due to land degradation as a consequence of improper land use (IAASTD 2009). Water scarcity can limit both intensification possibilities and the prospects for expansion of bioenergy plantations.[24] There can also be limitations and negative aspects of further intensification aiming at farm yield increases; high crop yields depending on large inputs of nutrients, fresh water, and pesticides can contribute to negative ecosystem effects, such as changes in species composition in the surrounding ecosystems, groundwater contamination and eutrophication with harmful algal bloom, oxygen depletion and anoxic "dead" zones in oceans being examples of resulting negative impacts.[25] However, agricultural productivity can be increased in many regions and systems with conventional or organic farming methods.[26]

Conversely, there are also reasons to look positively at the potential of biomass plantations. Studies reaching high potential for biomass plantations points primarily to tropical developing countries as major contributors and in these countries there are still substantial yield gaps to exploit and large opportunities for productivity growth – not the least in livestock production.[27] The low productivity of rain-fed agriculture that prevails in many regions can be improved through improved soil and water management, fertilizer use and crop selection.[28] Advances in plant breeding and genetic modification of plants not only raise the genetic yield potential but also may adapt plants to more challenging environmental conditions, such on marginal or degraded soils. Improved drought tolerance can improve average yields in drier areas and in rain-fed systems in general by reducing the effects of sporadic drought and can also reduce water requirements in irrigated systems. Selection and development of suitable plant species and genotypes for given locations to match specific soil types, climate, and conversion technology is possible, but is at an early stage of understanding for some energy

22 E.g Alexandratos, N. (2009). World food and agriculture to 2030/50: highlights and views from mid- 2009. In: Proceedings of the Expert Meeting on How to Feed the World in 2050, Rome, Italy, 24-26 June 2009. Economic and Social Development Department, Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 78.

23 Johnston, M. et al. (2009). Resetting global expectations from agricultural biofuels. Environmental Research Letters, 4(1), 014004

24 Berndes, G. (2008). Water Demand for Global Bioenergy Production: Trends, Risks and Opportunities. Report commissioned by the German Advisory Council on Global Change. Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, Berlin, Germany, 46 pp.

25 Donner, S.D., and C.J. Kucharik (2008). Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. Proceedings of the National Academy of Sciences, 105(11), pp. 4513-4518.

26 Badgley, C., J. et al. (2007). Organic agriculture and the global food supply. Renewable Agriculture and Food Systems, 22(02), pp. 86-86.

27 Wirsenius, S. et al. (2010). How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems (2010), doi: 10.1016/j.agsy.2010.07.005

28 Lal, R. (2003). Offsetting global CO_2 emissions by restoration of degraded soils and intensification of world agriculture and forestry. Land Degradation & Development, 14(3), pp. 309-322.; Rost, S., et al. (2009). Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters, 4(4), 044002 (9 pp.).

plants.[29] Thus, there is a large yield growth potential for dedicated biomass plants that have not been subject to the same breeding efforts as the major food crops.

Besides reducing land requirements for meeting food and materials demand by increasing yields, plant breeding and genetic modification could make lands initially considered unsuitable available for rain-fed or irrigated production. Landscape approaches that integrate bioenergy production into agriculture and forestry systems to form multi-functional land use systems producing multiple (bioenergy, food and fiber) products could contribute to development of farming systems and landscape structures that are beneficial for the conservation of biodiversity and that also help restore and maintain soil productivity and healthy ecosystems.[30] Conservation agriculture and mixed production systems (double-cropping, crop with livestock and/or crop with forestry) hold potential to sustainably increase land and water productivity and improve food security and efficiency in the use of limited resources such as phosphorous.[31] Integration can also be based on integrating feedstock production with conversion – typically producing animal feed that can replace cultivated feed such as soy and corn and also reduce grazing requirement.[32]

29 See e.g. Chapple, C., M. Ladisch, and R. Meilan (2007). Loosening lignin's grip on biofuel production. Nature Biotechnology, 25(7), pp. 746-748; Karp, A., and I. Shield (2008). Bioenergy from plants and the sustainable yield challenge. New Phytologist, 179(1), pp. 15-32; Lawrence, C.J., and V. Walbot (2007). Translational genomics for bioenergy production from fuelstock grasses: Maize as the model species. Plant Cell, 19(7), pp. 2091-2094.

30 Note that such multiple output systems could be regarded as biorefineries depending on definition and system boundary (compare definitions in Chapter 2).

31 Heggenstaller, A.H. et al. (2008). Productivity and nutrient dynamics in bioenergy double-cropping systems. Agronomy Journal, 100(6), pp. 1740-1748; Herrero, M. et al. (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. Science, 327(5967), pp. 822-825.

32 Dale, B.E., et al. (2010). Biofuels done right: Land efficient animal feeds enable large environmental and energy benefits. Environmental Science & Technology, 44(22), pp. 8385-8389.

CONCLUDING REMARKS

To sum up, the size of the future biomass potential is dependent on a number of factors that are inherently uncertain and will continue to make long-term potentials unclear. Important factors are population and economic and technology development and how these translate into fibre, fodder and food demand (especially share and type of animal food products in diets) and the development in agriculture and forestry. Additional factors include climate change impacts on biological productivity and future land use including its adaptation capability; considerations set by biodiversity and nature conservation requirements; and consequences of land degradation and water scarcity. Nevertheless, it can be concluded that it might be possible to produce several hundred exajoules (EJ) per year of biomass as feedstock for bioenergy and other bioproducts – if developments are favourable. This can be compared with the present biomass use for energy at about 50 EJ per year.

Organic waste and residue flows in agriculture and forestry represent important sources of biomass, but consideration of biodiversity and the need to ensure maintenance of healthy ecosystems and avoid soil degradation set bounds on residue extraction in agriculture and forestry. It is clear that high biomass potentials require that biomass plantations become established on a large scale and that these achieve high yield levels. Thus, agriculture development and increased land use productivity are prerequisites for reaching high biomass supply potentials. Grasslands and marginal, or degraded, land have potential for supporting substantial biomass production, but biodiversity considerations, water shortages, and the difficulty of establishing viable production on such lands may limit this potential.

At the same time, the development of suitable biomass production systems, using also new types of plants, may make it possible to produce biomass on lands less suited for conventional food crops and integrated (bioenergy, food, fiber) production systems can promote higher efficiency in the use of land, water and other resources.

While recent assessments employing improved data and modelling capacity have not succeeded in providing narrow, distinct estimates of the biomass resource potential, they have advanced the understanding of how influential various factors are on the resource potential and that both positive and negative effects may follow from increased biomass use for energy and biomaterials. The insights from resource assessments can in this way improve the prospects for expanding the use of biomass for energy and for other purposes by pointing out the areas where development is most crucial and where research is needed. Studies using integrated energy industry and land use cover models[33] can provide further insights into how an expanding bioenergy sector interacts with other sectors in society including land use and management of biospheric carbon stocks. Such insights are essential when contemplating the prospects for displacing fossil resources with biomass.

33 See, e.g., Melillo et al. (2009). Indirect emissions from biofuels: How important? Science, 326(5958), pp. 1397-1399. ; Strengers, B. et al. (2004). The land-use projections and resulting emissions in the IPCC SRES scenarios as simulated by the IMAGE 2.2 model. GeoJournal, 61(4), pp. 381-393.Wise et al. (2009) Implications of limiting CO_2 concentrations for land use and energy. Science, 324(5931), pp. 1183-1186.