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The Role of Biomass in the Sustainable Development Goals: A Reality Check and Governance Implications

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Content

1. Introduction

The United Nations Conference on Sustainable Development (Rio+20), which took place in 2012, launched a process to develop a set of Sustainable Development Goals (SDGs). Member states agreed that the SDGs would build upon the Millennium Development Goals (MDGs) and form part of the Post-2015 development agenda. Going beyond the MDGs, the SDGs are envisioned to be universal. Moreover, they shall address the three dimensions of sustainable development (economic, social, and environmental) and consider their inter-linkages, while accounting for national circumstances (UN 2012). A central aim of the SDGs is to address "inequalities in all areas, agreeing that no goal or target should be considered met unless it is met for all social and economic groups" (UN 2014a, p. 15). An Open Working Group (OWG) was established in January 2013, composed of representatives of a selected number of UN member states, to negotiate the SDGs, with the involvement of a broad range of stakeholders. After meeting for 13 formal sessions, the OWG released an outcome document on 19 July 2014 with 17 potential SDGs and 169 accompanying targets, covering areas such as poverty, food security, gender equality, water, energy, climate change, industrial development, and global partnerships. The SDGs will be further negotiated during the year 2015 and are expected to be adopted by the UN General Assembly in September 2015.

This paper highlights the cross-cutting, yet overlooked, role of different types of biomass in the SDGs. Biomass, derived from land-based organic materials, is a core foundation of human societies, in its use as human food, animal feed, biomaterials, or bioenergy (see also Box 1). In 2005, approximately thirteen billion metric tonnes of biomass was harvested worldwide, of which food and feed accounted for about 82 percent, bioenergy 11 percent, and biomaterials 7 percent (Wirsenius 2007, pp. 1–2). Biomass consumption differs between countries, but food makes up the largest share in all countries. At the same time, biomass is also increasingly used for non-food and non-feed purposes. In addition to its use as a traditional energy source (wood and charcoal), the modern energy mix progressively relies on the combustion of biomass-derived biofuels, such as biogas, bioethanol, biodiesel, as well as different forms of wood. This is largely in response to dwindling fossil fuel reserves, fluctuating prices, and the need to cut CO_2 emissions (IEA and OECD 2013). Biomass is also an important input in the chemical and pharmaceutical sectors, often as part of replacing fossil fuel inputs with renewables, as well as the worldwide trend to promote bio-based industrial development. In Germany, for example, in 2014, approximately 12.5 percent of arable land area was cultivated for energy crops and 1.8 percent for industrial use (FNR 2014).

Demand for various types of biomass is projected to increase dramatically in the medium-term, due to population growth, increasing average income, changing dietary patterns (OECD-FAO 2014), and politically determined incentives. Despite being renewable, biomass is a limited resource. If not cultivated and governed appropriately, the production and consumption of biomass can exacerbate challenges associated with land competition, resource scarcity, soil degradation, biodiversity loss, and climate change. For example, the production of biomass for purposes other than food and feed can jeopardize food security. In addition, biomass production can induce changes in land use, access, and ownership that can have unsustainable social, economic, and environmental consequences. Furthermore, the expansion of cultivation to serve the different demands for food, feed, biomaterials, and bioenergy might result in the conversion of areas (such as grasslands, savannahs, forests, and wetlands) that are not suitable for sustainable agriculture. Such expansion could lead to deforestation and also endanger biodiversity and the livelihoods of indigenous, poor, and vulnerable populations. Intensification of land use might also reduce water quality and availability, and might further disturb the global carbon and nitrogen biogeochemical cycles.

Many of the proposed Sustainable Development Goals are reliant on biomass. Producing and consuming the various types of biomass sustainably is therefore essential and should be a central concern of the Post-2015 agenda. The current set of SDGs, however, does not reflect the sustainable production and consumption of biomass in an explicit and integrated way. Biomass production is implicit in a number of goals, such as the goals on food security, energy, industrial development, consumption and production patterns, and the protection of ecosystems (see Table 1). Various analyses of the currently proposed set of SDGs have been made. They focus on specific topics related to biomass, such as food security (Stockholm Environment Institute 2014; Biovision and Millennium Institute 2014), forests (IIED 2014), or climate (CAN 2014). However, there is a need to look at biomass production and consumption across its different uses – food, feed, biomaterials, and bioenergy – as they rely on the same land resources and may therefore come into direct competition with each other. To ensure a comprehensive consideration of the role of biomass in the SDGs, our assessment proposes an integrated heuristic approach. Drawing on a nexus framework, the paper identifies and analyses the interdependencies and trade-offs between different forms of biomass demands. This implies protection of the natural resource base that is required for biomass production and impacted by it. It further implies recognizing the socio-economic objectives at the heart of the joint Rio+20 commitments, in particular the focus on equity and intergenerational sustainability. The assessment takes note of the influence of political economy, climate change, and the global repercussions of national biomass choices. Overall, our nexus approach is used to identify and address the challenges of meeting a diversity of social needs within given ecological boundaries.

Table 1: Relevant SDGs for biomass

SDG 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all
SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
SDG 12: Ensure sustainable consumption and production patterns
SDG 13: Take urgent action to combat climate change and its Impacts
SDG 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

The SDG negotiations demonstrate the need – and offer the opportunity – to raise awareness of these complex and interdependent issues, and to address the prospects and challenges of sustainably produced and consumed biomass within the Post-2015 development agenda. The aim of this paper is to show that, in their current form, the proposed SDGs are not sustainable, because future demands for biomass, as implied by the proposed SDGs, cannot be met sustainably. Moreover, it aims to contribute to the debate on related governance implications, in the context of the implementation of the SDGs.

The paper proceeds as follows: Section 2 discusses the projected land demand for the production of different types of biomass as implied by the proposed set of SDGs. Moreover, it considers land demanded for other purposes, such as nature conservation, that must be considered within the context of the overall limited availability of land. It also discusses the challenges associated with the available data, and calls for greater recognition of demand-management issues. Section 3 contrasts these projections for biomass-related land with existing projections of land availability, showing a shortfall between projected demand and availability of land for biomass production. Section 4 reviews existing problems of large-scale biomass production that might be exacerbated by associated competition for land, and which must be resolved to ensure that biomass production and consumption are sustainable. Specifically, this section considers widespread socio-economic and environmental problems. Section 5 pulls together the different threads of the previous sections and on the basis of an integrated nexus approach derives key governance issues that have to be accounted for during SDG implementation, in order to ensure that the SDGs are sustainable, and that the targets – with their implicit biomass demands – can be met sustainably. In concluding, Section 6 elaborates on key features of governance and possible next steps toward the operationalization of the SDGs in general, and sustainable biomass regimes in particular.

Box 1: Biomass glossary

Biomass refers to organic products and to wastes and residues from agriculture, forestry, and other sources including fisheries and aquaculture. In this paper, we focus on biological material produced on land for human food, animal feed, material, and energy use. This comprises crops (including residues and waste), wood (including harvest residues and waste), and other lignocellulosic biomass (including *Miscanthus* and switchgrass).

Bioenergy is the conversion of biomass resources such as agricultural and forest products and residues, organic municipal waste, and energy crops into useful energy carriers, including heat, electricity, and transport fuels.

Traditional **biomaterials** include wood in furniture and as a construction material. Novel biomaterials comprise a range of biochemicals, such as bioplastics, lubricants, and solvents synthesized from biomass instead of fossil sources.

2. Projected land demand for food, feed, biomaterials, and bioenergy production and consumption, as implied by the SDGs

This section considers how much more land is required to meet the multiple biomass demands implied by the current set of SDGs. A distinction is made between production of biomass for (i) food, (ii) feed, (iii) biomaterial, (iv) bioenergy purposes, and (v) its function as a major component of nature conservation agendas.

2.1 Food

Food security is a main priority in the Sustainable Development Goals and the Post-2015 development agenda. Goal 2 aims to end hunger, achieve improved nutrition, and promote sustainable agriculture. The challenges posed by Goal 2 are enormous: i) achieving food security, ii) ending malnutrition, iii) doubling agricultural productivity and incomes of small-scale food producers, iv) ensuring sustainable food systems, and v) maintaining genetic diversity of seeds and domesticated animals (UN 2014b, p. 8). Most of these challenges will have to be met by the 570 million farms in the world, of which 72 percent are estimated to have land holdings of less than one hectare (ha) (FAO 2014a, p. 2).

It is uncertain how much more agricultural produce will be required to feed a growing world population sufficiently in the future. Tilman et al. (2011, p. 20261), for example, estimate that the global demand for crops will increase by 100 to 110 percent. The projections of the Food and Agriculture Organization of the United Nations (FAO), which are most often quoted in the debate on food production, estimate that global agricultural production would have to increase by 70 percent (23 percent in developed countries and nearly 100 percent in developing countries) over the period from 2005/07 to 2050 in order to provide sufficient food for the growing world population. In this scenario, crop production would increase by 1.1 percent per annum. For example, an additional one billion tonnes of cereals would need to be produced annually by 2050 (Bruinsma 2009, p. 5).

Existing projections of land demand for food production do not differentiate between land take by food or feed production, but subsume feed under food. Therefore, we will introduce food-related land demand projections together with feed production and consumption trends in the next section, 2.2; and also discuss the degree to which feed production might compete with food production for land.

2.2 Feed

As part of SDG Goal 2 on sustainable agriculture and food security, it is important to account for the shift in diets. Global population will not only grow in size, but per capita incomes in most developing nations are expected to grow in line with economic growth. As a consequence, the demand for agricultural products is expected to change: away from cereal staple crops to more protein-rich foods like meat and dairy. Bruinsma (2009, p.5) estimates that an additional 212 million tonnes of meat would need to be produced annually by 2050. Bailey et al. (2014, p. 5) project that the increase in demand for meat (76 percent) and dairy products (65 percent) will grow faster than that for cereals (40 percent) from 2005/07 to 2050. The Agrimonde Scenario Analysis projects that dietary changes could be greater in developing than in developed countries, particularly in Asia and Sub-Saharan Africa, whose middle class are catching up with Western diets (Paillard et al. 2014, p. 65).

An increase in meat and dairy production means that biomass would increasingly be produced for feed purposes. For example, according to the FAO, 80 percent of the additional 480 million tonnes of maize produced annually by 2050 would be for animal feed (Bruinsma 2009, p. 6). The OECD-FAO Agricultural Outlook 2014 – 2023 projects that an additional 58 million tonnes of meat will be consumed by 2023, of which 80 percent will occur in developing countries. The demand for feed will increase accordingly, and the OECD-FAO Outlook projects that 160 million tonnes of additional feed will be demanded by 2023 (OECD-FAO 2014, p. 32). The increase in biomass for feed purposes will depend not only on the amount of meat demanded, but also on the type of meat. As Wirsenius (2007, p. 3) states, ruminant (e.g. cattle) meat "requires 10 to 20 times more land and biomass per unit produced than pig and poultry meat and milk, and even relatively small changes in its consumption level have significant effects on the requirement of agricultural land, not only of grassland, but also of cropland". The composition of meat demand varies largely by region, driven by cultures and traditions as well as income levels (OECD-FAO 2014, p. 181).

The Steinfeld et al. (2006, p. xxiii) report on *Livestock's Long Shadow* predicts that the "environmental costs per unit of livestock production must be cut by one half, just to avoid the level of damage worsening beyond its present level" – in the form of high emissions of greenhouse gases and its contribution to land and water degradation. As of today, livestock production uses about "30 percent of the Earth's land surface" (ibid), which amounts to about "70 percent of all agricultural land" (Steinfeld et al. 2006, p. xxi). A large land share is composed of pastures, and an estimated 33 percent of global arable land is used for feed production. Case studies from Latin America show that clearing of forests to access new pastures is a main driver of deforestation (ibid).

Thus, dietary changes have significant implications for food security as well as for social and environmental goals (e.g. deforestation, adequate work, biodiversity; see Weis 2013a; Steinfeld et al. 2006; Oliveira and Schneider 2014). However, none of these models consider the potential and/or future necessity to reduce meat demand or to slow the increase in demand, for instance, through public education. According to a study by Chatham House (Bailey et al. 2014, pp. 2 – 3), the lack of attention to this topic of sustainable meat and dairy consumption is largely due to a lack of awareness, and the fear of backlash by governments in addressing individual choices, despite the multiple environmental and public health benefits. Meat consumption is a major contributory factor to obesity, cancers, and cardiovascular diseases, and feed production is a major driver of deforestation and greenhouse gas emissions (Steinfeld et al. 2006; Bailey et al. 2014; Weis 2013b). Moreover, future land take for feed purposes is projected to be dramatically higher than that for food – to the extent of threatening food security (FAO 2006; De Schutter 2009). The case of soy production highlights the increased land take by feed production. Over the past 60 years, global soy bean production has risen by 1,000 percent and the land area used to produce it has quadrupled. The majority of total world soy production is used for livestock feed (Oliveira and Schneider 2014, p. 2).

How will the additional food and feed demand be met?

All projections presume that more food and feed will have to be produced to meet global demand. The increased output is estimated to come from intensification of agricultural production (e.g. higher yields and multiple cropping per season) and net land expansion. The FAO projects that 77 percent of the incremental agricultural production to 2050 will be achieved by yield increases, and 14 percent by increases in cropping intensities. These figures vary by region: In the Middle East and North Africa (MENA) region, 90 percent of additional agricultural output is expected to be produced by increasing yields. In Sub-Saharan Africa and Latin America, 69 and 52 percent, respectively, of additional output will come from yield increases (Bruinsma 2009, p. 6).

A historical perspective shows that, over the past six decades, farmers were able to keep up with the food demand of a rapidly growing world population, which more than doubled globally and tripled in developing countries over that period (UNPOP 2014). However, these productivity increases differed across regions. Greater productivity advances have been observed in Latin America and Asia than in Sub-Saharan Africa. Most of the increases have been due to the development and uptake of modern seed technologies, irrigation, fertilizers as well as modern farming equipment and techniques.

The question arises of whether advancements at this scale can be maintained over the next two decades, how, and at what cost. Mueller et al. (2012, p. 255) postulate that the potentials to close the gaps between observed and attainable yields in maize, wheat, and rice are high in Eastern Europe, Sub-Saharan Africa, and East and South Asia, but are lower in North America and Western Europe, where yields are already high. In addition, Grassini et al. (2013, p. 4) find that yields have plateaued in some of the world's most intensive cereal cropping areas, in the United States and Europe.

Importantly, increased yield and cropping intensities may not suffice to meet the additional food and feed demands, both of which might also compete with each other. The FAO, for example, estimates a net land expansion of 70 million ha between 2005/07 and 2050 (Bruinsma 2009, p. 2). The FAO models predict that arable land in use will grow by 0.1 percent per year from 2005/07 to 2050, down from 0.3 percent per year from 1961 to 2005. Most of the expansion in land take is expected to occur in Latin America and Sub-Saharan Africa, because these regions are estimated to have the highest land crop production potential, while no expansion is expected in the Middle East, Near East and North Africa, or East and South Asia (Bruinsma 2009, p. 13). However, scenarios for agricultural expansion do not consider social contexts, such as land ownership, actual use, or governance (see Section 3 for a discussion of the models). The Global Land Use Assessment of the United Nations Environmental Programme (UNEP) arrives at the same conclusions: that the growing demand for food and feed will be met by yield increases and agricultural land expansion (UNEP 2014). The report states that agricultural land could increase by between 71 and 300 million ha to meet the additional demand for food and feed. Most of this expansion could occur by moving into grasslands, savannahs, and forests (UNEP 2014, p. 20).

Therefore, increases in food or feed production will have to go beyond technological solutions to ensure that growth is achieved and shared in a sustainable way. Increases in output will depend on putting the right institutions and structures in place and opting for more sustainable and inclusive forms of agricultural production. This includes, for example, the consideration of agro-ecological practices as well as improved and more equal access to land, productive resources, services, and infrastructure for all farmers. At the same time, meeting the needs of today's poor and food-insecure as well as adequately feeding a growing population will not only depend on producing more in a people-centred way – it also implies improving access to food. Further, it means establishing appropriate demand management options, such as reducing food waste in the agricultural value chain; or addressing the increase in meat and dairy production and consumption. Particularly, the changing dietary patterns of a growing middle class might compete with the broader goals of achieving food security for all.

2.3 Biomaterials

Biomass for material purposes encompasses a number of products, most prominently paper, pulp, rubber, and cotton. Other examples include solvents and plastics that can be used by the chemical industry. There are fewer projections of future biomass demand for material purposes than for food and fuel purposes. Hoogwijk et al. (2003, p. 129), using historical trends, estimate that the total demand for biomass for material purposes could range between 4335 and 6084 million tonnes in 2050, whereby wood-based products would continue to make up the majority of products, followed by pulp and chemicals. This could be reduced to 820 – 2570 million tonnes if all production residues are used effectively. The authors estimate that the amount of land required to meet the estimated biomass demand for material purposes would range between 503 and 678 million ha, of which the majority (approx. 351 million ha) will be forests (ibid).

Recent life cycle assessments comparing the use of biomass for energy and materials conclude that a cascading use of the feedstock is most efficient, i.e. using biomass to produce wood products or high-value biomaterials (bioplastics, lubricants, etc.) first. According to this concept, energetic use of biomass follows the end of the materials' life cycle. However, material applications do not yet enjoy similar legislative and financial support to that provided for energy uses of biomass, and are therefore hardly competitive at present. It is thus unclear how the market for biomaterials and cascading uses of biomass will develop in the future, and what this might imply regarding the demand for specific types of land.

How will the additional materials demand be met?

As mentioned above, the majority of biomass demand for material purposes is expected to be based on wood-based materials. Increased demand for forest products will promote competition between different forest products, e.g. timber used in construction, the paper industry, and wood-based biomass for energy (Raunikar et al. 2010, pp. 55–56). The rising demand for forest-related products is currently met by increased harvest rates from primary and secondary forests as well as forest plantations.[2] This can have serious repercussions for the quality of soils and carbon storage. In places where existing forests are poorly managed, the growing demand for forest products comes at the risk of overexploitation, be it through the formal forestry sector or by illegal logging and trade (Boucher et al. 2011, p. 65; GPFLR 2011).

The rising demand for biomass for material purposes would have to be met by using materials more efficiently through recycling, as well as by increasing yields and land expansion. The UNEP Global Land Use Assessment, based on an extensive study of projections that consider future trends, states that global crop land expansion through increased demand for biomaterials will vary from 4 to 115 million ha (UNEP 2014, p. 20). It is unclear where this land is supposed to come from, and – at this stage – demand management options have not entered the debate on biomaterials, beyond the focus on efficiency.

2.4 Bioenergy

With increasing global population and per capita income, the global demand for energy is projected to increase by 37 percent to 2040 (IEA 2014, p. 1). SDG 7 calls for ensuring access to affordable, reliable, sustainable, and modern energy for all. In particular target 7.2 states "by 2030, increase substantially the share of renewable energy in the global energy mix". This would mean that the demand for fuel biomass will also rise. In fact, the IEA (2014, p. 3) projects that the share of renewables in total energy generation will increase from 21 percent in 2012 to 33 percent in 2040. Biofuel use could triple from 2012 to 2040, of total road transport fuel demand by 2040 (ibid).

Besides the aim to improve access to modern energy services, many states have committed themselves, for instance under the Kyoto Protocol and the UN Sustainable Energy for All Initiative, to support renewable energies to fight climate change. Renewable energies, including energy derived from biomass, can contribute to lowering CO_2 emissions, but such energy sources must be produced sustainably to achieve this aim (IPCC 2011, pp. 18–19). Several industrialized countries implemented policies to increase the share of renewables within their national energy mix. For example, the European Union (EU), in its Renewable Energy Directive (EU Directive 2009/28/EC), aims for 20 percent of energy to come from renewable sources by 2020, comprising solar thermal, solar photovoltaics, hydro (tide, wave, and ocean), wind, geothermal, and biomass (European Commission 2015). Regarding biomass, the Directive has a subtarget of reaching a 10 percent share of biofuels in transport fuels (European Commission 2015). At the national level, feed-in tariffs, subsidies, and tax breaks are common to support such frameworks. The United States also offers subsidies and credits in order to increase the share of renewable sources, including biomass, in the national energy mix, e.g. via the Re-

[1] ***Primary forests*** *refer to untouched, pristine forests relatively unaffected by human activities. Primary forests are the most biologically diverse of all forest types.* ***Secondary forests*** *are forests that have recovered from disturbance by human activities or natural events. Examples include degraded forests recovering from selective logging, slash-and-burn agriculture, or storm damage.*

newable Electricity Production Tax Credit or several incentives at the state level. The International Renewable Energy Agency (IRENA), in its global bioenergy supply and demand projections, suggests that global biomass demand for energy purposes could more than double, from 53 Exajoules (EJ) per year in 2010 to 108 EJ per year in 2040.

Regarding energy consumption, most projections postulate a shift away from traditional uses of biomass, such as wood-burning for cooking and heating in residential homes, to transport fuels and electricity generation. For example, it is expected that 28 percent of the total biomass demand for energy in 2040 will be for liquid transport fuels, of which 63 percent will be first-generation biofuels and the remaining 39 percent second-generation biofuels (IRENA 2014, pp. 3–4). Looking at the regional breakdown of the demand for biofuels, the study finds that 30 percent would come from Asia (driven by China, India, and Indonesia), followed by North America (driven by the USA and Mexico), and Latin America (driven by Brazil). The combined demand of the USA, China, India, Brazil, and Indonesia is expected to make up 56 percent of total demand for biomass for energy purposes in 2030 (IRENA 2014, pp. 24–27). Energy projections tend to differ, because they depend on assumptions about energy inputs to generate electricity or heat. Caution is, therefore, required when considering different statements about the value of one energy source over another in the global energy mix (Martinot et al. 2007).

How will the additional energy demand be met?

Bioenergy can be produced from three sources: (i) dedicated crops, (ii) residues from agriculture and forestry, and iii) organic wastes. IRENA (2014, p. 27) assumes that, by 2030, 38–45 percent of total biomass supply for energy purposes will be met by crop residues and other waste products, with the remainder met equally by crop production and forests. As in the case of food and feed production, not all demand for biomass for energy purposes will be met by increasing yields. The UNEP Assessment of Global Land Use summarizes that crop land expansion due to increased use of biofuels could be between 48 and 80 million ha (UNEP 2014, p. 20). Other estimates from integrated assessments models simulating ambitious climate mitigation policies often project large-scale bioenergy production and hence much larger land requirements to cultivate energy crops of 300-600 million ha (Beringer et al. 2011; Popp et al. 2014).

At the same time, demand management is important for the sustainable sourcing of plant-based energy. A high degree of energy efficiency will become more critical, given that the middle class is expected to increase from 1.8 billion people to 3.2 billion by 2020 and 4.9 billion by 2030. The majority of this growth (85 percent) is projected to occur in Asia (Kharas 2010, p. 27). A growing middle class will demand more and secure access to energy. Target 7.2 addresses energy efficiency by stating “By 2030, double the global rate of improvement in energy efficiency”. Reaching an energy efficiency target by 2030 implies cutting waste and increasing research into energy saving practices and technologies. It also means investing more in energy infrastructures. This will be valid for all energy sources, including energy produced from biomass. In view of the unequal global consumption of energy, it will also be important to reduce consumption in those countries with the highest per capita demand in order to reduce the impacts on soils, land competition, and climate, while making space for others to access and increase their energy consumption.

2.5 Ecosystems protection and climate change mitigation

Forests cover 31 percent of the global land area or about 4 billion ha (FAO 2010, p. xiii). Forests constitute a vital basis for numerous resources (e.g. timber, fuel wood, and non-wood forest products) and services (e.g. the conservation of soils, carbon stocks, and water and biological diversity). For example, eight percent of the global forest area (or 330 million ha) is dedicated to the protection of soil and water resources (FAO 2010, p. xxi). Deforestation or the degradation of forests drives the loss of these complex resources and services. Deforestation is also responsible for the release of large quantities of greenhouse gases into the atmosphere, thereby accelerating climate change (UNEP 2014, p. 11). Moreover, forests have a strong cultural dimension (e.g. sacred forests) and provide the basis for indigenous livelihoods and key resources for the rural poor (e.g. energy).

In the SDGs, forests are addressed by Goal 15, which calls for the protection, restoration, and promotion of the sustainable use of terrestrial ecosystems, the sustainable management of forests, counteracting desertification, and the halt and reversal of land degradation and biodiversity losses. In particular, target 15.2 states "by 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and increase afforestation globally" (UN 2014b, p. 21).

Despite their undisputed importance, the total forested area is declining dramatically, although at a lower rate than a decade ago. The FAO Global Forests Resources Assessment (FRA 2010) states that, between 1990 and 2000, deforestation and the loss of forests by natural causes amounted to almost 16 million ha per year. This slightly decreased to 13 million ha per year between 2000 and 2010 (FAO 2010, p. viii). According to FRA (2010), the greatest net forest losses between 2000 and 2010 occurred in South America, followed by Africa and Oceania (FAO 2010, p. xvi). Current greenhouse gas emissions from deforestation and forest degradation amount to 4 billion metric tons of carbon per year (on average). Three quarters of net emissions from forests resulted from deforestation and one quarter from forest degradation (FAO 2015).

In Europe, North America, and some transitional countries, afforestation resulted in gains in forest area (ibid). However, forestry research emphasizes the need to account for the global repercussions of regional or national land use choices as well as land use changes in the context of trade and investment. Strengthening protection in one location might favour foreign imports, thereby resulting in negative implications in other places (Mayer et al. 2005, p. 359).

The remaining forests are a major carbon sink, and afforestation is regarded as a cost-effective strategy for climate change mitigation (Humpenöder et al. 2014). The Intergovernmental Panel on Climate Change (IPCC 2014a, p. 31) states that "the most cost-effective (climate change) mitigation options in forestry are afforestation, sustainable forest management, and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management, and restoration of organic soils".

The recent update of the planetary boundaries analysis (Steffen et al. 2014) concluded that the global area of forested land, expressed as the percentage relative to the potential forest area, i.e. the area of forests assuming no human land use change, should remain at more than 75 percent, with an uncertainty range of 54–75 percent. Steffen et al. report a global value of 62 percent of forests remaining today, which is below the planetary boundary threshold of 75 percent but remains within the zone of uncertainty that characterizes this boundary projection. In any case, further deforestation will exacerbate these effects and poses the risk of exceeding another planetary boundary value.

How will the additional demand for biomass conservation be met?

The Bonn Challenge, launched in 2011, calls for the restoration of 150 million ha of deforested and degraded forests by 2020. The New York Declaration of Forests (2014) expands the Bonn Challenge by an additional 200 million ha by 2030. One recent country-led regional initiative, called 20×20, aims to restore 20 million ha of land in Latin America and the Caribbean by 2020 in support of the Bonn Challenge (WRI 2015). Afforestation and reforestation will help to realize a number of existing international commitments, including CBD Aichi Target 15, the UNFCCC REDD+ goal, and the Rio+20 land degradation neutral goal, which aim to enhance ecosystem resilience, prevent, and reverse land degradation, and enhance forest carbon stocks. At the same time, effective protection of existing forests and restoration of degraded forest areas reduces the area available for expanding crop production and hence requires more biomass to be produced on existing croplands.

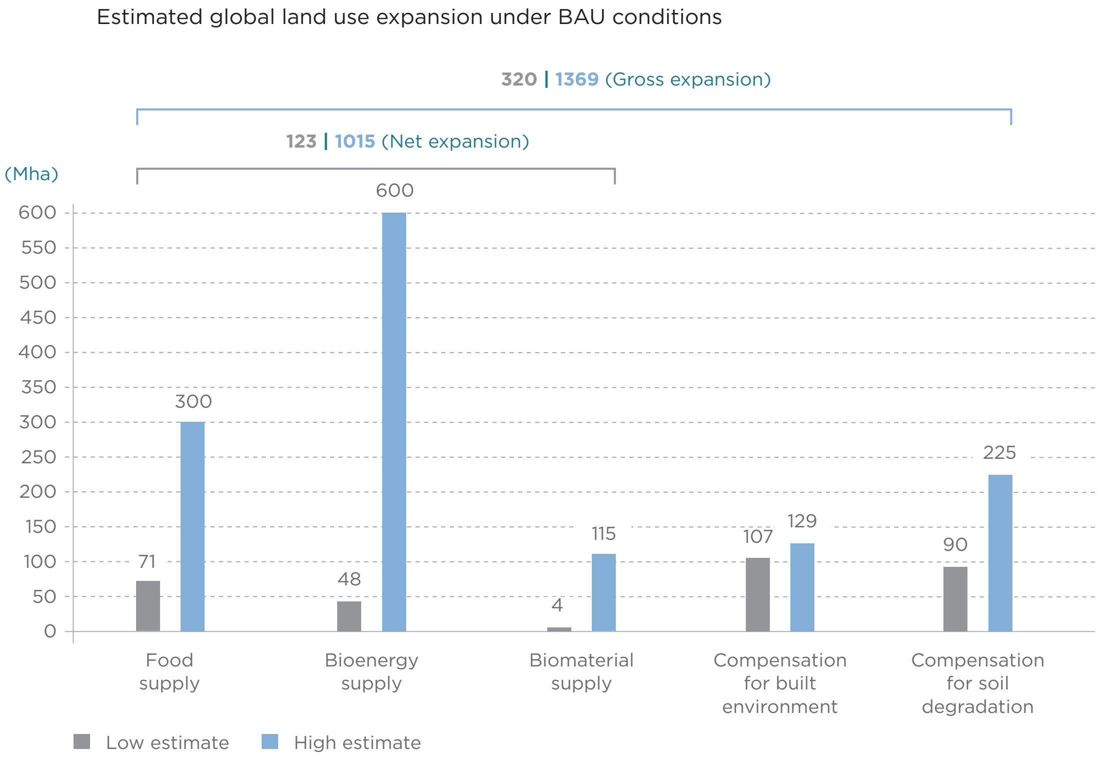
3. Growing demands, finite supply: Availability of land for biomass production over time

Projections of future land demand for biomass production predominantly rely on two different approaches (Paillard et al. 2008, pp. 73–75). Firstly, they quantify the general equilibrium of a particular form of biomass production and consumption (e.g. studies by the International Food Policy Research Institute and the Millennium Ecosystem Assessment). Land use scenarios related to these demand/supply models make assumptions about the future biomass demand and the factors that influence whether this demand can be met by supply, such as yield gains, availability of irrigated land, irrigation efficiency, cropping intensity, soil fertility and/or degradation, land conversion (e.g. urbanization, infrastructure) (ibid). Secondly, an evolutionary approach is applied that projects the future availability of arable land, using estimates about current land use and building on current trends. This approach has been widely applied by the FAO (ibid). All models make assumptions about global and regional agricultural and societal developments to estimate future land use. Moreover, they assume a rising demand for biomass in all four uses (see Section 2).

As with the demand for biomass, projections of the availability of land are highly dependent on the model assumptions, such as political decision-making frameworks, land qualities, land availability, and complex socio-economic transformations, which may not necessarily reflect reality. Nonetheless, it is important to consider the most prominent projections of land take for biomass production, as they have been very influential in political decision making, particularly in their framing of regions and countries as biomass providers and/or land abundant. These projections are also widely used by the private sector to identify potential business opportunities and market creation (e.g. Lonrho 2012).

Several studies assess the quantity and location of land that is available to meet the growing demand for different types of biomass, and draw highly diverse conclusions (see also Section 2). Some publications see potential for expanding agricultural production (Bruinsma 2003) while others argue that there is no surplus land (Chamberlin et al. 2014). In practice, “land availability is not a given, but strongly depends on development in demand, crop prices, agricultural developments, environmental demands” (Kampman et al. 2008, p. 40). It also depends on social contexts, namely who owns or uses the land, and/or whether adequate institutions are in place to support the production of biomass (see Figure 1 for an overview of predicted land demand).

The FAO model – the most widely cited future projection – highlights these problems associated with modelling land availability in greater detail. The model focuses on available land for agricultural production. It estimates that, at present, 11 percent (more than 1.5 billion ha) of the global land surface (13.4 billion ha) is used for crop production. This area represents slightly more than one-third (36 percent) of the land projected to be somewhat suitable for crop production according to FAO projections (Bruinsma 2009, p. 9). It is estimated that there is some 2.7 billion ha of land with crop production potential, which suggests there is scope for further expansion of agricultural land (ibid). As mentioned in Section 2, the FAO projects a net expansion of some 70 million ha by 2050 for food and feed production, comprising an additional 120 million ha in developing countries and an expected decrease of 50 million ha in developed countries (Bruinsma 2009, p. 14). The FAO methodology defines ‘suitable land’ as follows: “it is enough for a piece of land to support a single crop at a minimum yield level for it to be deemed suitable” (Bruinsma 2003, Section 4.3).



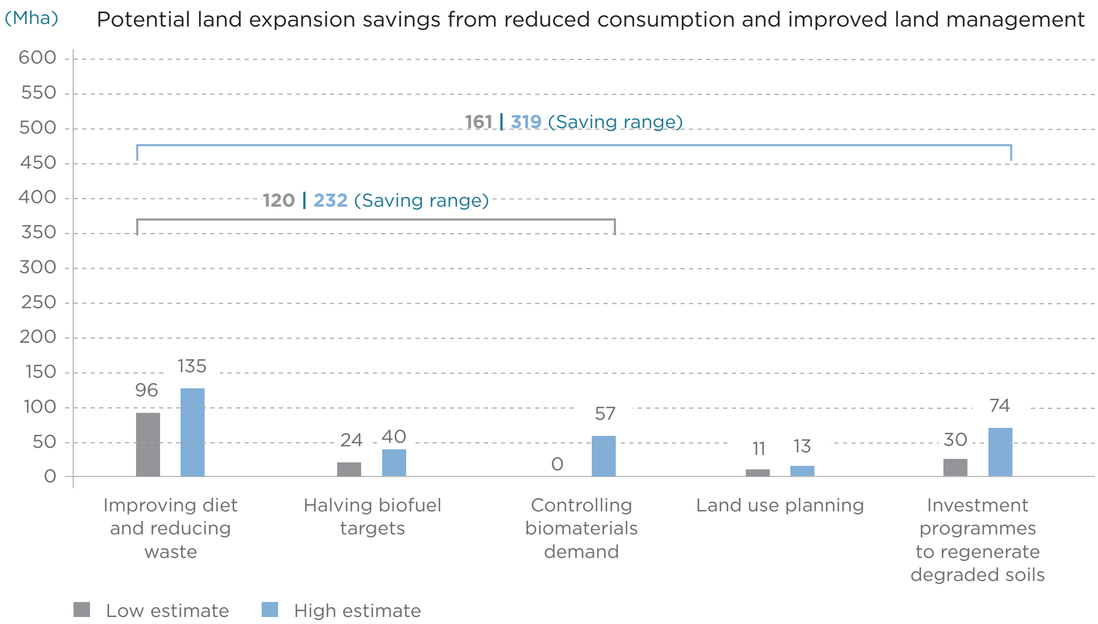


Figure 1: Expansion of global cropland from 2005 to 2050 under business-as-usual (BAU) conditions and possible savings from reduced consumption and improved land management in million hectares (Mha).

Source: UNEP (2014), Popp et al. (2014)

However, as Bruinsma (2009, p. 2) acknowledges, projections of land expansion have to be heavily qualified: "Much of the suitable land not yet in use is concentrated in a few countries in Latin America and Sub-Saharan Africa, i.e. not necessarily where it is most needed, and much of the potential land is suitable for growing only a few crops not necessarily the crops for which there is the highest demand. Also much of the land not yet in use suffers from constraints (chemical, physical, endemic diseases, lack of infrastructure, etc.), which cannot easily be overcome (or it is economically not viable to do so). Part of the land is under forests, protected or under urban settlements, and so on".

Therefore, the FAO land estimates do not consider the existing uses of the candidate arable land – such as forest cover, human settlements, or economic infrastructure – that usually occupy so-called "uncultivated arable land". They also do not consider who uses the land or how that land is governed – both significant considerations for the actual availability of land. Chamberlin et al. (2014, p. 62), in their study on land availability in Africa, assert that the notion of abundant land reserves in Africa is not in accord with the reality on the ground.

This means that land identified as suitable for cultivation might *de facto* only be suitable for a single crop, which makes it difficult to understand how much land is actually available for food and/or other forms of biomass production. It might also be owned or used by someone not willing or able to change its use or to produce for world markets. In addition, so-called abundant land reserves, as estimated by the FAO, in regions of Latin America and Sub-Saharan Africa are concentrated in only 13 countries, with the majority being located in only seven countries, namely in (in order of estimated availability) Brazil, the Democratic Republic of Congo, Angola, Sudan, Argentina, Colombia, and Bolivia (see Bruinsma 2009, p. 11).

Overall, the abstraction from the political economies in these countries and other ecological, and/or socio-economic dynamics that determine net land expansion and/or land use changes makes the projections problematic, if not unrealistic. Making this land available for agricultural production could mean resettling or dispossessing people and furthering deforestation, with uncertain consequences for social development and micro-climate, respectively (Colchester and Chao 2011; Chao 2015; WB 2011; ILC 2012). This will be further discussed in Section 4. In addition, as pointed out in Section 2, uncultivated arable land that is assumed to be available for the expansion of agricultural production may lack appropriate infrastructure and institutions, and suffer from ecological fragility or poor soil quality (Binswanger-Mkhize 2009).

Treated uncritically, these projections could promote the unsustainable production and consumption of biomass. For instance, the projections disregard the competition for land for non-food and non-feed biomass; land governance issues and actual uses of land, and they may fail to account for other ecological and social dimensions of agricultural land expansion. Broader trends of human development, such as demographics, urban sprawl, or urbanization are also unaccounted for in these models. In addition, the regional and global repercussions of national land use changes remain unaddressed, such as deforestation-induced changes in weather patterns (Millan 2008).

While we only discuss the limitations of the FAO estimates of land availability, other models' assumptions and projections of arable land availability face similar limitations. For example, the Agrimonde projections (Paillard et al. 2014, p. 88) assume that the irrigated land area can be expanded by constructing dams, thereby increasing total availability of arable irrigated land. If not governed and managed sustainably, the potentially harmful character of such large-scale projects is well-known. In fact, the voluntary private regime of global governance, the Equator Principles, applied by private commercial banks, emerged in response to the continued civil protests over the social and environmental impacts of such large-scale infrastructure projects (Goetz 2013; Ganson and Wennmann 2012, pp. 6–7).

In summary, this section shows that global land availability is restricted. The SDGs are associated with massive land requirements to serve the different types and functions of land-based biomass. While current projections lack accuracy, it is widely agreed that there is not sufficient land available to meet these competing demands.

4. Review of existing problems with large-scale biomass production

This section reviews current socio-economic (4.1) and environmental (4.2) problems associated with large-scale biomass production, which might be exacerbated by the above-mentioned mismatch between the availability and demand for land.

We focus on the production of biomass for bioenergy and biomaterials, which increasingly compete with food production and the provision of ecosystem services. A number of potential trade-offs are identified, and illustrated with case studies. Clearly, other types of biomass production and consumption also entail social, environmental, and economic problems. For instance, industrial-scale livestock production is associated with problems such as deforestation, displacement of smallholders, food insecurity, biodiversity loss, and greenhouse gas emissions (Steinfeld et al. 2006; Weis 2013a).

4.1 Socio-economic problems

Socio-economic problems associated with the production and consumption of bioenergy and biomaterials include issues of labour rights, land relations, gender equality, capacity building, loss of traditional cultural practices, and conflicts between competing land use types.

A broad overview is given by the Intergovernmental Panel on Climate Change (IPCC) assessment report (Table 3, below). The report argues that biomass production and consumption can have negative and/or beneficial impacts, depending on the contextual circumstances in which they occur. It further indicates that effects take place at different scales, spanning the local to national to international realms. While the IPCC's assessment is a good starting point for the discussion, it does not sufficiently address the emerging global dimension of biomass production and related land governance (Sikor et al. 2013). Current trends in biomass production are influenced by regional or international policies such as the EU Biofuel Directive; by private governance schemes like the Responsible Agricultural Investment principles adopted by the World Bank; or the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries, and Forests in the Context of National Food Security, by the FAO. Such policies are relevant for determining *what* is being produced, *how* production takes place, *where* and by *whom*. The same holds for national policies like Germany's Renewable Energy Sources Act (EEG).

Effects	Scale
Can improve or weaken land tenure and use rights for local stakeholders	Local to national to international
Cross-sectorial coordination or conflicts between forestry, agriculture, energy, and/or mining	Local to national
Impacts on labour rights along the value chain	Local to national
Competition with food security, including food availability (through reduced food production at the local level), food access (due to price volatility), usage (as food crops can be diverted towards biofuel production), and consequently food stability.	Local to global
Integrated systems can improve food production at the local level creating a positive impact towards food security.	Local
Exacerbating or alleviating existing conflicts or social tensions	Local to national
Impacts on traditional practices: using local knowledge in production and treatment of bioenergy crops, or discouraging local knowledge and practices	Local
Displacement of small-scale farmers. Bioenergy alternatives can also empower local farmers by creating local income opportunities	Local
Promote capacity building and new skills	Local
Gender impacts	Local to national
Increase in economic activity, income generation, and income diversification	Local
Mono-cropping and contract farming imply higher degree of economic dependence	Local
Increase or decrease market opportunities	Local to national
Trade-offs between different land uses, reducing land availability for local stakeholders	Local
Contribute to changes in prices of feedstock	Local to global
May contribute to energy independence, especially at the local level (reduce dependency on fossil fuels)	Local to national
May promote concentration of income and/or increase poverty if sustainability criteria and strong governance are not in place	Local to regional
Uncertainty about mid- and long-term revenues	Local to national
Reduced domestic food security and increasing dependence on food imports	National
Social welfare costs from unsustainable biomass production	National to global
Employment creation vis-à-vis loss of employment in other land use sectors	Local to regional
Increasing infrastructure coverage. However, if access to infrastructure and/or technology is limited to a few social groups, it can increase marginalization.	Local
Bioenergy options for generating local power or to use residues may increase labour demand, creating new job opportunities	Local
Technology might reduce labour demand	Local

Table 2: Social and economic effects of the production of bioenergy and biomaterials

Source: Table adapted from IPCC (2014b). IPCC Fifth Assessment Report Chapter 11 on Agriculture, Forestry and Other Land Use (AFOLU) (2014 (11): 100 ff.)

All of the socio-economic effects listed in Table 3 require attention. Here, we focus primarily on three social and economic aspects: (1) food security, (2) struggles over access to land and land governance as some of the most serious and immediate threats to sustainable human development, and (3) micro- and macroeconomic risks and opportunities.

Food security

Food security is undoubtedly the most contested implication of biomass production for fuel and material purposes. With 805 million people estimated to be chronically hungry (FAO 2014b, p. 1), food security must remain at the heart of the Sustainable Development Goals and the Post-2015 Development Agenda. Reducing the land area available for food production and promoting its use for the production of energy and material is linked to lower per capita food availability (Alves Finco and Doppler 2010, p. 194; Haberl et al. 2013, p. 35 ff.).

In combination with other contributory factors, these trends led to a dramatic rise in world food prices in 2008. It is widely agreed that the 2008 crisis was also caused by the diversion of food crops to biofuel production; high prices of crude oil; the lack of storage systems in many countries to buffer rising food prices; poor harvests in some major production regions as a result of extreme weather events; and the global crisis in the financial sector, that contributed to a diversion of capital into natural resources and agricultural commodities. Moreover, it is debated whether food commodity speculation influenced food prices to an extent that jeopardized food security (cf. von Braun 2008, p. 2; de Schutter 2010, p. 1).

High food prices, particularly for staple crops like rice, maize, and wheat, are a general concern of people everywhere. The poor are hardest hit, as they spend a larger proportion of household income on food (von Braun 2008, p. 4; Koizumi 2013, p. 107). The 2008 world food crisis illustrates how a surge in food prices can contribute to social unrest and political instability in developing countries (FAO 2014c) and highlighted concerns over negative terms of trade in a number of major food-importing nations (UNCTAD 2008, pp. 28–29).

The world food price crisis also shows that in a global market for primary commodities, the effects of biomass production and consumption decisions go far beyond the locality where the biomass is produced. Food security might, for instance, be put at risk if major food-exporting countries use their production surpluses for domestic biofuel production rather than delivering it to world markets (Haberl et al. 2013, p. 40). At the same time local and national biomass production and consumption decisions can only be understood in wider political and economic contexts. Therefore, biomass production is a global challenge in which land use decisions and land-intensive policies of one political or legal jurisdiction are responded to in other adjacent and even remote jurisdictions.

In view of the implications of the decrease in land area available for food production that results from expanding the production and consumption of other types of biomass, it is important to revisit the possibilities for mitigating this trend. Examples include productivity increases, the use of so-called marginal land, mixed production systems, demand and waste management (see below), alternative land management approaches, and providing appropriate incentives and institutional support for sustainable food production (IAASTD 2008). However, it is important to note that neither of these options guarantees any positive effects regarding land competition and its associated negative implications. Instead, as mentioned above, the socio-economic and political conditions under which these measures are enacted determine their relative success or failure. We will briefly elaborate on this in the following paragraphs.

The use of so-called marginal or degraded land for energy and material purposes has been championed as a win–win solution by some authors in the biomass debate (for a review, see Immerzeel et al. 2014). According to these studies, bioenergy and material production on degraded lands does not interfere with food production, while entailing a range of positive environmental effects including soil protection, water retention, biodiversity habitat, and carbon sequestration (Van Dam et al. 2009, p. 1705). While these studies indeed appear promising, in practice, however, any type of biomass is rarely produced on marginal or degraded land because it is seldom profitable (Swinton et al. 2011; Rajagopal 2007). Furthermore, even if production on marginal or degraded land was profitable, the second crucial condition, namely 'unused', will seldom apply (Baka 2014; Cotula 2012, p. 655; Dufey et al. 2007, p. 13). In practice, there is hardly any land that is literally empty and unused (Berndes et al. 2003; Rossi and Lambrou 2008). The Rights and Resources Initiative reports that more than 93 percent of land used for mining, logging, agriculture, and oil and gas development was inhabited and used prior to those activities (Alforte et al. 2014, p. 1). Therefore, competing demands for food, feed, and the production and consumption of biomaterials and bioenergy can result in a range of additional negative effects, such as unsustainable land use change and the expulsion of land users (German et al. 2013; Cotula 2012; Mwakaje 2012; Scheidel and Sorman 2012).

Concerning the option of mixed production systems, this only represents a feasible strategy to balance land competition by way of integrating fuel and material production into crop rotation. While several cases exist where fibre and fuel production have been successfully integrated into small- and medium-scale agriculture with crop rotation or intercropping systems (Langeveld et al. 2013; Egeskog et al. 2011), the great majority of biomass for biomaterial and energy purposes is produced under large-scale monoculture conditions (Colchester and Chao 2011; Oliveira and Schneider 2014).

As discussed in Section 2, management of demand and wastage represent additional important strategies to reduce overall pressures on land and underpinning ecosystems resulting from competing forms of biomass production and consumption (Linz and Lobos Alva 2015). Take the example of inefficient supply chains: The FAO (2011b, p. v) estimates that 1.3 billion tonnes of food are wasted every year, either through post-harvest losses, including storage, pest management, and transport; or food waste at the household level. Per capita food losses per year are estimated to be 280–300 kg in Europe and North America and 120–170 kg in Sub-Saharan Africa and South Asia. Per capita food wastage at the consumer level is a greater problem in developed countries (95–115 kg/year) than in developing countries (6–11 kg/year) (FAO 2011b, ibid). According to the CTA (2012, p. 1), approximately 5–30 percent of food crops harvested are lost every year. Food spoilage and waste account for annual losses of $310 billion USD in developing countries, where nearly 65 percent of food is lost at the production, processing, and post-harvest stages (CTA 2012, p. 1). Depending on the crop, between 15 and 35 percent of food may be lost before it even leaves the field (ibid.). Similar problems occur at the retail and consumption level, where food crops are lost due to periodical oversupply and insufficient consumption planning. The United States Department for Agriculture accordingly estimates an annual loss of around 31 percent of food worth 163 billion USD in the United States alone (Buzby and Hyman 2012, p. 561). Significant reductions in on-farm and off-farm food wastage could increase food availability. Successful management of food wastage could also relieve pressures on land and open up additional land for other uses, including the production of biomass for fuel and material purposes. However, from the broader perspective of competing demands for biomass, management of food wastage does not address other previously mentioned drivers of land competition that impact on food security, such as changing dietary habits driving the demand for feed production (Weis 2013a); or changes in land use toward biomaterial and bioenergy production.

In addition to these largely output-oriented concerns, it is important to consider how pro-poor incentives and institutions can ensure the inclusive production of, and provide access to, land and food. Such issues are important, as food security goes beyond questions of "inadequacy of food output and supply" (Sen 1997, p. 8), which means that increasing production does not necessarily result in greater resource security.

Land governance

The production of biomass for fuel and material purposes can entail a loss of access to land among marginalized social groups. In many such cases, increasing land demand – and, associated competition between different types of land uses – can result in the expulsion of marginalized actors vis-à-vis the concentration of land among powerful actors (German et al. 2013).

Dramatic shifts in access are less likely whenever a farmer has secure land rights and sufficient (access to) financial resources. Unequal land distribution is particularly worrisome in countries and regions with weak law enforcement systems, limited options for civil participation, and high political and economic inequality (Cotula et al. 2008, p. 14). Insecure land rights and radical changes in land use are particularly common in less- and least developed countries (Chao 2015; ILC 2012; WB 2011).

Loss of access to land is partly driven by governments that expropriate, redistribute, or withdraw land from users and re-allocate it to large-scale producers based on the perception that industrialized agriculture and crop production for bioenergy is economically more viable than other types of land use and likely to provide state revenues through exports (Cotula et al. 2008, p. 24; Chao 2015; Wolford et al. 2013). The production of biomass for material and energy purposes is particularly likely to attract actors who are able to engage in large-scale farming and to pursue economies of scale. A related reason for the loss of ownership and access to land is market-based land governance approaches that imply the highest bidder usually gains access to land and decides subsequent land uses (Cotula and Toulmin 2007; Chao 2015; Lahiff et al. 2007). Consequently, market forces may foster changes that deny marginalized groups access to land. For example, women, who have fewer and/or weaker land rights and access to other productive resources than men, lose control of high-value land, which tends to shift to men when production becomes profitable (Rossi and Lambrou 2008, p. 7). Loss of access to land also occurs as a result of the changing preferences and incentive structures driving biomass production. For example, "increases in food prices linked to the spread of biofuels may change the economic terms of trade between agriculture and other sectors of the economy, and between rural and urban areas" (see Cotula et al. 2008, p. 24). This often results in displacement of existing forms of biomass production, particularly in the case of food production, which "may retreat to areas that are less fertile but still fit for farming, pushing current users onto other lands" (Cotula et al. 2008, p. 24).

The concentration of and changes in access to land are often accompanied by discourses in which forested, pastoral, and other types of land are erroneously labelled as fallow or waste lands (Baka 2014; Cotula et al. 2008). Furthermore, activities practiced by local communities are labelled as economically inefficient, environmentally harmful, socially backward, or of minor significance to overall socio-economic development. What follows from this relabelling of land, its uses, and its users, is that certain land use types are supported over others, and that there is a shift in terms of which actors are granted access to the land (Duvenage et al. 2013; Ewing and Msangi 2009; Hall et al. 2009; German et al. 2013). Box 2, below, cites a case study by Cotula et al. (2008) on large-scale bioethanol production in Mozambique. The case perfectly illustrates how large-scale biofuel production, in particular, can result in social conflict over land access.

Box 2:
Case study: Large-scale biofuel production and access to land in Mozambique. Cited from Cotula et al. (2008, pp. 35–36)

The Mozambican government has pursued policies to attract large-scale investment in biofuels. Recent signing of a contract between the government and the London-based Central African Mining and Exploration Company (CAMEC) for a large bioethanol project, called Procana, illustrates this. Procana involves the allocation of 30,000 ha of land in Massingir district, in the Southern province of Gaza, for a sugar cane plantation and a factory to produce 120 million litres of ethanol a year. The land was allocated on a provisional basis for two years, within which the investor must initiate project implementation. Concerns have already been raised with regards to the effects of Procana on access to both land and water for local groups. The plantation will abstract water from a dam, fed by a tributary of the Limpopo River, which also supports irrigated smallholder agriculture. Farmers downstream have expressed concerns that the Procana project will absorb the bulk of available water, leaving little for local farmers. Government officials have disputed these calculations, arguing that the dam has enough capacity to meet the water demands of both Procana and local irrigation schemes. As for land, the Procana project attracted criticism from representatives of international donors and local communities, on the basis that the land allocated to the project had already been promised to four local communities displaced from their land by the creation of the Limpopo Transfrontier Park, a joint conservation initiative among Mozambique, South Africa, and Zimbabwe. The displaced communities, numbering more than 1,000 families, were promised housing, electricity, running water, and grazing at the new site after a protracted three-year battle with the government, in which they were supported by a local human rights organization ORAM (Organizacao Rural de Ajuda Mutua, Rural Organization for Mutual Help). However, according to press reports, the planned relocation has been postponed several times and has not yet occurred, because the same tract of land has been granted to the Procana bioethanol project. Community leaders have been told that there is sufficient land at the site for both the new villages and the biofuel plantations, but they are yet to see any construction work begin.

Micro- and macro-economic risks and opportunities

One important micro- and macro-economic challenge of biomass production for material and energy purposes relates to the volatility of primary commodity prices. In terms of the micro-economic dimension, a number of empirical cases indicate, for instance, that rising agricultural commodity prices can represent an opportunity for creating additional income and rural growth (Amigun et al. 2011, p. 1362; van der Hilst and Faaij 2012, p. 410; Arndt et al. 2012, p. 1930; Danielsen et al. 2009; Hanff et al. 2011; Huang et al. 2012; Mwakaje 2012). Other cases show, however, that producers also face considerable economic risks. For example, the industrial character of the sectors along the value chain, as well as the social and political conditions – both in countries where biomass is produced and consumed, often implies that biomass is mainly produced as large-scale monocultures (Oliveira and Schneider 2008; Chao 2015). This results in a tendency to abandon crop rotation and other types of on-farm diversification, which have an important function as a traditional safeguard against fluctuating market prices and crop failures (German et al. 2011). This problem is particularly eminent if the producer chooses to plant perennials such as palm oil trees (ibid.). In contrast to most annual plants, perennials like oil palm involve longer-term land use decisions. Perennials usually take much longer to mature, often requiring repeated harvesting to amortize investments.

Similar challenges to those discussed with respect to monocultures may occur with respect to capital investment in infrastructure and machinery. For instance, biogas fermenters or special-purpose harvesters require large capital investments and are therefore often only economical as long as the price for electricity remains above a certain critical level.

Another potentially problematic effect from a particular biomass boom is found at the macro-economic scale. For instance, a country that reduces its food production and instead focuses on biomass for fuel and material purposes may, ceteris paribus, become more dependent on food imports. In times of crisis, this can lead to highly negative trade balances; and, if storage is lacking, very high food prices in the importing country (UNCTAD 2008). Moreover, as investments in plantation development are often granted limited or zero taxation, and are not attached to local input requirements, state revenue is often less promising than could be the case for establishing public infrastructure and institutions and/or diversifying that country's economy into the secondary sectors. At the same time, history shows that state revenue of countries that rely strongly on large-scale biomass production for export can be volatile, depending on fluctuations in world market prices (UNCTAD 2008, pp. 28–29). A recent case study by GBEP on Indonesia, for instance, assumes that switching away from export orientation to a larger share of domestic consumption of palm oil could entail major welfare benefits (GBEP 2014).

4.2 Environmental problems

Environmental impacts from the production and consumption of biomass can vary greatly in intensity and extent in different locations and for different crops. Many environmental degradation processes that can be unleashed by the unsustainable production of biomass are irreversible. In addition, many of the environmental consequences described in the following sections can also occur alongside almost any type of land use and land cover change (Foley et al. 2010). Table 4 represents a slightly adapted version of the IPCC Fifth Assessment Report's synopsis on the potential environmental effects of producing biomass for non-food and non-feed purposes.

First and foremost, the rising and competing demands for land result in different forms of land use change (Bringezu et al. 2012, p. 224). Land use change for the production of bioenergy and biomaterials involves forest areas, wetland areas, and agricultural areas (Alves Finco and Doppler 2010; Koh and Wilcove 2008). In these cases, land use change is often connected to clearing, drainage, fertilization, and intensive tillage. It relates to bringing natural forests into productive use. As a case in point, globally, the use of remaining forest cover has increasingly been switched to a productive model. Between 2000 and 2005, the area of productive forests increased by 2.5 million ha, primarily for wood and fibre production, which accounted for 87 percent of the total forest plantation area (Kampman et al. 2008, p. 16). In sum, all of these land use changes are tantamount to a significant degradation of ecosystems, which in turn can reduce land productivity and thus biomass yields (Gasparatos et al. 2011, p. 114; see also Box 3 for a case study).

Since soils under production are integral parts of ecosystems, negative effects from land use change and unsustainable land management practices therefore tend to affect other parts of the ecosystem such as water, air, and living species (Gasparatos et al. 2011, p. 114). For example, clearing the land of its plant cover often initiates severe soil erosion as a consequence of sudden exposure to wind, water, and radiation. As such, land clearance contributes to global soil erosion that is conservatively estimated at 24 billion tonnes of fertile soil annually (Quinton et al. 2010; Bai et al. 2008). Furthermore, soil exposure catalyses biochemical processes such as nitrification, which in the long term reduce soil fertility. Once the preparation and planting of the biomass crop has started, agricultural practices can become a source of soil erosion. Unsustainable agricultural practices such as intensive tilling can cause further leakage and loss of nitrates, phosphorus, and other mineral soil components, risking soil and water contamination (Martinelli and Filoso 2008, p. 888). Similarly, there is imminent risk of soil and water contamination through the misuse of harmful agrochemicals. Soil erosion, soil fertility loss, and contamination of soils and water bodies can become so severe that the production of biomass and other land-based products is put at risk (Martinelli

Table 3: Environmental effects of the large-scale production and consumption of biomass for non-food, non-feed purposes

Source: Table adapted from IPCC (2014b). IPCC Fifth Assessment Report Chapter 11 on Agriculture, Forestry and Other Land Use (AFOLU) (2014 (11): 100 ff.)

Effects	Scale
Biofuel plantations can promote deforestation and/or forest degradation	Local to global
When used on degraded lands, perennial crops offer large-scale potential to improve soil carbon and structure, abate erosion and salinity problems. However, degraded land only seldom allows economically feasible production of biomass crops	Local to global
Large-scale bioenergy crops can have negative impacts on soil quality, water pollution, and biodiversity	Local to transboundary
Biomass production can displace other land uses and ecosystem services	Local to global
Intensification can lead to higher environmental impact	Local to transboundary
Multi-cropping systems can provide biomass while maintaining ecological diversity and reducing land-use competition. However, such systems are seldom established on large scales	Local to national

and Filoso 2008, p. 887). Land clearing, soil erosion, and the breakdown of organic matter can also severely decrease the capacity for soil water retention in catchment areas (Martinelli and Filoso 2008, p. 888). Limiting the soil's capacity to store water can be, simultaneously, the cause of drought and of flooding during periods of high precipitation.

Another dimension of land use change is its contribution to climate change through greenhouse gas emissions and altered micro-climatic conditions through land cover change. Carbon and methane emissions occur in the course of the biochemical breakdown of organic matter in exposed soils as well as from the burning and biochemical breakdown of trees and other woody plants (Searchinger et al. 2008, 2009; Smith and Searchinger 2012). On the Indonesian island of Borneo alone, the clearing of forests for palm oil plantations between 2000 and 2010 resulted in CO2 emissions of 0.038 to 0.045 GtC y-2 (Carlson and Curran 2013, p. 347). If not accounted for, the emissions problem associated to land use change and unsustainable agricultural practices will jeopardize the very aim of using biomass as an emissions-neutral alternative to fossil fuels (Danielsen et al. 2009; Fargione et al. 2008). In addition to immediate emissions, greenhouse gas emissions also occur from the use of agricultural machinery and, even more so, during the production and application of mineral nitrogen-based fertilizers (ibid.). Land use change, for instance forest clearance for agricultural crops, may further result in changes in micro-climate. Changes in micro-climate, such as increased temperature variability, exposure to radiation and wind, or changing precipitation patterns can have negative effects on agricultural and other biomass productivity. Over and above, a changing micro-climate affects human and animal health (Cançado et al. 2006, p. 725) and livelihoods (e.g. floods).

Land use change, i.e. changes in land cover and land use intensity, can further cause loss of biodiversity due to habitat destruction (Koh and Wilcove 2008), and are associates with excessive use of agrochemicals and machinery and over-extraction of crop and forest harvest residues.

Box 3:
Case study: Oil palm expansion and rainforest destruction in Indonesia

Indonesia provides a particularly telling example of the often dramatic environmental consequences of deforestation associated with oil palm expansion. The expansion of oil palm plantations for food, cosmetics, and fuel products is one of the most significant causes of rainforest destruction in Southeast Asia. In Indonesia alone, deforestation of rain forest for palm oil plantations is estimated at more than 4 million ha (Colchester et al. 2006; CIFOR 2009). In Indonesia, more than 56 percent of oil palm expansion has occurred by converting rainforest to palm plantations (Koh and Wilcove 2008, p. 60). Clearing tropical forests resulted in a carbon debt that will last for decades to centuries, thus contradicting one of the main reasons for pursuing biofuels in the first place. Plantation expansion in Kalimantan alone is projected to contribute 18–22 percent of Indonesia's 2020 CO_2-equivalent emissions (Carlson et al. 2012, p. 283). Apart from carbon storage, conversion compromises other vital ecosystem functions provided by rainforests that cannot be substituted by plantations, such as biodiversity, habitat complexity, seed dispersal, and pollination services (Koh and Wilcove 2008). In 2009 the Indonesian Government disclosed plans for another dramatic increase of the area planted with oil palms, of up to 20 million ha during the next 10–20 years, mostly coming from cleared forests. In May 2011, the President of Indonesia signed a two-year moratorium on new permits to clear primary forests and peat lands, potentially slowing oil palm expansion; however, secondary forests and existing contracts are exempt.

5. Beyond silo-thinking toward a nexus perspective: A discussion

This paper shows that different types of biomass in the form of food, feed, bioenergy, and biomaterials play a crucial – yet to date a largely neglected – role in the Sustainable Development Goals. Without doubt, to achieve SDG 2 will require a major increase in food production in the near future, notwithstanding the fact that hunger and malnutrition are to a considerable degree problems of distribution and access, which also have to be accounted for. SDGs 7 and 13 imply a rising and competing demand for biomass in the context of its double function, i.e. as a renewable energy source and as a carbon sink in the form of organic matter in soils and/or as standing plant biomass in forests and other ecosystems. Along these lines, SDG 8 (sustainable industrialization and innovation) and SDG 12 (sustainable consumption and production) both point to the growing interest in, and use of, plant-based biomaterials as an alternative to traditional fossil fuel-based raw materials. SDG 15 implies that land-based biomass will be ever more crucial in the context of nature conservation.

The discussion in Chapter 2 shows that the SDGs' implicit emphasis on increased production and consumption of biomass will be connected to massive demands for additional land. There is, however, insufficient land available to meet these competing demands. Projections of land availability indicate a considerable mismatch between what is available and what would be required in the near future. One response to this emerging problem will be to reduce land requirements by improving the ways in which we produce and consume biomass. Yet, while land management and demand management efforts are pivotal, it is also certain that they will not suffice to fully offset the widening gap between land requirements and land availability; nor do they address the necessity to balance and prioritize competing demands to ensure that basic human resource needs can be met – such as food security. A debate about balancing will be crucial in view of the rising competition for land to produce different forms of biomass, particularly as long as the current emphasis on biomass in the SDGs is not addressed in an integrated way. It is important to consider the consequences of this mismatch between increasing land requirements and limited land availability for biomass. The mismatch also raises questions on what these consequences imply for the wider context of achieving the Sustainable Development Goals.

The implications of the prominence of biomass for achieving the SDGs can be understood as the latest phase in an on-going trend to increase different forms of biomass consumption and production. Accordingly, there are already numerous, well-documented experiences on the effects of large-scale biomass production and consumption. Our review in Chapter 3 shows that these effects can take the form of a multitude of socio-economic and environmental problems. For example, devoting land to large-scale bioenergy production and other non-food uses will at times compete with food production and undermine food security. Moreover, there are many cases in which related land use changes are connected to changes in land access and ownership, resulting in the loss of access for traditional land users, contributing to the concentration of land ownership, and exacerbating gender inequality. At the same time, the decision by countries and producers to settle on a particular type of large-scale biomass production can impose not only economic opportunities but also comes with a range of micro- and macro-economic risks. Lastly, putting additional land into production via land cover change and/or intensifying land use on plots already in production has been connected to a variety of detrimental environmental effects, including deforestation, erosion, greenhouse gas emissions, and loss of biodiversity.

Returning to the case of biomass in the SDGs, our message is therefore straightforward: The findings stress that the multiple types of biomass are a limited resource. If not produced and governed appropriately, the large-scale production and consumption of biomass can aggravate human development challenges such as resource scarcity, biodiversity loss, and climate change, with the potential to undermine social development. Regarding the production of biomass for non-food purposes, it often results in competition for land, and can endanger food security, while the commercial pressure on land and/or the introduction of large-scale monocultures can negatively impact rural development, lock-in economic structures that are unfavourable for a country's medium-term development trajectory, and aggravate land governance challenges. Land use changes can also increase greenhouse gas emissions. Furthermore, the intensified use of land resources may influence water and soil quality and availability, and might negatively affect the global carbon and nitrogen biogeochemical cycles.

Thus, the emphasis on large-scale biomass consumption and production inherent in the SDG targets carries significant risks, and the lack of sufficient land for the competing demands necessitates a debate about how these might be best balanced. If unaddressed, the achievement of one biomass-related target will necessarily inhibit, and at times even contradict, the achievement of others, while the production and consumption of biomass will have unsustainable effects. In other words, the Sustainable Development Goals in their current framing propose a number of goals and targets that cannot be achieved within given ecological boundaries and that might aggravate existing socio-economic and ecological problems associated with large-scale biomass production and consumption. In the context of the limited availability of land, and in the light of existing problems, biomass-related targets will have to be weighed against each other, with the consequence that the achievement of some targets, namely food, will have to be prioritized over others, such as bioenergy and biomaterials. Moreover, it matters how the different biomass types are produced.

While the prioritization of biomass uses and production patterns involves a complex and conflict-laden yet necessary political process, the review of existing problems of large-scale biomass production shows that simply choosing one option over another is also inappropriate. From the nexus perspective that has guided our assessment of large-scale biomass demands in the SDGs, it becomes obvious that different forms of biomass production are not only in competition with each other but, if production is unsustainable, they might undermine the very conditions on which any forms of biomass production and consumption rely. Take, for example, the issue of soil fertility and water retention capacity, both of which are crucial prerequisites for sufficient yields of any type of biomass, including bioenergy and biomaterial crops. Moreover, biodiversity is a crucial source for breeding different varieties of crops, both for non-food and food purposes, yet tends to decline in the case of large-scale biomass production. Therefore, sustainable biomass production and consumption patterns are necessary to alleviate the documented anthropogenic pressures on ecosystems and biodiversity associated with large-scale production.

Moreover, the sustainability of biomass is defined by the conditions under which it is produced, encompassing working and market conditions, governance of access, and ownership of land and productive resources. In many respects, these conditions are also determined by social, political, and economic processes that take place outside the production area. Furthermore, it implies consideration of dynamics in the realms of regional, and international political relations, policy, social circumstances, finance, and trade flows, in order to fully account for the prospects and trade-offs of increased production and consumption of biomass along these parameters (Duvenage et al. 2013). For example, incentives and decisions in the realm of international trade and investment will at times contradict national efforts for sustainable resource planning and governance. International trade obligations may thus counteract domestic attempts to address the consequences of rising food prices, or to introduce environmentally or socially sound practices. Consequently, international trade and investment need to be recognized both as drivers of unsustainable development trajectories and also as a powerful mechanism by which to incentivize sustainable biomass production and consumption. At the same time, as we have highlighted in Chapter 3, land use decisions in one country might have global repercussions, such as when forestry conservation targets in one country are met by increasing wood imports from another country.

What follows from our integrated discussion of the problems and prospects of sustainable biomass production and consumption in the context of the SDGs is the obligation to address the challenges and trade-offs associated with large-scale biomass consumption and production in the future. Otherwise, it is certain that the SDGs imply a major risk of further aggravating the negative effects we are facing in the context of biomass. This, however, would mean that – with respect to biomass – implementing the SDGs would lead to a form of development that represents the very opposite of what the SDGs were initially intended to bring about.

Considering our discussion up to this point, the question arises of how to address the conflicting targets in the SDGs towards governing biomass sustainably. In this regard, *balancing* inherent norm-conflicts is a major aspect that has to be addressed in the context of governance, and regarding the implementation of the SDGs. Balancing norm-conflicts is not possible at the indicator level (alone), as these norm-conflicts are also part of the broader world context of which the SDGs form a part. Instead, balancing requires identifying those goals and targets that compete with each other, sometimes to the extent of counteracting each other, and assessing how to moderate associated risks through various techniques, such as prioritization of some goals over others (e.g. food); scaling down demand where possible; and/or ensuring more equitable distribution, access, and participation in the value chain of biomass production and consumption. Moreover, balancing also implies considering the global effects of national land and resource production and consumption decisions in order to ensure that the balancing of competing demands and forms of production does not externalize the trade-offs.

More concretely, this also means discussing the particular responsibilities of different countries and actors involved in large-scale production toward achieving the SDGs; developing adequate review mechanisms of SDG implementation; and establishing a platform to exchange experiences and practices that have proven sustainable. These aspects will be discussed in greater detail in our concluding Chapter 6, which provides an outlook on the governance implications of the above discussion on the role of biomass in the SDGs.

6. Governance implications for sustainable biomass in the SDGs

The year 2015 will be a milestone for sustainability governance worldwide, when the international community decides upon the final set of global sustainable development goals (SDGs) as part of the Post-2015 development agenda. The SDGs are intended to constitute a comprehensive normative framework that will be universally applicable. As the SDGs will be a much more complex set of goals, covering a much wider area of issues than the former Millennium Development Goals (MDGs), and being universal in reach, it is crucial to start thinking of adequate governance schemes that moderate the trade-offs and interlinkages between the increasing and diverse demands identified for biomass.

Overall, our nexus approach emphasizes the challenge of meeting a diversity of social needs within given ecological boundaries. The paper has shown that governance schemes in the context of SDG implementation must account for this challenge. This implies considering the socio-economic ambitions of the Sustainable Development Goals – in particular their focus on equity, as well as the protection of the natural resource base that is required for biomass production and impacted by it. Against this background, inequalities in terms of power, opportunities, and access to resources need to be considered when deliberating adequate governance schemes; as well as the high degree of worldwide interdependency, where one country's or region's biomass choices can have effects in places beyond that particular jurisdiction.

Moreover, a discussion is required on appropriate mechanisms for different levels of governance. While those questions already arise in the set of goals discussed at UN level to date, further norm-collisions and uncertainties about how to disaggregate global goals within national responsibilities can be expected once implementation by member-states is on the political agenda. In this context, the broader macro-political setting within which the SDGs are placed would need to be systematically assessed to identify mechanisms and normative frameworks in place that might strengthen or challenge the SDGs' universal, multidimensional (social, economic, environmental) features. This also means accounting for those frameworks and mechanisms – such as the Convention on Biological Diversity (CBDR) or the United Nations Declaration on the Rights of Indigenous Peoples – that are in accord with sustainable biomass production, and examining whether it is possible to build on their data, insights, and/or institutions. Moreover, it is important to deliberate on necessary features of sustainable biomass governance, such as trade standards and land governance, and review the status quo of existing governance regimes for international economic governance (e.g. WTO regulations); national legislations; and private governance schemes. Do these support a more sustainable governance of biomass? Would these need adjustments? How can we strengthen the sustainability aspects within and across existing regimes? Would an overarching set of safeguard principles be a useful starting point?

From the *perspective* of *common but differentiated* responsibilities that are part of the universal set of SDGs, the competing biomass demands and related trade-offs also raise questions of what the national application of the universal goals should (ideally) look like, given the highly uneven international geography of development. For instance, to halt the loss of biodiversity, industrialized countries could focus on the efficiency and overall reduction of their total biomass consumption, to leave development space for the benefit of emerging economies and least developed countries.

Furthermore, for the SDGs to be effective, robust mechanisms for monitoring, review, and accountability will need to be developed in order to connect the national, regional, and global levels (Müller et al. 2015). For the latter, the UN High-Level Political Forum on Sustainable Development will play a key role. Review mechanisms should be based on multi-stakeholder dialogue platforms in order to increase stakeholder ownership over the implementation of the SDGs, and to empower marginal and vulnerable groups to raise concerns over the ways in which countries will pursue their sustainable development agendas (ibid). Such an approach will allow stakeholders, especially at the national level, to jointly set priorities for implementation and to respond to changing dynamics over time. Furthermore, these mechanisms should build on experiences gained from similar multi-stakeholder dialogue platforms and fora. In the case of sustainable biomass governance in Germany, an example is offered by the "Initiative Sustainable Supply for Raw Materials for the Industrial Use of Biomass" (INRO).[2] A further example is the process currently carried out to implement the German Sustainability Strategy.

In view of the issues covered in our paper, the following steps could be useful to strengthen the sustainable governance of biomass: It is important to identify and assess existing safeguards and human rights regulations (e.g. responsibility to protect) or frameworks (e.g. right to food) that might apply to the ecological and governance implications of biomass production and consumption, and to establish whether they might be strengthened, and/or informed by indicators. It is also useful to build on and strengthen existing sustainability governance mechanisms and agencies to promote sustainable biomass production and consumption, rather than introduce a new set of institutions. It is further advisable to start an inventory of good policies. Moreover, it is vital to develop effective monitoring, review, and accountability mechanisms in order to continuously assess and discuss SDG topics in general and sustainable biomass in particular. Simultaneously, the great economic and power disparities between and countries worldwide imply a move beyond market-based mechanisms in sustainability governance of biomass. Theory on sustainable transformation suggests that the agency of state and non-state actors is crucial for transformation, and needs alternative state policies as well as changes in the norms of production and consumption. Finally, it is important to raise broad awareness of the sustainability challenges associated with biomass, and to engage with the public and a wide range of stakeholders on the topic of sustainable production and consumption.

[2] *For more information, see the Initiative's website (http://www.inro-biomasse.de/en.htm).*

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