chapter 1

SCOPE Bioenergy & Sustainability

Technical Summary

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SCOPE Bioenergy & Sustainability is a collective effort with contributions from 137 researchers of 82 institutions in 24 countries[1].

The volume is the outcome of an assessment that included a meeting held at UNESCO, Paris, in December 2013. Fifty experts discussed bioenergy sustainability across its whole lifeline and crosscutting aspects including energy security, food security, environmental and climate security, sustainable development and innovation.

This is a technical summary of one of the outcomes of this effort, the Bioenergy & Sustainability Synthesis of Knowledge volume. Additional facts and numbers that substantiate some of the key findings reported here can be found in Chapter 2 (Bioenergy Numbers)[2] or in the SCOPE Bioenergy & Sustainability background chapters (as referred throughout this summary)[3].

Background chapters were commissioned to provide context, raise issues, and report on status and technological developments for bioenergy expansion. Background themes were chosen so that the report would range from land use and feedstocks, to technologies and impacts. They represent a selection of topics authors considered the most relevant to enlighten decision-making based on current scientific knowledge on bioenergy. They created the basis to consider how bioenergy expansion and its impacts performed in the energy security[4], food security[5], environmental and climate security[6], sustainable development and innovation[7] nexus. And most importantly authors highlighted important gaps of knowledge and suggested the science needed to fill them.

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1 (http://bioenfapesp.org/scopebioenergy/index.php/project-overview/roster-of-experts/)

2 (Chapter 2)

3 (also consult Background Chapters 8 to 21, this volume)

4 (Chapter 3)

5 (Chapter 4)

6 (Chapter 5)

7 (Chapter 6)

Scientific evidence was evaluated on the impacts and constraints for bioenergy expansion from data reported in over 2,000 references and major assessments. The report was subjected to an extensive internal and external peer-review process.

When assessing important drivers for bioenergy expansion, such as sustainable development and Innovation and global climate change the group addressed some of the perceived “showstoppers”:

- the need for integrated policy to maximize bioenergy benefits and positive synergies;
- the concern that at the scales needed cannot be attained;
- the high costs and technological complexities of developing sustainable biorefinery systems;
- bioenergy governance;
- bioenerg certification and social aspects;
- financing the bioenergy effort;
- bioenergy trade expansion;
- competition with food production;[8]

Bioenergy science and technology is being developed that improve economics, land use, biomass production, environmental benefits and livelihood

Over the last 5 years plentiful improvements on producing and using bioenergy have been documented and much is already commercially available.

The report offers solution oriented scientific recommendations to maximize bioenergy benefits[9] and highlights practices that can contribute to the modernization of agriculture, the recuperation of degraded land, increasing of soil carbon, the improving of soil quality and ecosystem services as well as its contribution to improving human health.

[8] (Box 1.2 - The food vs. biofuels land competition issue)

[9] (Box 1.1)

Box 1.1. Maximizing bioenergy benefits

Bioenergy benefits can be expanded by[a]:

- promoting high yielding bioenergy crops with positive attributes with respect to water use and soil impacts
- increasing the share of bioenergy derived from wastes and residues
- integrating bioenergy production with crop production systems and in landscape planning
- increasing crop land productivity especially in developing countries, freeing up crop land for bioenergy crops, with a particular focus on pasture intensification for livestock production
- deploying marginal or degraded lands together with breeding of crops that can maintain productivity on marginal land
- using co- and by-products
- removing the correct amount of plant material to avoid reducing soil fertility, cause loss of organic matter or predispose the soil to erosion
- avoiding deforestation by promoting agroecological zoning
- adopting voluntary market-based incentives for appropriate resource management
- considering externalities, giving value to clean water, clean air, and other ecosystem services to encourage their protection
- establishing financial incentives to reduce carbon emissions
- integrating bioenergy production into existing activities (forest products, buffer strips, perennial rotations)
- producing bioenergy in land that makes a small contribution to food production, which includes the huge quantity of global pasture land
- using excess agricultural capacity for energy production to bring additional value and resilience into agricultural economies and the human communities that depend on them

[a] (Chapter 5, Chapter 16, Chapter 6)

1.1 Introduction

Our understanding of the challenges and opportunities associated with bioenergy production has evolved considerably in the last 5 years. The contribution of bioenergy expansion to increased food prices was considerably smaller than initial predictions [10]. The potential negative environmental effects associated with indirect land use change (iLUC) have turned out to be subjective and uncertain[11]. Several high yield feedstock options are available. Sugarcane, maize, miscanthus and other perennial grasses, eucalyptus, willow, and other woody species, oil palm, agricultural residues and wastes, to name a few[12], are all options that together contribute to provide biomass supply in many regions of the world. New energy crops are being developed, with greatly increased yields and tailored for advanced biofuels that open the path for expansion with different technological options on many fronts[13]. Data on land availability[14], required infrastructure and costs for a reliable supply of biomass in many countries and scenarios are available[15]. Ethanol, biodiesel, renewable diesel, and wood pellets trade created an international market, spurred by policy efforts. At the same time, a number of voluntary schemes for certification of biomass, biofuels, and bioenergy production according to criteria and principles set by the specific sustainability schemes emerged, with the aim to increase the sustainable production and logistics of supply of biomass to conversion processes making fuels, energy, and products based on economic, environmental, and social considerations. Several voluntary sustainability schemes already existed for forest products and agriculture but without climate or energy specific criteria. Multiple standards and more stringent sustainability criteria are developing[16].

One of the main motivations for increasing the use of biomass to generate energy is that under the correct conditions greenhouse gas (GHG) emissions are reduced[17]. Decreasing emissions is critical and urgent to avoid serious interference with the climate system as reported by the IPCC 5th Assessment Report[18]. At the same time, more than 2 billion people lack access to modern energy services, which are a fundamental prerequisite for poverty reduction and human development. To transition into a sustainable energy matrix the United Nations has launched the SE4ALL initiative to achieve three global interlinked energy policy objectives by 2030: 1) ensuring universal access to modern energy services; 2) doubling the global rate of improvement in energy efficiency; and 3) doubling the share of renewable energy (RE) in the global energy mix by 2030[19]. IRENA summarizes the bioenergy situation: "Biomass currently

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[10] (Chapter 8)

[11] (Chapter 9) (Chapter 17) (Bioenergy Numbers 2.3.6, Bioenergy Numbers 2.2.2, Bioenergy Numbers 2.2.4, Bioenergy Numbers 2.3.1)

[12] (Chapter 9, Chapter 10, Chapter 12)

[13] (Chapter 10)

[14] (Chapter 9)

[15] (Chapter 11, Chapter 12)

[16] (Chapter 19)

[17] (Chapter 5, Chapter 6, Chapter 17, Chapter 1 Box 1.2)

[18] IPCC 5th Assessment Report (http://www.ipcc.ch/report/ar5/)

[19] Sustainable energy for all - A Global Action Agenda. (2012). United Nations. http://www.un.org/wcm/webdav/site/sustainableenergyforall/shared/Documents/SEFA-Action Agenda-Final.pdf

makes up 75% of the total renewable energy consumption, with traditional biomass use accounting for more than 50% of all the renewable technologies. Not all traditional biomass used today is sustainable. As the use of traditional biomass decreases, the shares of modern renewables will more than triple. As energy demand continues to grow, this requires a quadrupling of modern renewables in absolute terms. Technology costs have fallen significantly and will continue to decline through technology innovation, competition, growing markets and regulatory streamlining"[20]. These are very ambitious goals considering that the tripling of modern bioenergy in a short period has only been achieved by the US dry mill corn ethanol industry[21]. In order to achieve the desired climate effects, and reach more than double of bioenergy, intensified research, development and deployment (RD&D) policies are needed[22]. Moreover there is an accompanying requirement for standards, quality control, technology co-operation and project development capacity together with sustainability considerations and research throughout development, implementation and monitoring. More recently the New Climate Economy report of the Global Commission on the Economy indicated that it is possible to finance a reduction of 50% GHG emissions, with investments in renewables including modern bioenergy technologies partially compensated by reduced costs for conventional energy and savings from efficiency[23].

Our report considers the constraints, best options and science for bioenergy to realize its potential. The goals of this SCOPE Bioenergy & Sustainability project is to assess and communicate the complex nuances and opportunities of this key issue, to integrate scientific research and help inform the policy process, indicating options for the sustainable expansion of bioenergy use and production around the world.

1.2 Sustainable Development and Innovation

Different drivers motivated adoption of bioenergy options in different regions of the world including energy security, economic development and environmental concerns. One of the most important is the role it can play in facilitating sustainable development: meeting society's needs without jeopardizing the welfare of future generations by exceeding the carrying capacity of natural systems.

Improvement of universal, affordable access to clean energy that minimizes local pollution and health impacts[24] as well as mitigates global warming is of global concern.

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[20] REmap 2030 - A Renewable Energy Roadmap (2014). International Renewable Energy Agency. http://irena.org/remap/REmap Summary of findings_final_links.pdf

[21] (Chapter 12)

[22] (Chapter 7)

[23] The New Climate Economy Report (2014). http://newclimateeconomy.report

[24] (Chapter 2 section 2.4.3)

It is important to recognize the potential role of bioenergy in an *integrated* policy framework[25] that meets the 2030 UN SE4ALL goals referred to earlier. Modern bioenergy is naturally an integrating energy resource, linked to improving health[26], livelihoods and education[27] when properly designed and implemented. Modern bioenergy can be promoted from small-scale local use in stand-alone applications or mini-grids[28] as well as large-scale production and commoditization[29], through automotive biofuels[30] and bioelectricity[31], with a large capacity to substitute for the inefficient traditional burning of biomass largely used in the developing world[32]. Sustainable bioenergy production promotes more efficient uses of agricultural and woody biomass, reducing deforestation by replacing the overuse of natural forest firewood, reducing land degradation that is associated with low-productivity agriculture, fuelwood or charcoal use[33].

The potential for sustainable bioenergy development is dependent on the needs, available resources and infrastructure of particular countries and regions. IPCC 5th Assessment Report[34] points out that: "infrastructure and integration challenges vary by mitigation technology and region. While these challenges are not in general technically insurmountable, they must be carefully considered in energy supply planning and operations to ensure reliable and affordable energy supply". Technological development in biomass supply and transformation is reducing costs, generating new business models, driving innovation in science and technology, and supporting continuous improvement of infrastructure and extension services. A number of examples exist, where innovation has given rise to new business models[35]. The production of multiple outputs (energy, food, feed, material products, and use of co- or by-products) is an example where different business opportunities have been combined. Innovation in feedstock production[36], biomass processing and utilization[37], development of new biorefinery systems[38], and advanced biofuels[39] are scale and context dependent technologies for different countries and regions, both developed and developing, and have the potential to enable the advancement of a bioeconomy generating abundant jobs and promote economic development[40]. These innovation efforts should be incorporated in the Millennium[41] and Sustainable Development[42] policy goals.

1.3 Global Climate Change

Integrated studies of the energy sector show that bioenergy is an essential component of GHG reduction technologies displaying a critical role for environmental security

25 (Chapter 7)
26 (Chapter 2 section 2.4.3)
27 (Chapter 2 section 2.4.4)
28 (Chapter 2 sections 2.2.3.10, 2.2.4, Chapter 21)
29 (Chapter 2 sections 2.2.3.1, 2.2.3.3, 2.3.8)
30 (Chapter 2 sections 2.2.3.2, 2.2.3.3)
31 (Chapter 2 section 2.2.3.9)
32 (Chapter 2 Box 2.1)
33 (Chapter 6, Chapter 21)
34 IPCC 5th Assessment Report (http://www.ipcc.ch/report/ar5/)
35 (Chapter 6, Chapter 11, Chapter 12, Chapter 14)
36 (Chapter 2 Box 2.7)
37 (Chapter 2 section 2.3.2)
38 (Chapter 2 Box 2.4)
39 (Chapter 2 sections 2.2.3.5, 2.2.3.6)
40 (Chapter 6, Chapter 15)
41 United Nations Development Goals (http://www.un.org/millenniumgoals/)
42 United Nations Sustainable Development Goals (http://sustainabledevelopment.un.org/?menu=1300)

and climate change mitigation. Global warming levels greater than 2 °C will lead to significant adverse impacts on biodiversity, ecosystem services, natural ecosystems, water supply, food production and health. Any potential impacts of bioenergy should be viewed in this context[43], but not exclusively since there are multiple benefits described for well-executed projects and potential trade-offs.

At present, approximately 87% of energy demand is satisfied by energy produced through consumption of fossil fuels[44]. Although the IEA predicts that this share will fall to 75%, the total consumption of fossil fuels will continue to rise, adding another 6 Gt of carbon to the atmosphere by 2035[45]. Global surface temperatures are increasing and the rate of ocean acidification has not been this high in 300 million years, having increased by 30% over the last 150 years. The main cause is emissions from fossil fuel burning, especially the release of CO_2. The oceans are an important CO_2 sink absorbing 26% of the CO_2 emissions, but due to accelerated acidification and rising sea surface temperatures, this capacity may be reduced[46].

As awareness of the evidence that combustion of fossil fuels is causing climate change has expanded, bioenergy has come to be seen as a mechanism for decreasing the carbon cost of energy use[47]. In the transport sector, biofuels offer a climate-compatible approach that also supports agricultural development; approximately 50 countries, including many developing countries, now have biofuels mandates, some driven by climate security efforts other by energy security or other reasons[48].

1.4 Planning the Expansion of Bioenergy

Bioenergy has evolved to a comprehensive role for heat, power, and transportation fuels at a range of scales from households to nations. Further, bioenergy can play a significant role in policy decisions if evaluated as an important option for increasing energy security[49]. In several scenarios (IPCC/SRREN or AR5, IEA, GEA, WWF and Greenpeace) bioenergy will grow to an average of 138 EJ by 2050 with a low of 80 EJ and a high of 180 EJ. These absolute amounts of biomass-derived energy correspond to a range of 14 percent to over 40 percent of the primary energy projected supply[50]. IRENA in its recent REmap2030 report[51] proposes that if all the technology options envisaged in the REmap analysis are deployed, biomass use could reach 108 EJ worldwide by 2030, double the current level, and could account for 20% of total primary energy supply and 60% of final renewable energy use. There are three major land classes that can grow terrestrial biomass: cropland (~1.5 Bha), forestland (~4 Bha)

43 (Chapter 8, Chapter 5)

44 (Chapter 2 Figure 2.1)

45 (Chapter 8)

46 (Chapter 5)

47 (Chapter 2 section 2.2.4)

48 (Chapter 3, Chapter 20)

49 (Chapter 3)

50 (Chapter 9 Figure 9.1)

51 REmap 2030 - A Renewable Energy Roadmap (2014). International Renewable Energy Agency. http://irena.org/remap/REmap Summary of findings_ final_links.pdf

and pastureland (~ 3.4 Bha)[52]. IPCC[53] reports that land availability will depend on the extent to which bioenergy can be grown on areas with little current production and that considerations of trade-offs with water and biodiversity are crucial to avoid adverse effects. Around 0.9 Bha of global land complies with the above points being interpreted as rainfed land that is being either unused in economic terms or pasturelands, which are lightly used and thus could accommodate other options. To grow bioenergy crops to generate 100-200 EJ/year of bioenergy by 2050 around 50 to 200 million rainfed hectares would be needed. This corresponds to the use of 0.4 to 1.5% of total global land to provide a share of 10-20% of total primary energy with modern bioenergy or 5-20% of the available rainfed unused or poorly used land. This calculated bioenergy land of 50 to 200 million ha needed excludes the land needed for food crops, native and planted forests, and urban and other protected landscapes[54].

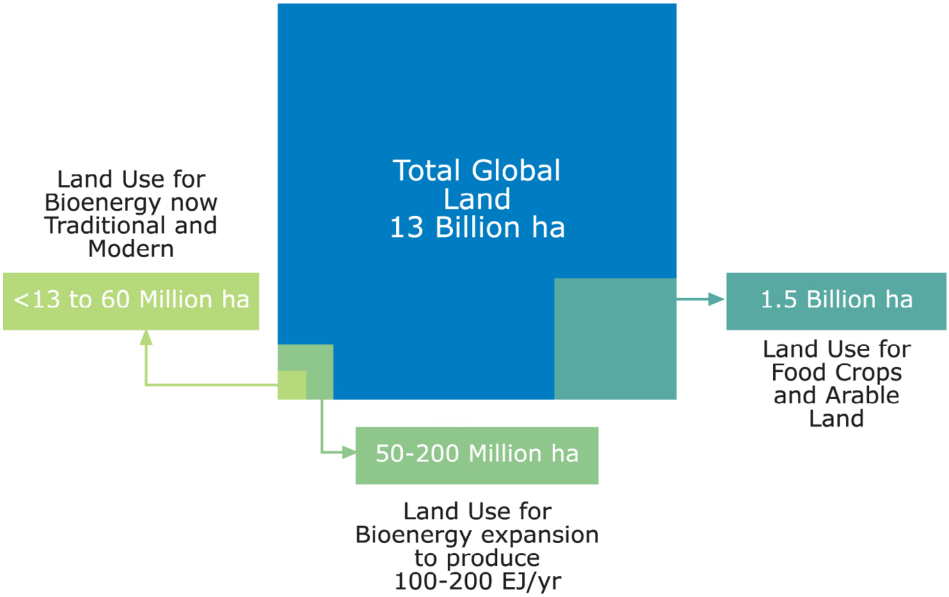

Figure 1.1. Global land use for bioenergy. Approximate numbers.

When properly planned and managed, bioenergy may have positive synergies with other policy priorities such as water and food security, as well as supporting energy access, economic development, growth, stability and environmental goals[55]. As efforts to adapt to and mitigate climate change increase, and the realization that fossil fuels may no longer be an option becomes clearer, bioenergy is expected to be increasingly important to energy security issues because of the relatively low carbon intensity of bioenergy

[52] (Chapter 9 Table 9.15)

[53] IPCC 5th Assessment Report (http://www.ipcc.ch/report/ar5/)

[54] (Chapter 9)

[55] (Chapter 8, Technical Summary Box 1.1)

compared to fossil fuels. Greater utilization of lignocellulosic materials, enabled by technology advancements ranging from improved cooking stoves for underdeveloped regions to the production of lignocellulosic biofuels, can significantly increase the useful resource base globally and alter the geopolitical landscape due to different national resource endowments[56]. Land availability in global terms is not a constraint but availability is expected to be concentrated in two main regions: Latin America and Africa[57].

1.4.1 Integrated Policy to Maximize Bioenergy Benefits and Positive Synergies

Integrated policy frameworks for bioenergy are desirable at several levels including the management sectors (agriculture, forestry, energy, transportation, for instance), across physical landscapes (such as in the establishment and monitoring of agroecological zoning) and across financing schemes to consider technological options and multiple potential benefits. Making bioenergy an integral part of sustainable development strategies requires a systems approach in developing assessments, policies, strategies and business models.

To avoid reliance on staple food crops and to avoid excessive reliance on productive agricultural lands for bioenergy, several options exist that could be stimulated such as using degraded lands, expanding coproducts, practicing integrated land use management, and promoting advanced biofuel technologies that use multiple feedstocks[58]. On the utilization side, promoting improvements on the conversion efficiency of biofuels in vehicles and power generation can increase the positive impacts of the whole chain[59].

Political leadership, providing long-term, consistent policy, legal, and institutional frameworks are necessary to leverage the necessary investment in innovation and scale up of the existing and emerging examples of good practices[60].

Integrated resource assessment is at the heart of any decision-making process, particularly in integrated water management and land use planning. Furthermore, projected energy, food and materials needs should be accounted for as part of assessments. Policies need to be long-term, providing investor security, and have to be consistent with climate, rural and industrial development, energy and food security policies[61].

As we look toward the future, it is clear that global policy frameworks should more explicitly address bioenergy production and provide appropriate incentives for sustainable integration with food and timber production. Such policies must have the flexibility to adapt to local social and biophysical circumstances, yet also drive management practices that achieve global greenhouse gas (GHG) reduction goals. There are many strategies that can be used to achieve that integration, providing large quantities of fuel while enhancing ecosystem services and addressing socioeconomic needs. Central to all of these strategies are embedded concepts of multifunctional landscapes, integrated landscape design, and resilience in the

56 (Chapter 3)

57 (Chapter 2 Box 2.5)

58 (Chapter 4)

59 (Chapter 2 Box 2.2)

60 (Chapter 6)

61 (Chapter 6)

face of changes yet to come[62]. In this sense, adaptive approaches that account for changing resource endowments, natural conditions, technology advancements, and geopolitical change are needed[63] as well as monitoring of these areas to continuously improve practices.

A careful analysis is required when policy and regulatory approaches are applied for bioenergy production, conversion, and use. Policy measures can enable or inhibit positive synergies being more site-specific than other energy sources [64]. Bioenergy deployment in several countries has shown different outcomes, even for apparently similar situations, that are strongly influenced by the local context and supporting policies. In the case of ethanol production in Brazil and Thailand, technology development and management practices evolved slowly in the former, to make it the largest sugarcane ethanol producer in the world, and they served as starting point to the latter, being adapted to the local conditions. Strong and adequate policies were the key factor for the success of both cases[65] and also for downfall as the recent stress on the Brazilian bioethanol industry caused by policy that lower fossil fuel prices exemplifies[66].

In terms of implementation, policy measures and investment in research, pilots and business development will be required[67]. A lesson learned is that sufficient time of operations of pilot plants is extremely important to minimize future development risks and costs[68]. Attention must also be given to technical support for farmers, land tenure schemes and development of cooperatives for sustainable agriculture[69]. Policy instruments specific to biofuels have been put in place in several countries, but they still need to be linked to wider country-level objectives on food production, coproduction of chemicals, education and land use planning[70].

Box 1.2. The food vs. biofuels land competition issue[b]

Concerns on the production of bioenergy based on global land availability and linking biofuels production to increased food prices are unfounded.

The overall land required to meet bioenergy demand has been estimated as ranging from 50 Mha to 200 Mha in 2050 with biofuels being the most land intensive sub-sector. Between 40 and 50 Mha is required to grow the feedstocks for conventional biofuels, providing between 7% and 17% of primary energy in 2050. The remaining 10 to 150 Mha of land demand is for lignocellulosic biomass from energy crops and could be met from a combination of rainfed agricultural land and pastureland arising from pasture intensification. Additional feedstocks and land for bioenergy could effectively be made available from forestry activities. A small (0% to 11%) portion of potentially available land considered suitable for rainfed agriculture is required for energy crops.

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62 (Chapter 13)
63 (Chapter 3)
64 (Chapter 3)
65 (Chapter 14)
66 (Chapter 8)
67 (Chapter 7)
68 (Chapter 12)
69 (Chapter 4)
70 (Chapter 15)
b (Chapter 9, Chapter 4, Chapter 2 section 2.3.1)

» Irrigation should not be excluded per se from considerations of biomass supply where water is available. Efficiency is almost always greater in irrigated systems, including for bioenergy.

That said, it is important to mention that there is enough land available that does not require irrigation. Potentially available land for rainfed agriculture is estimated to be in the range of 900 Mha in 2050. Based on population and dietary trends, the FAO projects a net increase in land used to grow food crops by 2050 of about 70 Mha resulting from an increase in land area under agriculture in developing countries of 130 Mha and a decrease of over 60 Mha in developed countries. By 2050, 1.2 Bha of land could be considered as available for uses other than food/feed including bioenergy feedstock production[c]. Forestry, protected lands and urban demands account for a further 1.8 Bha. Approximately 0.6 BHa of land that has been farmed in the past but is not currently farmed is available worldwide.

At a global level, land is not a constraint but availability is concentrated in two main regions, in Latin America and Sub-Saharan Africa, and is currently used predominantly for low intensity animal grazing. Developed countries also have land available but agricultural area in those regions is expected to remain stable.

The projected rate of increase in global food demand (2.4% per year) is now outstripping the increases in production. However, malnourishment is not primarily a problem of food production, but also of downstream factors and disposable income. Roughly 20-30% of people with food insecurity (180-270 million) live in urban areas and are mainly affected by high food prices. However, 70-80% (630-720 million) of food insecurity problems occur in rural areas where energy insecurity or energy poverty is also concentrated. Positive synergies can thus be obtained between expanded food AND energy production, by offering new sources of income for farmers and new sources of energy in rural areas. Together with increased agricultural and rural development, local and national economies will be boosted.

In defining bioenergy policies it is important to manage risks of food insecurity and climate change in ways that take into account persons who are underrepresented because they are poor or unable to look after themselves. Since food insecurity, lack of energy access and low life expectancy go together, there is often a cycle of negative environmental impacts with little or no economic return, such as the traditional, unhealthy practice of using fuelwood or dung for cooking. In stimulating development that benefits rural communities, bioenergy has a clear potential to help achieve food security and other aspects of human development, and should be considered as a viable option for investment schemes.

c (Chapter 9 Table 9.5)

1.4.2 Sustainable and Reliable Biomass Supply

Considerable advances have been made in the improvement of crop yield[71], in the understanding of the key criteria that need to be met for sustainable production, which crops best meet these criteria, the changes needed to further improve sustainability and the impact of climate changes on productivity[72]. The quantity of dedicated energy crops and their yields are important determinants of land needed[73]. The challenges of meeting biomass supply through yield improvement and expansion of feedstocks in sustainable ways can be met[74], but only with secure and prolonged support and sensible, easily adoptable policies that recognize the environmental as well as the economic goals. Policies are needed so that strategies for increasing feedstock production in sustainable ways can be implemented immediately[75] to meet the ambitious goals of SE4ALL, for instance. Crop breeding and the development of suitably adapted varieties of energy crops is a long-term process. Nearly all of the 100 billion liters of biofuels used today consist of ethanol and biodiesel produced using maize, sugarcane, rapeseed and soybean[76] that were expanded using intensification and thus requiring very little additional land, approximately 13.5 Mha[77]. These crops have been bred for many decades to achieve their current high yields[78]. Maize yields 72.8 GJ/ha and sugarcane yields 156.8 GJ/ha (3900 L/ha and 7200 L/ha ethanol respectively)[79]. There is consistent evidence of many potential bioenergy feedstock options[80] including the use of residues, sugarcane bagasse, corn stover, other energy grasses or woody plants such as eucalyptus that can double the energy output through the use of advanced biofuel technologies, current high efficiency thermal cycles commonly in cogeneration schemes, direct combustion or power generation[81]. Measures for their immediate deployment and development are needed to release this potential in time to fight global climate change[82].

Emerging perennial crops and woody feedstocks that may be grown on marginal land, i.e. land unsuited to arable crop production or semi-arid land could allow large-scale replacement of fossil fuels[83]. Pasture intensification will be an important tool to contemplate land demand. However, this will require the implementation of policies that favor these new land uses and policies that support the realization of the potential of producing cellulosic fuels. Acceptance of biotechnology for bioengineered crops will be important since crop yields in marginal lands are low and could benefit from more rapid improvement made possible with the use of biotechnological tools[84].

Cropping intensification[85] and agro-forestry integration are additional ways to increase yields and decrease land demand[86]. Harmonizing forestry and agriculture policies is

71 (Chapter 10)

72 (Chapter 2 section 2.3.4)

73 IPCC 5th Assessment Report (http://www.ipcc.ch/report/ar5/)

74 (Chapter 2 section 2.3.2)

75 (Chapter 10)

76 (Chapter 2 Figure 2.1)

77 (Chapter 2 section 2.2.2)

78 (Chapter 2 section 2.2.1)

79 (Chapter 2 Figure 2.1)

80 (Chapter 10 Table 10.1)

81 (Chapter 2 section 2.2.3)

82 (Chapter 10)

83 (Chapter 9, Chapter 10)

84 (Chapter 10)

85 (Chapter 9)

86 (Chapter 13)

fundamental for the implementation of integrated approaches to sustainable production and supply of bioenergy. Regulations that ensure the sustainability of biofuel-specific agriculture and forestry practices have not yet been developed in many countries. The necessary legal and institutional frameworks are also lacking particularly those related to tenure, and the customary land rights[87].

It is not clear how biomass supply will be affected by climate change[88]. Yield reductions of zero to -2.5% appear small in relation to historic rates of yield improvement per decade in maize and wheat. For rice and soybean no reductions are indicated. But extreme weather events may alter rainfed crop performance, pest and disease incidence. Field experiments with crops under CO_2 2050 predicted levels increased the yield of rice, wheat and soybean by 15%, but did not affect maize yield, however effects may not be globally uniform[89]. It will be important to better understand the impacts and interactions of climate change on bioenergy crops for sustainable feedstock production in an uncertain future.

1.4.3 Developing Sustainable Biorefinery Systems

Biomass has the unique capability among all energy sources of providing solid, liquid and gaseous forms of energy carriers that can be transformed into analogues provided by the fossil fuels industry[90]. IPCC[91] considers that land demand for bioenergy depends, among other things, on the share of bioenergy derived from wastes and residues. The design of new biorefinery systems can contribute to decreased land use by optimizing the use of biomass resources alongside water, land and other factors of production. Integrated biorefineries will minimize losses by using wastes and residues for bioenergy and non-energy products[92], while addressing long-term soil quality through recycling of nutrients[93]. Recently, 250 projects related to the industrial development of advanced biofuels and renewable materials based on innovative technological paths have been described[94]. This wide array of technological pathways in hundreds of chemical and energy industries is expanding and maturing. Almost half of the projects are in the US and Brazil, with initiatives also underway in Germany, The Netherlands, Canada and the UK. In Scandinavian countries a significant intensification of use of biomass for bioelectricity and heat is observed. As the bioeconomy is a promising but infant industry in most of the world, policies should stimulate its development. Technological change that reduces costs and stimulates full biomass utilization for food, feed, energy, materials and chemicals might improve its competitiveness in relation to the fossil fuels industry. The development of more efficient biomass conversion routes, especially routes that can convert lignocellulosic

87 (Chapter 13)

88 (Chapter 2 section 2.3.4)

89 (Chapter 4)

90 (Chapter 2 section 2.2.3)

91 IPCC 5th Assessment Report (http://www.ipcc.ch/report/ar5/)

92 (Chapter 12)

93 (Chapter 2 section 2.4.2, Chapter 18)

94 World Directory of Advanced Renewable Fuels and Chemicals. 2014. Elabora. http://www.elaboraeditora.com.br/world-directory-of-advanced-renewable-fuels-and-chemicals

biomass into biofuels and biochemicals[95], will accelerate the transition towards a competitive biobased economy[96].

Development and commercialization of lignocellulosic technologies have been moving at a slower pace than anticipated by governments or by the private sector for many reasons but, now, it seems to be accelerating. The industry had to develop biomass production, logistics for biomass collection, storage, and delivery to the conversion facility for biofuel manufacture with agreements of purchase for fuel distribution and use, and had to reach fuel product acceptance. Significant improvement is possible to bring the cost of these technologies down in both the enzymatic hydrolysis and thermochemical lignocellulosic ethanol pathways[97]. Initial industrial scale operations of several lignocellulosic ethanol processes as first-of-a-kind plants started in 2013-2014[98]. The positive outlook of advanced biofuels is conditional on accelerated deployment of whole supply chains. This would help achieve: process stability, reliability, and availability that can lead to production costs falling to competitive levels[99].

Bioenergy is part of a larger transition to a bioeconomy in which bioproducts will be competing ultimately by means of efficiency and price. Policies and energy prices are key drivers for current bioenergy and the emergent bioeconomy. Technological change and full biomass utilization might create a competitive industry. A coherent temporary policy package can stimulate an immature industry and regulation can deal with the indirect effects[100].

Although the policy focus in support of bioenergy has an understandable focus on energy and climate, sustainable technology development requires attention to other environmental impacts as well. Significant advances have occurred in water recovery and recycling to reduce water requirements for conversion processes as well as effluent production that justify policy efforts to stimulate emerging sustainable bioenergy practices[101]. Feedstock production and conversion stages can, in some cases, be integrated to use resources more effectively and support good land and water management. Examples include the recirculation of sludge to willow plantations, vinasse application to sugarcane fields, the use of perennials to reduce erosion and nutrient runoff[102], and possibly, the use of biochar as a soil amendment[103]. More work is needed to integrate all the elements of the value chain, including assessments of environmental performance and overall system sustainability (environmental, social, and economic)[104].

Lignocellulosic biofuels may show higher GHG mitigation potential than current biofuels, but the exact potential of the new processes is still to be verified when in commercial scales.

95 (Chapter 7)
96 (Chapter 20)
97 (Chapter 12, Figure 12.21)
98 (Chapter 8, Chapter 12)
99 (Chapter 12, Chapter 2 section 2.3.3)
100 (Chapter 20)
101 (Chapter 12)
102 (Chapter 2 section 2.4.2)
103 (Chapter 18)
104 (Chapter 12)

1.4.4 Bioenergy Governance

Adequate governance schemes need to be in place to ensure that bioenergy sustainability is achieved and that its benefits are distributed equally. There is enough suitable land available to accommodate both increased food demands and a considerable contribution to energy production but it is important to study and monitor bioenergy expansion to maximize benefits ensuring positive impacts and sustainable agricultural practices[105]. Sustainable implementation of bioenergy options requires strengthening institutions and governance at all scales, from local to global[106]. Governments worldwide can influence the deployment of sustainable bioenergy using appropriate assessment practices and policies[107]. Even in developed countries capacity is lacking with regard to implementation of certain elements of sustainability certification. Thus, the assumption cannot be automatically made that existing policies in those countries eliminate the need for verification, and that only underdeveloped countries lack the governance structures and warrant oversight[108]. Good governance, strong institutions, market based voluntary certification, and access to information about appropriate management strategies and tactics all support sustainable resource use and management that can benefit biodiversity and ecosystem services. Developing such management strategies around the world represents a long-term undertaking that is connected to improving agricultural and forest management[109].

Governance is especially important regarding the issue of biodiversity and ecosystem services protection. The negative effects of bioenergy and biofuel production on biodiversity and ecosystem services can be avoided or reduced and positive effects enhanced by attention to three guiding principles: (1) identification and conservation of priority biodiversity areas; (2) identification of effects of biofuel feedstock production on biodiversity and ecosystem services that are context specific; and (3) implementation of location-specific management of biofuel feedstock production systems to maintain biodiversity and ecosystem services[110]. Governance policies are needed that are especially designed to avoid the implications of unsustainable exploitation of natural forests for biofuels, which frequently lead to “exporting” deforestation to other regions in the same country or to other countries as well as encouraging illegal logging and trade in wood and non-wood forest products[111]. Participatory governance that engages the general public and key stakeholders in an open and informed dialogue is required for a broad public support of bioenergy[112]. Negative indirect effects of bioenergy are better addressed by policy directly supporting sustainable land use, food security, education, health care, and ecosystems supportive of public health. Policy should focus on public governance failures, and recognize the limitations of private, third party sustainability certification to address community-level issues[113]. The application and enforcement of Agroecological Zoning (AEZ) principles is of paramount importance to avoid the

105 (Chapter 3, Chapter 4, Chapter 5, Chapter 6)
106 (Chapter 13)
107 (Chapter 5)
108 (Chapter 19)
109 (Chapter 16)
110 (Chapter 5) (Chapter 16)
111 (Chapter 5)
112 (Chapter 20)
113 (Chapter 19)

conversion of ecologically significant and sensitive areas. As a highly innovative industry, biofuels can be part of the solution to environmental development[114].

1.4.5 Bioenergy Certification and Social Aspects

If "sustainability" is to have real meaning, government policy (and third party certifiers) must evolve from being theoretical to a more applied consideration of the technical and economic requirements needed for measurement and the capacity necessary to transform aspirational standards to on-the-ground results. Case studies demonstrate that even in developed countries, where some programs and tools already exist, gaps remain[115]. Technical capacity problems are likely magnified for developing and underdeveloped countries. Bioenergy policy, therefore, must provide scientific, educational and technical support to producers to ensure fulfillment of certification requirements. International efforts should consider implementing support mechanisms for building knowledge networks that translate skill sets and lessons learned to those charged with implementing sustainability practices and outcomes locally[116]. Examples of efforts in this direction are those led by GBEP and RSB[117].

In the context of equitable development, energy solutions that reduce health impacts and provide higher quality energy services at reasonable costs are preferred. Social aspects should be included in bioenergy policy and certification schemes especially considering education benefits and job generation[118]. Women and children disproportionally bear the ill effects of inefficient bioenergy use ranging from the hard labor of biomass collection to indoor air pollution issues[119]. Gathering fuelwood for traditional stoves to cook and heat homes occupies young women with provisioning for energy at the cost of formal education [120]. Transitioning away from traditional biomass use to modern energy services can reduce the time needed to collect water and firewood, which means that many women and children have more time to study or for income generating activities[121]. Additionally, women play a significant role in agriculture and various forms of land rights in developing countries have frequently discriminated against women. Educating communities, and particularly women about their own land rights is crucial[122].

1.4.6 Financing the Bioenergy Effort

Studies indicate that it is possible to finance a reduction in GHG emissions of 50-90% of what is needed by 2030 to avoid the 2°C global warming [123] at lower cost than is currently used to subsidize fossil energy. A significant challenge to transition to a low carbon economy is that the petroleum industry invests based on internal rates of return of about

114 (Chapter 16)

115 (Chapter 14)

116 (Chapter 19)

117 (Chapter 19)

118 (Chapter 2 section 2.4.4)

119 (Chapter 3)

120 (Chapter 3, Chapter 15, Chapter 6)

121 (Chapter 6)

122 (Chapter 15)

123 (Chapter 2 section 2.3.7)

15% per annum, a number that is difficult to obtain with most types of unsubsidized bioenergy[124]. To correct for market failures, extensive research, development and demonstration (RD&D) programs relating to renewable energy are present in rich countries. According to the International Energy Agency they spent at least USD 4.1 billion on RD&D related to renewable energy in 2011[125]. Even though these policy instruments may boost returns for bioenergy to an acceptable level in the short-term, uncertainty about the duration of policy support for bioenergy may preclude long-term capital investment. In particular, capital investments may be based on approximately 30-year lifetimes. Thus, there is a need for long-term stability of regulatory mechanisms[126].

1.4.7 Bioenergy Trade Expansion

As international trade expands, bioenergy issues will play an increasingly larger role in the geopolitical dialogue, including the complexities across multiple energy segments and the interconnectivity with other geopolitical issues including food, water, trade, human rights, and conflict[127]. All commercial biofuels have been increasingly traded internationally as have solid biomass pellets and other densified materials, which enable transport at longer distances to supply a variety of markets, such as power generation and cogeneration for district heating and power[128]. Many biofuels and feedstocks were exported and received sustainability certification according to criteria and principles defined by several sustainability schemes accepted by the EU Renewable Energy Directive[129]. International harmonization efforts must account for unique regional and local socio-environmental conditions; certification should not lead to north-south trade barriers[130].

1.5 Conclusions

SCOPE Bioenergy & Sustainability provides a guide to bioenergy possibilities, paths for sustainable expansion and recommendations for realizing its techno-economic potential. It shows there is probably no one-size-fits-all solution for bioenergy development with different paths available for adoption depending on resources endowment, technology suitability and appropriate policy frameworks. It also highlights the gaps in knowledge and proposes the science and technology needed for bioenergy to realize its maximum benefits. Enough land is available, that need not pose a threat to food security, biodiversity and ecosystem services, and the improvements this industry has been attaining (improving soils, integrated chains, use of co-products, improved conversion technologies) add up to reach climate mitigation much more effectively while improving economic performance to benefit broader societal needs.

124 (Chapter 3)
125 (Chapter 20)
126 (Chapter 3, Chapter 6 Figure 6.2)
127 (Chapter 3)
128 (Chapter 2 section 2.3.8)
129 (Chapter 12)
130 (Chapter 19)

Bioenergy science and technology is bringing solutions that improve economics, land use, biomass production, environmental benefits and livelihoods. For additional information visit Boxes on Chapter 2[131].

Bioenergy Numbers - Box 2.1 – to decrease pollution

Bioenergy Numbers - Box 2.2 – to increase efficiency for competitive deployment

Bioenergy Numbers - Box 2.3 – to decrease costs

Bioenergy Numbers - Box 2.4 – to establish the cellulosic ethanol industry

Bioenergy Numbers - Box 2.5 – to recuperate soils

Bioenergy Numbers - Box 2.6 – to protect biodiversity and ecosystem services

Bioenergy Numbers - Box 2.7 – to increase crop yields

Bioenergy Numbers - Box 2.8 – to decrease water use

[131] (Chapter 2 Boxes)