chapter 5

Environmental and Climate Security

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Highlights

- Bioenergy is critical for environmental security and climate change mitigation. Global warming levels greater than 2°C will lead to significant adverse impacts on biodiversity, natural ecosystems, water supply, food production and health. Any potential impacts of bioenergy should be viewed in this context.
- In general, environmental security deals with local to regional issues, while climate security deals with global issues. Geophysical distribution of land and climate around the globe is not homogeneous. The impact in local activities such as biofuels production will be singular, demanding specific engagements of governments and regulatory constraints.
- The expansion of biofuels production across less profitable (degraded, abandoned or marginal) lands may have positive impacts on biodiversity and biofuel and food production. Land Use Change (LUC) can result in the loss of biodiversity, wildlife habitat and the alteration of ecosystem structure and delivery of ecosystem services but these effects can be minimized through appropriate choice of bioenergy crop and management practices. Biodiversity losses caused by Indirect Land Use Change (iLUC,) due to the displacement of existing agricultural activities to pristine areas beyond the biofuels croplands are of less importance than previously reported.
- Environmental impacts need to be considered at appropriate scales, across the whole feedstock production and bioenergy processing chain and across landscapes, catchment basins, functioning ecosystems and where migratory species are affected, dispersion areas.
- Environmental impact assessment frameworks have evolved, integrating individual metrics such as water, soil, and biodiversity into a systematic view. However, the requirements to conduct and implement such assessments still present formidable technical and sociopolitical challenges.
- Conservation of priority biodiversity is paramount; effects of biofuels on biodiversity and ecosystem services are site and context specific; and management practices in biofuels production should minimize threats. Of critical importance is the conserving of primary tropical forests, and strengthening the representation of ecosystems in effectively managed protected areas across the globe. Appropriate management systems can reduce negative impacts on new croplands and enhance biodiversity in previously degraded lands.

- Water use in bioenergy production systems is highly variable and the impacts are site-specific. Wherever possible, full water budget analysis, rather than a reliance on water use efficiency metrics, should be conducted. Poorly managed bioenergy production may decrease water abundance and quality. However, locally optimized feedstocks, improved wastewater management, proper agronomic practices, and landscape-level planning can minimize these impacts and may, in some case, improve the status of water resources.
- Mining nutrients from the soil with inadequate or insufficient fertilization, removing excessive amounts of plant material or improper disposing of residues may reduce soil fertility, cause loss of organic matter and predispose soil to erosion. However, properly managed bioenergy crops can help to maintain soil quality and even result in carbon accumulation, thus mitigating CO_2 emission.
- 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 illegal trade in wood and non-wood forest products.
- Sustainable biofuel production must be part of sustainable forest management and sustainable agriculture (food security) where both are needed as integral components of land use with clear understanding of the uniquely complex set of environmental, economic and social issues involved.

Summary

Bioenergy has a key role to play in the stabilization of global climate change. In this chapter we assess the potential environmental and climate security opportunities and risks associated with bioenergy expansion and examine the main guidelines, regulations, incentives and policies that will help promote it in an environmentally and climate-friendly way.

Current projections are that climate change will be more severe than originally predicted. Warming at a level greater than $2^{\circ}C$ could have significant adverse impacts on biodiversity, natural ecosystems, water supply and food production. Stabilization of global warming to less than $2^{\circ}C$ has thus become an imperative. Challenges also need to be faced with respect to the environmental consequences of intensive agriculture for food production, and of urban expansion, such as building on prime soils, increased soil erosion, loss of soil organic carbon, excess nutrient run-off, increased pollution and loss of biodiversity. Bioenergy is recognized by many as being critical to combating many climatic and environmental problems (e.g. energy supply, soil remediation, nutrient run-off). There is now strong scientific consensus that achieving a low carbon energy future is more likely with bioenergy than without it. However, it has also been posited that bioenergy expansion may result in unacceptable negative impacts, such as substantial greenhouse gas (GHG) emissions, biodiversity losses, land degradation and water scarcity, primarily through land use change (LUC). Here, we examine these issues and demonstrate that through awareness, careful management and appropriate integrated policies, we can produce sufficient bioenergy sustainably to fulfill its anticipated role in mitigation of climate change, whilst encouraging positive benefits and minimizing negative impacts on natural resources.

In general, environmental security is determined at local- and regional-scales and climate security is at a global scale. Assessment of environmental impacts should be carried out at appropriate scales (farm, landscape, region, country, global) that recognize that impacts may operate at the ecosystem (e.g. forests, grassland, arable, coastal) level. It will be important to develop integrated and complementary management systems, in which the interdependencies of forestry and agriculture policies, as well as systems for producing food crops, meat and dairy, and bioenergy feedstocks should be recognized and harmonized. Increasing agricultural productivity and reducing food waste are essential to reduce the overall needs for expansion of lands (Chapters 4 and 13, this volume).

The more recent studies of indirect Land Use Change (iLUC), arising from displacement of existing agricultural activities to non-cultivated areas beyond the biofuels, report lower effect than earlier studies. Estimates for new land brought into cultivation due to production of bioenergy feedstocks on cropland have been reduced by an order of magnitude for corn ethanol, and by 3-fold for sugarcane ethanol. Similarly, new evidence indicates that postulated biodiversity losses caused by iLUC are far smaller than previously reported. Thus, recent results indicate that the land use sectors are capable of accommodating a significant part of the modeled bioenergy expansion without claiming new land. However, it should be noted that iLUC studies investigate modest bioenergy scenarios compared to prospective biomass demand in the 2050 time frame; about 2.5 EJ of biofuels was produced in 2013, compared with the prospective biomass demand of some hundreds of EJ per year.

Clearly, the expansion of bioenergy (and food crops) to meet human needs will likely have major implications for land use. However, whilst LUC involving previously non-cultivated land for bioenergy production can have negative impacts on ecosystem services, this does not mean it has to. Use of previously cultivated but abandoned lands and of marginal lands deemed less suitable or profitable for food production, may have positive effects. This will be helped by improvements in feedstock selection and agricultural practice to compensate for the poorer quality of such lands. Pressure on land use can be further reduced by including wastes and crop residues as sources of biomass, although a proportion of crop residues should be left to maintain carbon and nutrient levels in soils.

Effects on biodiversity and ecosystem services are both site and context-specific. Many possible impacts are valid concerns for arable food crops, however, many bioenergy plants, particularly grasses and woody plants have specific attributes that can be advantageous if used properly. These include their longer growing seasons, perenniality and associated stability of habitat, and their reduced need for fertilization and cultivation. Management practices for bioenergy crop production should exploit positive attributes of these cropping systems and minimize threats to biodiversity and ecosystem services. Effective management of water and nutrients can be achieved through a systems approach that recognizes the spatial heterogeneity of landscapes, ecosystems and species, and landscape level processes dependent on catchment connectivity, fluxes in water-yield and nutrient cycling (Figure 5.1). Bioenergy cropping can either cause soil degradation or help maintain or improve soil quality and can even cause carbon accumulation, thus mitigating CO_2 emission. Negative impacts can be minimized by careful crop selection for soil type and climate.

To manage environmental impacts, new bioenergy croplands should be selected and developed following both Strategic Environmental Assessments (at a regional scale) and Environmental Impact Assessments (at local/site scale) as these provide baselines for monitoring positive and negative impacts and guide adaptive management strategies. Sustainable bioenergy production should be based on, and support, good governance,

Figure 5.1. A future multifunctional landscape for both environmental and energy security. Strategic spatial integration of bioenergy crops on poorer land with food cropping on arable land can provide energy and alleviate environmental problems associated with arable land use. Perennial bioenergy crops can provide natural refugia for biodiversity, regulate flooding and provide filters to remove excess nutrient run-off into waterways. Arable crop and urban food wastes can be converted to various energy forms by anaerobic digestion, together with animal slurries, whilst waste water can be applied to biomass crops such as willow. Note; for ease of illustration, elements are simplified and not drawn to scale or directly connected.(Source; L.Castle, Rothamsted Research, UK).

strong institutions, market based voluntary certification, and access to information about appropriate management strategies that support sustainable resource use and benefit biodiversity. Scale and cost of the bioenergy end product should be part of this equation. To ensure compliance with sustainable forest management, and sustainable agriculture, national and regional integrated forestry, agriculture and bioenergy governance policies will be required. These will need to address the full valuation of forest goods and services and opportunity costs of forestland and cropland conversion, whilst recognizing law enforcement and institutional capacities and safeguarding local user rights and land tenure arrangements.

5.1 Introduction

This cross-cutting chapter examines the potential environmental and climate security opportunities and risks associated with bioenergy expansion and the main guidelines, regulations, incentives and policies that will help promote bioenergy in an environmentally and climate-friendly way.

5.1.1 Security is Important

Bioenergy production exploits the natural opportunity offered by plants to remove carbon dioxide (CO_2) from the atmosphere and convert it into dry matter (biomass) that can be used as substitute for fossil fuel-based energy. Plants are also the principal source of carbon in soils. Bioenergy implementation can cause gains or losses of carbon in soils and vegetation. The outcome depends on the character of the bioenergy system and on local conditions, not the least prevailing land use. The use of biomass for energy in combination with carbon capture and storage can deliver net removal of atmospheric carbon along with energy provision. Thus, the contribution of bioenergy to climate change mitigation can vary widely depending on the character of the bioenergy system and the implementation strategy.

Climate change is arguably the biggest environmental and developmental challenge facing humanity. The latest IPCC (Intergovernmental Panel on Climate Change) Report (IPCC 2013) has concluded that “warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia...[and that]...continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system”. The world has warmed by nearly 1^{O}C compared to pre-industrial revolution stage. IPCC Working Group II (IPCC 2014a) has concluded that any warming level greater than 2^{O}C will lead to significant adverse impacts on biodiversity, natural ecosystems, water supply, food production, health etc. In fact, there is scientific evidence that climate change is already affecting natural ecosystems and food production. The Copenhagen Accord, taken note of by delegates at the Fifteenth Session of the Conference of the Parties (COP 15), expresses a strong political will to urgently combat climate change and prevent dangerous anthropogenic interference with the climate system. The Accord recognizes the scientific view that the increase in global temperature should be kept below 2°C and that deep cuts in global emissions are required. Many scenario studies and assessments, including IPCC (2011), GEA (2012) and the forthcoming IPCC (2014 b, c), the IEA (2014), Greenpeace, and the World Wildlife Fund, have all highlighted the role for bioenergy in meeting greenhouse gas (GHG) stabilization targets judged compatible with a $2^{O}C$ target. These observations are indicative of strong scientific consensus that achieving a low carbon energy future is more likely with bioenergy than without it. Sustainable bioenergy production has thus become both urgent and imperative.

Many bioenergy production systems are based on farming practices that have fewer impacts than intensive agricultural food production. As with all technologies, however, not all bioenergy routes will be appropriate in all circumstances. Unfortunately, the negative image of those systems that fail to meet all expectations are in grave danger of impeding the beneficial bioenergy production systems that are urgently needed. To achieve full sustainability goals, the expansion of bioenergy production has to be progressed within a framework of the broader ecosystem functions associated with land use. This chapter focuses on key issues in environmental and climate security, whilst land availability, bioenergy energy supply, impacts on food production and sustainable development are covered by Chapters 3, 4 and 6, in this volume.

5.1.2 Key Opportunities and Challenges

The low carbon energy scenarios cited above suggest a strong growth in the use of biomass for energy, equating it in places to exploitation by humans of photosynthesis of comparable scale to that for agriculture or forestry today. For instance, the SRREN review of 164 long-term energy scenarios predicted bioenergy deployment levels in year 2050 ranging from 75 to 150 EJ per year (for ~440–600 ppm CO_2eq concentration targets) and from 115 to 190 EJ per year (for less than ~440 ppm CO_2eq concentration targets). As a comparison, the energy content in the global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers and pulses) was estimated at about 60 EJ per year in IPCC (2011). See also Chapters 3, 4 and 9, this volume, for further information.

The expansion of bioenergy offers considerable opportunities for the agriculture and forestry sectors, which can find new markets for their products and also make economic use of biomass flows earlier considered to be waste. However, bioenergy growth has prompted much concern about possible negative impacts such as biodiversity losses, land degradation and water scarcity. Sustainability concerns further include direct and indirect social and economic aspects, including land-use conflicts, human rights violations and food-security impacts. The view that bioenergy represents an attractive alternative to fossil fuels has also been challenged based on the notion that bioenergy expansion may cause substantial GHG emissions associated with land use change (LUC) (SCOPE 2009; IPCC 2011).

While bioenergy can be developed in ways that have negative impacts, there is strong scientific evidence that bioenergy can also be deployed in ways that offer substantial benefits including, but not limited to, mitigation of climate change. In support of this, we note that there is a great deal of land that is suitable for growing bioenergy crops exclusive of current and anticipated cropland, forest, protected land, expansion of the built environment, and land reservation for protection of native vegetation and biodiversity (Chapter 9, this volume). Much of this land is classified as pasture land, although not all of it has livestock on it, for which the contribution to global food production is quite small (Chapter 9, this volume). Integration of bioenergy production into existing land uses can in many ways improve the productive use of land and water, and can provide environmental benefits in addition to the GHG savings (Chapters 16-18, this volume). Bioenergy demand also opens new opportunities for climate change adaptation. For example, cultivation of hardy and drought tolerant plants as bioenergy feedstocks presents an opportunity to diversify land use and reduce vulnerability to failures in production from major food crops that are more dependent on intensive agricultural inputs. Furthermore, in some countries bioenergy expansion could be driven by the need to create energy access, mitigate fuel poverty and to promote self-reliance and/or rural development. Governments also promote bioenergy to improve energy security, especially to reduce dependency on oil and fossil gas. Thus, bioenergy deserves attention for many more reasons than just the need to meet renewable energy obligations.

Governance of bioenergy development is imperative in order to promote benefits and avoid, or at least mitigate, negative effects. In the sections that follow, the potential environmental and climate security threats and opportunities associated with bioenergy expansion are assessed and policies and measures that address these threats and opportunities are suggested. It is made evident that although there are trade-offs in some situations, there is also clear potential for win-win approaches that should be followed. Implementation of the recommendations would require the development and enforcement of guidelines, regulations, incentives and policies that promote environment and climate-friendly bioenergy. It should be noted that whilst many of the issues raised here apply to bioenergy in general, the current momentum in the area of liquid biofuel production has attracted somewhat more attention, and this emphasis is reflected here.

5.2 Key Aspects

5.2.1 Climate Change

The availability and distribution of natural resources is of growing concern in the context of human population expansion (Rockström et al. 2009). Environmental and climate security both refer to concerns about the impact of human activities on environment and climate, and conversely about how changes in climate and other environmental factors influence the human society. Both environmental and climate security deals with issues at multiple scales. The climate change issue is global by nature, but both mitigation and adaptation strategies are formulated on local, regional and global scale. Environmental impacts are commonly experienced on local to regional level, but are caused by the way society exploit resources and shape production processes to meet the demand for goods and services, which increasingly follows a global uniform pattern.

Resource depletion and environmental degradation threatens the functional integrity of the biosphere and can lead to economic losses as well as social and political instability and conflict. Society faces the challenge to address the underlying causes, including unsustainable land use practices, while mitigating and adapting to climate changes that are increasingly being recognized (Jordan et al. 2013). The frequency and intensity of climate extremes (floods, drought, hurricanes, tornados, etc.) have important social, economic, and environmental consequences. There is scientific consensus that the slow, but monotonic increase in global average temperatures can adversely affect the distribution ranges of both natural and cultivated/domesticated species. Changes in rainfall patterns and temperature are critical to agricultural productivity, whether for bioenergy or food. These are also important at the regional level, because some areas are warming much faster than the average (IPCC 2013) and/or are experiencing different environmental challenges. For example, some regions, such as Southern Latin America, experienced a 30% increase in precipitation over the last 50 years, while others, such as Southern Australia, experienced important precipitation reduction.

Figure 5.2 illustrates how temperature has varied in the last 110 years. As a consequence, the impact in local activities will demand specific engagements of governments as well as specific regulatory constraints. Global climate change brings instability and difficulties in long-term planning for food and energy production - a relatively new issue that is being addressed in this volume.

5.2.2 Land Use Change (LUC)

Land use change (LUC) associated with bioenergy production is a central factor in this, and many chapters in this Volume, due to it being a common denominator in food, energy and environmental sustainability. In Section 5.2.3 we consider LUC within the context of major ecosystems most likely to be affected by bioenergy expansion (agricultural, forest and grassland landscapes, coastal areas and marginal or degraded land), whilst here we discuss LUC in generic terms.

Bioenergy production and its potential are dependent on human activity. Regional demographic demand is affected by local infrastructure and socio-economical context and the long-term sustainability of bioenergy options will be dictated by factors like local climate and soil-water availability (Chapters 10, and 12). Direct LUC (dLUC) refers to the changes in land use that occur where bioenergy feedstock production becomes established, such as the “change from food or fiber production (including crop rotation patterns, conversion of pasture land, and changes in forest management) or the conversion of natural ecosystems”. Indirect LUC (iLUC)

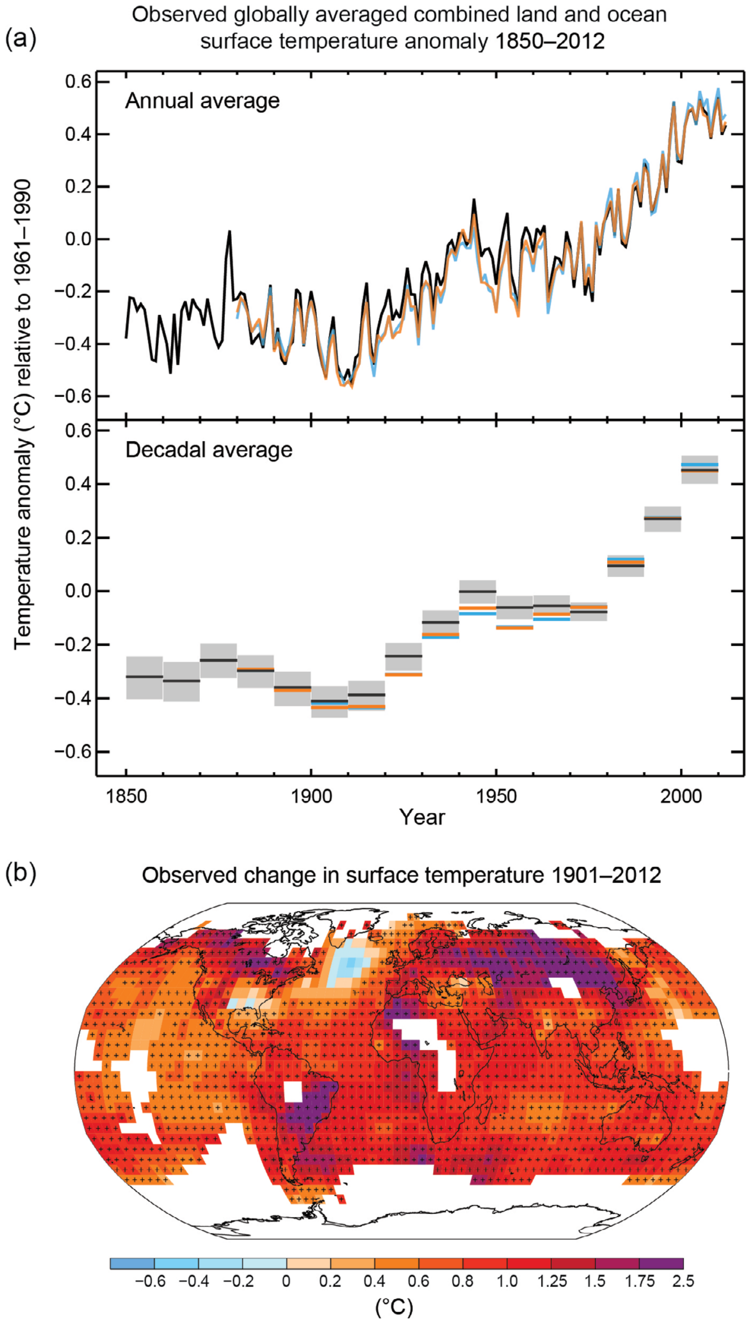


Figure 5.2. Temperature variations over 110 years period. a) Three global land and ocean annual mean temperature series are shown on continuous and decadal averages. b) Overall warming trends are apparent. For regional trends only one data set is shown. Source: IPCC 2013.

“refers to the changes in land use that take place elsewhere as a consequence of the shift to produce bioenergy feedstock. For example, displaced food producers may re-establish their operations elsewhere by converting natural ecosystems to agriculture land, or due to macro- economic factors, the agriculture area may expand to compensate for the losses in food/fiber production caused by the shift to produce bioenergy feedstock. A wide definition of iLUC can include changes in crop rotation patterns and/or intensification on land used for food or feed production” (Berndes et al. 2011) (see also Searchinger et al. 2008; Kloverpris et al. 2008; Hertel et al. 2010; Delucchi 2010; Berndes et al. 2013).

Land use and LUC are inevitable consequences of the continuous changes in the human society. LUC is associated with many human activities inextricably linked with agriculture. Given this, it is expected that effects on local biodiversity and other environmental consequences will occur. However, the effects do not have to be negative. Land use under sustainable bioenergy cropping could be a steady and significant part of the cost-effective portfolio of climate change mitigation strategies (Rose et al. 2012). LUC associated with bioenergy projects can result in both positive and negative effects on environment and resource quality. For example it is widely recognized that converting land planted in row crops to perennial grasses can be accompanied by significant benefits in terms of biodiversity, habitat, and increased soil carbon and fertility. Environmental consequences of converting pasture land to bioenergy crops, or more intensive pasture (which could make room for energy crops), could be positive or negative, depending on how this conversion is managed. Similarly, there are sustainable forest management practices that can provide net benefits to both habitat and livelihoods, while there are others that are abhorrent from an environmental stand point. Worst-case scenarios such as clearing rain forests or draining peat land to make land available for bioenergy are important to avoid. The challenging posit is how to improve the awareness of governments and society that it is possible to avoid or mitigate negative effects whilst taking advantage of the positive benefits of bioenergy crops to address environmental problems.

While GHG emissions can be appropriately treated as a global impact, the climatic consequences of rising atmospheric GHG concentrations are experienced on global, regional and local scales. Thus, as other environmental impacts, climate change needs to be considered within the local context. The risks and resiliency of individual regional niches to the impact of land cover change, biomass removal, and climate vary greatly and continue to change.

Improved data collection and processing and modeling capability now allow high resolution assessment of local impacts. Environmental impact assessment frameworks have evolved, integrating individual metrics such as water, soil, and biodiversity into a systematic view (Chapter 12, this volume). However, the requirements to conduct and implement such assessments (Table 5.1) still present technical and socio-political challenges.

Table 5.1. Regional impact assessments.

Requirements to conducting regional impact assessments
Fairly detailed regional baseline
Adequate understanding of mechanistic linkages in regional environmental processes
Reconciliation of overlapping boundaries for different ecosystem service components in region
Characterization of complex interactions between bioenergy production systems and other regional activities including other human and non-human use
Models sufficiently reticulated to forecast changes in the above
Technical expertise and computing infrastructure
Requirements to implementing knowledge gained from regional impact assessments
Consensus for desired outcomes (e.g. minimizing 'damages', restoration/improvement criteria and goals, etc.) appropriate to region
Political will and consistent guidance through regulatory requirements
Regional stakeholder participation
Reconciliation of disparate and overlapping political governance and ecosystem/watershed boundaries
Translation of goals and assessment outcomes into reliably measurable and enforceable regulated metrics

5.2.3 Ecosystem Change

The increase in area used for bioenergy feedstock cultivation may come from a variety of land uses, principally agricultural (food) and pasture production, natural ecosystems (forests), marginal lands and coastal areas (FAO 2010; Cai et al. 2011; Chapter 9, this volume).

5.2.3.1 Agricultural, Forest and Grassland Landscapes

Agricultural, forest and grassland landscapes have long provided humans with food, fiber and energy as well as a range of other ecosystem goods and services. LUC, especially forest conversion to agricultural land, has been and still is the primary driver of global deforestation and forest degradation in many countries, currently especially in the tropics, in addition to mining, urban development and other anthropogenic changes.

One of the most important environmental concerns is deforestation and land clearing. Forests around the world face pressures from many human activities including agriculture (for both row crops and animal grazing), urban expansion, mining, and land tenure disputes. The forestry-agriculture nexus is clearly demonstrated through the competition for food, fiber and fuel production and consumption. In many parts of the world these three systems, plus others, have been traditionally practiced simultaneously, with minimal coordination among individual regulatory policies. Pasturelands have the potential to provide large amounts of land for bioenergy expansion (Cai et al. 2011; Horta Nogueira and Capaz 2013), with less impact than that of forests. However, the relatively recent surge, particularly in biofuel feedstock production and consumption, has introduced some imbalances in land use systems, especially in the tropics (FAO 2013). In order to adequately protect forest resources and other natural landscapes, all LUC drivers and trade-offs ought to be well understood. In addition, the land-sparing potential of highly productive systems needs full consideration. Crop and pasture intensification, although usually associated with increased use of fertilizer and other agrochemicals, can significantly increase biomass production, thus sparing land for other uses, including forest preservation (Lapola et al. 2014; Martha Jr et al. 2012; Snyder et al. 2009; Chapter 9, this volume).

Direct LUC is relatively straightforward to estimate for feedstocks such as soy in Argentina and oil palm in Indonesia and Malaysia but iLUC is more difficult to estimate and the cause of much debate and concern (see Sections 5.2.3.1 and 5.2.3.3). There have been particular concerns that rapid expansion of oil palm may have resulted in many of the consequences outlined above. However, so far, bioethanol is being produced mostly without clearing forests. Corn for ethanol in the USA is grown mainly in the cornbelt and only 0.6% of the sugarcane expansion in Brazil in recent years (2000 to 2010) occurred in forests (Adami et al. 2012). Whilst there might be isolated instances of unsustainable practices (Lapola et al. 2014), the importance of iLUC has been over estimated (Langeveld et al. 2013; Finkbeiner 2013) but further research is needed to address methodological challenges and help avoid premature conclusions (Pacheco et al. 2012). Trade-offs, including those related to poverty, equity and the environmental integrity must also be evaluated when choosing a bioenergy system.

One of the relatively recent initiatives that can potentially integrate policies governing landscape management systems is REDD+1. It is believed that REDD+ strategies can reduce deforestation, improve global carbon balance and enhance land use efficiency by steering agricultural expansion for biofuel production to already degraded lands that have low potential for regeneration of carbon-rich forests and directing agricultural extension for food production to priority landscapes and to those with minimal potential conflicts within the REDD+ strategies (Kissinger 2011).

5.2.3.2 Coastal Areas

Coastal areas and the open ocean are suffering strong changes due to environmental and climate change, and protection of marine ecosystems becomes even more important when bioenergy crops and production facilities are located in coastal regions. Ocean acidification is a serious issue that could have critically important consequences. Never in the last 300 million years has the rate of acidification been so high. In the last

[1] REDD+ is “Reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries”. http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

150 years, acidity in oceans increased by 30%. 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 (Le Quéréet al. 2010; McKinley et al. 2011; Schuster and Watson 2007). The effects of such acidification on ocean biodiversity are large. It is predicted that in a few decades the increased acidity of oceans could affect severely all marine organisms. Coral reefs will be threatened as well, due to the importance of calcareous compounds in their structure.

Because of run-off from continental areas, coastal zones are under pressure. Run-offs from small catchments to large rivers usually carry pollutants and agricultural residues. Worldwide, there are now more than 500 'dead zones' covering 250,000 km^2 (UNDP 2013). Insecticides and fertilizers are important agents in these changes. The increase in the level of nutrients, such as nitrogen and phosphorus, is causing important impacts at coastal ecosystems (Canfield et al. 2010; Liu et al. 2012) and to the human populations that depend on them.

Most of these factors can be readily controlled through appropriate location of bioenergy crops and associated conversion activities. Some bioenergy crops, for example short rotation coppice willow, can be used as natural filters to help prevent run-off, whilst others, for example some energy grasses, have been selected to cope with the more extreme environments found in coastal areas that make food production impractical. The rooting of these crops can help in the fight against coastal erosion and the land cover can help provide habitats for coastal fauna. Adequate agricultural practices are also important to prevent or decrease the amount of nutrients that go into surface and groundwaters (Fixen 2009; Neary and Koestner 2012; Snyder et al. 2009).

5.2.3.3 Marginal and Degraded Lands

To reduce competition with food production and because of economic factors, expansion of biofuels crops is often foreseen on non-cultivated land, previously un-managed ecosystems, or marginal/degraded lands (Plieninger and Gaertner 2011), and less profitable arable crop lands that have recently gone out of production (idle land) (Gelfland et al. 2013; Chapter 9, this volume). More than a billion acres of idle land may be available for bioenergy production (Cai et al. 2011; Chapter 3, this volume). LUC can result in the direct loss of biodiversity due to the loss of wildlife habitat and deep alteration of ecosystem structure (Koh et al. 2011) but impacts will depend on the ecosystem being replaced and the bioenergy cropping system introduced (Chapter 16, this volume). iLUC effects, although formerly very controversial (Zilberman et al. 2011) are now seen to have far less impact than previously thought (Kim and Dale 2011: Langeveld et al. 2013; Finkbeiner 2013). The use of marginal or degraded lands for biofuel crops can be associated with the general impacts of agricultural intensification (Prins et al. 2011), including an increase in the use of agrochemicals with consequential effects on the biota and the physical environment (e.g., Meche et al. 2009; Schiesari and Grillitsch 2011; Verdade et al. 2012). However, these can be minimized, and even remediated, by careful choice of bioenergy crops (see

Section 5.4). Similarly, degraded lands are usually associated with soil and water limitations that require the selection of plant species adapted to such circumstances (Li et al. 2010). Whilst expansion of biofuels production over less profitable lands can affect food security (Chapter 4, this volume), it may also have positive environmental effects in comparison with expansion of annual agricultural crops (Milder et al. 2008). Harmonizing forestry and agriculture policies is key to achieving sustainable bioenergy production by ensuring integration of bioenergy crops into existing landscapes in ways that enhance benefits and avoid bad practices (Figure 5.3).

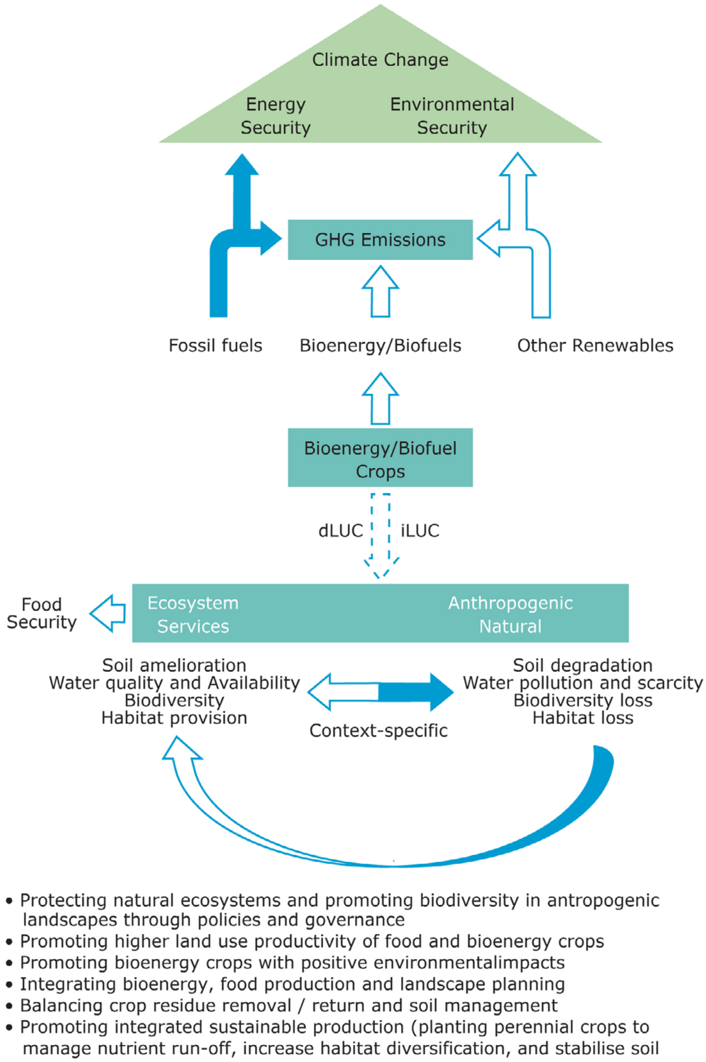


Figure 5.3. Schematic of the energy security environmental security nexus. White arrows indicate positive impacts and blue arrows negative impacts.

Key Messages

- Harmonizing forestry and agriculture policies is fundamental for the sustainable production and supply of bioenergy through integration into cropland and forestland, and land currently classified as pasture, in ways that do not compromise food production or other ecosystems services. These should include policies for marginal land and coastal areas where bioenergy expansion might also be expected.
- Rational and state-of-the-art agricultural practices can also lead to increased biomass productivity for bioenergy and spare land and sensitive ecosystems.
- Pasturelands are more abundant than croplands and have the potential to provide large amounts of land for bioenergy expansion; both crop and pasture intensification can significantly increase biomass production, thus sparing land for other uses
- In drawing up national and regional integrated forestry, agriculture and bioenergy policies it is imperative to address the underlying drivers of land conversion and unsustainable use of resources. Issues for such multi-sector policies include full valuation of forest goods and services, opportunity costs of forestland conversion and alternative cropping systems, governance and law enforcement, institutional capacities, safeguarding local user rights and land tenure arrangements.
- Enabling conditions for effective land use policies include, *inter alia*, integrated land use mapping and planning, as well as eliminating perverse subsidies or regulatory barriers. There is also an urgent need to increase the coordination of objectives and planning within governments, as well as between governments and concerned international institutions, NGO's and the private sector.
- Incorporating initiatives such as REDD+ programs and Green Economy into national development strategies would constitute another venue to strengthen cross-sector forestry and agriculture policies and aligning implementation pertaining to bioenergy.

5.3 Environmental Security

Understanding of the potential environmental implications of bioenergy production is a prerequisite to maximizing positive benefits, whilst ensuring that negative impacts are minimized. In this Section we demonstrate that provided there is awareness of the key issues, bioenergy production can be expanded without compromising ecosystems services. Although environmental issues need to be considered in relation to whole feedstock chains, in principle they revolve around both feedstock production and bioenergy production (Rowe et al. 2013). More emphasis is given to feedstock production here. For impacts associated with conversion see Chapter 12, this volume.

The environmental effects of industrial plants will depend upon the technologies used for feedstock processing, energy conversion and waste handling (Chapter 18, this volume), and on whether the infrastructure needed (buildings, transport, etc.) already exists. The environmental implications of feedstock production will depend on whether there is use of existing resources (e.g. forests, crops and residues), expansion of land under forests, or crops that are already widely grown (e.g. sugarcane, maize, oil palm, eucalypt), or whether there is planting of crops that have not previously been grown extensively (e.g. perennial energy grasses, fast growing trees, Jatropha) (Chapters 10 and 11, this volume).

As discussed in Section 5.2.3, whilst the initial change will occur in a specific location (e.g. a plantation or field, or use of a site for an industrial plant), environmental effects need to be considered at appropriate scales (Chapter 12, this volume). Water, for example should be considered with respect to whole catchments (see Section 5.3.2) whilst biodiversity needs to be considered in the clear understanding that spatial ranges for foraging, dispersal and reproduction will be species-dependent and potentially far-ranging (see Section 5.3.1 and Chapter 16, this volume).

Technology options for sustainable bioenergy will differ depending on context. This includes both choice of feedstock chain and scale of adoption. Smaller scale adoption (such as for domestic heat) will normally result in much lower and even negligible impacts compared with large-scale adoption (such as for industrial power). Even at the large scale, negative impacts can be minimized if conversion of extensive and continuous land areas to bioenergy cropping is avoided and more dispersed introduction encouraged, resulting in diversified landscapes. Such landscapes would have multifunctional uses that are more in keeping with the existing ecosystem (Section 5.2.3).

To minimize negative impacts, cropping systems should be used that are known to be suitably adapted through breeding and appropriately scaled field trials in multiple environments. Use of bioenergy crops that have not been previously subjected to appropriate breeding and field testing should be discouraged, as this can lead to substantive failures that set the industry back and result in lost confidence in both the industrial and agricultural sectors (Section 5.3.3). Mismatch of crop with environment can lead to unwanted environmental consequences (e.g. invasion, excessive water use) or complete crop failure as plants succumb to local environmental stresses for which they lack tolerance. Sufficient research and development time should be supported to allow breeding and field trials of those bioenergy crops recently identified as potentially important (Chapter 10, this volume), so that informed decisions can be made about optimal siting, infrastructure needs, and economic considerations.

5.3.1 Biodiversity Related Impacts

Although any form of LUC is considered as a potential threat to biodiversity, the extremely rapid growth and the anticipated upward trajectory of the biofuels industry and consequent biodiversity losses is particularly relevant in Southeast Asia, Africa and Amazon region in South America. This, in turn, was considered to negatively impact on ecosystem services and contribute to an increase rather than decrease in GHGs and global warming. However, these concerns are not supported by recent research. Life cycle analyses of key biofuels feedstocks indicate that they significantly reduce GHGs; that biofuel production in Brazil does not threaten Amazonian rain forests; forests (Horta Nogueira and Capaz 2013); that current and proposed feedstock species do not pose risks of invasiveness; and that ecosystem services can be maintained if appropriate agricultural practices are implemented. Biofuels can contribute to the avoidance of the greatest threat to biodiversity – climate change.

This positive trend in research results should not be taken to mean that bioenergy does not pose any risks for the environment. Three general principles for sustainable biofuels production systems can be recognized (Chapter 16, this volume):

1. *Conservation of priority biodiversity is paramount*. Recent meta-analyses on global trends in species extinction rates point to three key issues of importance to the biofuels industry. First, when it comes to maintaining tropical biodiversity, there is no substitute for primary forests (Gibson et al. 2011). Second, the rapid disruption of tropical forests probably imperils global biodiversity more than any other phenomenon (Laurence et al. 2012). Third, protected areas are the cornerstone of conservation efforts and now cover nearly 13% of the world's land surface, but globally, half the important sites for biodiversity protection remain unprotected (Butchard et al. 2010). Thus, the development of the biofuels industry must take into account the critical vulnerability of tropical ecosystems for the maintenance of the world's diversity of life.
2. *Effects of bioenergy on biodiversity and ecosystem services are site and context specific*. Biodiversity resources are unevenly distributed across the globe. As a consequence, any consideration of the impacts of bioenergy on biodiversity is likely to be biome-, site- and context-specific. Similarly, the agricultural potentials, socio-economic context, technical and scientific capacities and political trajectories of countries vary significantly around the globe. Feedstock selection and bioenergy production guidelines need to be location specific. Existing global and regional information systems makes possible the identification of key biodiversity sites of concern to guide decisions on land use planning.
3. *Management practices in bioenergy production should minimize threats to biodiversity and ecosystem services*. Good practice guidelines, standards and certification systems, technology transfer and capacity development programs are available for sharing between biofuels producer and user countries. These should optimize bioenergy productivity while minimizing threats to natural capital. The breeding, testing and use of selected feedstocks for environmentally safe, economically profitable and socially acceptable use in degraded lands and areas of marginal agricultural productivity should enjoy priority instead of the expansion of biofuels production over non-cultivated lands.

Advances towards more sustainable bioenergy production systems will benefit from a systems perspective, recognizing the spatial heterogeneity of landscapes, ecosystems and species, the temporal dynamics of seasonality in animal breeding and migration behavior, and landscape level processes dependent on catchment connectivity, fluxes in water-yield and nutrient cycling. Agricultural practices that incorporate mosaics of natural habitats, pastoral lands, croplands and forestry plantations will optimize the maintenance of biodiversity and ecosystem processes while ensuring sustainable production, resilience to uncertain future changes, and preservation of cultural values in the living landscape (Herrero et al. 2010; Vilela et al. 2011). Mixed systems also bring economic advantages because short cycle crops or livestock are regular source of income. The maintenance of corridors of riverine and wetland ecosystems, forest patches and woodlands should be included in integrated land use planning and zonation based on explicit, recent, spatial information systems of the appropriate scale and policy relevance. Both biophysical and socio-economic data should be incorporated into such information systems, which will need trans-disciplinary approaches to design, collect and use in biofuels production systems.

The adoption of more sustainable agricultural practices entails defining goals for sustainability within the particular context, developing easily measured indicators of sustainability and monitoring them over time, moving toward integrated agricultural systems, and offering incentives or imposing regulations to affect behavior of land owners. 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 (Verdade et al. 2014b).

5.3.2 Water Supply and Quality Impacts

5.3.2.1 Impacts on Water Resource Abundance

Agriculture is a major user of water and expansion of agriculture can affect water availability for other uses (see Chapter 18, this volume). Additionally, there are specific concerns relating to many bioenergy crops, which are fast growing with a capacity for high biomass yields, and consequently potential "high water users". They can also have deeper root systems and longer growing seasons than arable crops, raising concerns over impacts on water recharge. However, the estimates for water use in bioenergy production are highly variable. Processing of biomass to biofuel typically requires one to six liters of water per liter of fuel (Chapter 12, this volume). The water requirements for biomass production vary significantly by crop, cultivation practice and location, and estimates of the water requirements due to methodology differences. Several hundred to several thousand liters of water per liter biofuel can be consumed in natural evapotranspiration of rain-fed crops and is included as water loss in many estimates, rather than an ecosystem service. Competition for water will occur in water-limited areas and it is in such areas of production that bioenergy feedstocks need to be carefully managed. Climate change also needs to be taken into consideration as this may change the distribution of water availability in both space and time.

Most crop models indicate that the available water content of the soil is one of the most critical factors limiting yield, alongside day length and temperature. The soil available water content depends on both soil type and climate. Sandy soils have limited water-holding capacity (both water and nutrients drain away), whilst clay soils may hold too much water resulting in limited oxygen for root growth. To avoid excessive run-off, use of soil maps is essential (see also Section 5.3.3).

The evaluation of bioenergy systems with respect to reference systems is not well developed. The reliance on water footprints obscures complete impact analysis, discounting local effects. The use of water use efficiency (WUE) concept, which refers to the use of water in relation to biomass or bioenergy produced, can be misleading and is not as informative as the total water budget, which considers water used throughout the season. Important considerations with respect to different cropping systems, in addition to WUE, include canopy architecture, length of growing season, canopy duration, rainfall interception by the canopy, rooting depth and litter/residue coverage. Thus, a perennial with high WUE may start using water earlier than annual crops and continue using water for longer. Moreover, if the plant retains leaves after senescence, long into the winter, there will be a degree of rainfall interception by the leaves.

Through good cooperation with breeders and proper landscape-level planning, optimal crops can be selected for different environmental conditions so that negative water impacts are minimized, particularly where water availability is of concern. For example, plants such as short rotation coppice (SRC) willows can be used to mitigate against water-related environmental problems, such as flooding, excess nutrient run-off, and wastewater treatment (Mirck et al. 2005). Growing SRC willow in this way is attractive to farmers as the added value that the phytoremediation confers on the energy produced has the potential to improve the economic sustainability of the crop (Rosenqvist and Dawson 2005). Such environmental applications have become increasingly important to meet the requirements for improved organic waste handling and for operational tools aimed at water protection, such as the water framework directive of the EU. As climate change will result in exacerbation of many environmental issues continued crop breeding of plants adapted to water-limited and water-excess environments is essential.

In seasonally water-limited areas, it is impossible to rule out the unsustainable use for water in any agricultural or silvicultural endeavor under current policy regimes in most nations. Although there is no inherent need for bioenergy feedstocks to use irrigation, the growth of bioenergy feedstocks is an economic activity that occurs in the context of agricultural and silvicultural production, and, in some areas, managed production of plant materials for a variety of uses includes irrigation. Sometimes, supplementary irrigation in rain fed areas can significantly increase biomass yield (Gava et al. 2011) with little additional water use. Unfortunately, irrigation can involve the unsustainable use of water resources. Since this can present ethical problems related to water security, water withdrawals (both quantity and timing) should be carefully considered in context of watershed needs, vulnerability, and resiliency. Use of drought-tolerant plants, plants adapted to regional seasonal water constraints, and proper management of water transfers and groundwater recharge can mitigate water stress impacts.

Water requirements for biofuel processing continue to improve. Water use per ton of feedstock has decreased dramatically for both corn and sugarcane ethanol (Januzzi et al. 2012). However, water demand by new or expanded facilities can still be problematic in water stressed regions. Technological improvements in water recovery and recycling have progressed to the point that some facilities are able to use municipal wastewater and some have achieved closed loop recycle.

To determine whether growing and processing bioenergy feedstocks impacts on water availability for other uses requires a complete understanding of the water balance at the watershed and/or basin level. This means a full understanding of the land cover-soil-atmosphere feedbacks on the hydrologic cycle in the context of all human uses and ecosystem functions (Chapter 18, this volume). Determining “competition” requires a common understanding of “acceptable limits” to change in the hydrologic system components and requires agreement on metrics, methodology, and ethical values, including social, economic, and environmental sustainability criteria.

5.3.2.2 Impacts on Water Quality

As mentioned above, some bioenergy crops have a unique advantage of being able to take up excess nutrients and even pollutants such as heavy metals. However, the expansion of bioenergy production provides both an opportunity to improve water quality and the potential to decrease it. The effects will depend entirely on management choices including the fit of the feedstock to the local watershed and the methods used to establish, maintain, and harvest such feedstocks. The negative effects of agriculture (tilling, the use of pesticides and herbicides, and overuse of synthetic fertilizers) and industrial processing (discharge of chemicals) on surface and ground water are well documented (Liu et al. 2012; MacDonald et al. 2011; Sutton et al. 2013). However, there are improved wastewater management, agronomic practices, and novel bioenergy feedstocks that can diminish or eliminate many of these impacts (Fixen 2009; IFA 2009; Neary and Koestner 2012; Snyder et al. 2009). When combined at the landscape level, these new practices can increase water quality in some watersheds.

Nutrient runoff and erosion remain concerns for sustainable bioenergy production. While there has been some progress in management practices for both corn and sugarcane ethanol production systems, some watersheds continue to see high nutrient loads, including no-till and green harvest for sugarcane. The use of riparian buffer strips to capture nutrients from field run-off has increased and offers an opportunity for next-generation perennial crops and woody biomass to improve water quality. Perennial systems are already being deployed to control runoff and erosion (see Box 5.1 and Chapter 18, this volume).

Bioenergy conversion processes have non-negligible impacts on water quality; however, these impacts are similar to activities such as electricity and beverage alcohol production. Stillage from biofuel production represents both a problem and an opportunity. Several companies have developed processes that treat and recycle water from stillage within the facility (Mutton et al. 2010). Nutrients can be recovered directly, as is the common case of vinasse fertirrigation in Brazil, (Magalhães et al. 2012), or following treatment by anaerobic digestion or emerging technologies such as hydrothermal liquefaction. While biogas recovery from stillage is becoming more common in refineries in the U.S., nutrient recovery from the process has not been fully embraced.

Bioenergy can offer substantial solutions to remediation of wastewater and waste products from other activities. Generation of biogas from food waste, animal manure, and municipal wastewater not only addresses discharge of organic material into surface waters and reduces landfill, it can displace fossil methane use contributing to substantial GHG reductions. New data on the use of saline-tolerant lignocellulosic feedstocks that can remediate some wastewater streams provides strong evidence for substantial new landscape level optimization opportunities.

5.3.2.3 Selecting Watershed Appropriate Bioenergy Systems

The best approach to avoiding unwanted effects on watersheds is to appropriately match feedstocks and conversion systems to individual watershed requirements. Matching growing season to patterns of soil moisture availability, selecting for appropriate water use efficiency and tolerance to flooding and drought can alleviate stress in watersheds while improving productive capacity.

Climate change presents a special challenge and highlights the needs for a wide suite of resilient bioenergy feedstocks and appropriately adaptable conversion solutions. Government policy has an important role in incentivizing integrated sustainable solutions that fully consider effects on water resources. Policy regulating water withdrawal and water quality continues to evolve in both forest management and agricultural contexts in many countries; however, it is still considered largely insufficient for long-term sustainability goals. While bioenergy offers an opportunity to re-examine water policy, the dialogue should not be restricted to bioenergy only.

5.3.3 Soil Quality and Nutrient Cycling Impacts

The preservation of the soil chemical, physical and biological characteristics associated with soil quality is essential for long term productivity for different purposes, including food and bioenergy (Chapter 18, this volume). The exploitation of soils beyond their ecosystem capacity may jeopardize soil quality. Erosion, nutrient impoverishment, soil compaction, and reduction of microbiological activity or biodiversity may cause land degradation and compromise important soil resources. Agriculture and biomass production for bioenergy can be the cause of downgrading soils but also can help to protect or recuperate soil quality.

Soil erosion is a major source of land degradation. Over cultivation and excessive export of plant material can have detrimental effects on soil quality (Zuazo and Pleguezuelo 2008), especially in marginal lands and high sloping areas. However, plant cover and roots are important means of controlling or reducing soil erosion (Zuazo and Pleguezuelo 2008) and cultivation of grasses or perennial crops for bioenergy is a way of helping to preserve soils (Anderson-Teixeira et al. 2013; Khanal et al. 2013) and can be part of a sustainable land use system (Dimitriou et al. 2011).

Despite the well-known benefits of forest and perennial plant cover to soil preservation, the intense mechanical operations associated with plant and harvesting usually cause soil compaction and disrupt soil aggregation and structure (Bottinelli et al. 2014; Goutal et al. 2012; Goutal et al. 2013), which increases the risks of erosion, negatively affects plant rooting and water retention and infiltration. Therefore, proper management of forest resources for bioenergy is necessary for sustainable production (Bellassen and Luyssaert 2014; Egnel and Björheden 2013 Holub et al. 2013; Kleibl et al. 2014).

In any cropping system, mining nutrients from the soil with inadequate or insufficient fertilization, removing excessive amounts of plant material or improper disposing of residues may reduce soil fertility, cause loss of organic matter and predispose soil to erosion (Lal 2009). However, properly managed bioenergy crops, particularly perennial systems which recycle the majority of their nutrients and do not require annual cultivation of the soil, can help to maintain soil quality and lead to carbon accumulation, thus both improving soil quality and mitigating CO_2 emissions (Anderson-Teixeira et al. 2013; Figueiredo and La Scala Jr. 2011; Segnini et al. 2013).

Excessive use of nutrients may cause environmental problems if they contaminate ground water and surface water bodies. In addition, the manufacture and use of nitrogenous (N) fertilizers are important components of the GHG and energy balances of agriculture (Boddey et al. 2008; Lisboa et al. 2011). Those bioenergy crops that efficiently use N fertilizers usually have a better carbon footprint. There are several crops employed in biofuel production that present such characteristics. For example, sugarcane can have dry matter yields above 30 tha^{-1} with only 30 to 120 $kgha^{-1}$ of N fertilizers (Cantarella and Rossetto 2012); eucalyptus and other woody plants also have almost similar performance. Miscanthus, depending on when it is harvested, translocates most nutrients from the above-ground plant parts to the roots and rhizomes before harvest, thus preventing excessive removal of N from the field and reducing the need for fertilization (Chapter 11 and 18, this volume).

However, for some agricultural systems, especially for annual plants, crop intensification may be an option to enhance biomass production (Snyder et al. 2009). Although this usually means more agrochemical inputs, the overall effect may be positive in the sense that high plant yields allow for the optimization of other resources such as soil, water and solar energy. In addition, high yields may mean less land demand, thus helping to preserve other land uses, including natural ecosystems. The adoption of best management practices is important in crop intensification because it tends to minimize risks of excessive or inadequate use of inputs (Mead and Smith 2012; Snyder et al. 2009).

The high biomass production of some crop systems dedicated to bioenergy can also increase soil organic matter, which improves soil quality and may also mitigate CO_2 emission. Usually, the replacement of row crops with perennial plants or the cultivation of degraded land with crops for bioenergy enhances soil carbon content. Several studies have demonstrated that sugarcane harvested without burning causes a significant increase in soil carbon (Bordonal et al. 2012; Galdos et al. 2010; Pinheiro et al. 2010; Thorburn et al. 2012). On the other hand, corn stover, wheat straw and sugarcane trash, among others, are increasingly important feedstocks for bioenergy and the industry wants to collect as much as possible. However, excessive removal of plant material from the field may jeopardize long-term soil quality, causing economic and environmental losses. The amounts of plant residues that have to be preserved are site-specific (Cantarella et al. 2013; Gollany et al. 2011; Hassuani et al. 2005; Karlen et al. 2011; Leal et al. 2013; Tarkalson et al. 2011) and regional data are important to guide farming practices.

Bioenergy crops offer good opportunities for nutrient recycling, thus improving the overall sustainability of the system. Biofuels such as ethanol and biodiesel are composed of carbon (C), oxygen (O), and hydrogen (H). Therefore, the mineral nutrients contained in the biomass feedstock are not exported with the fuel and theoretically may be recycled back to the fields. Typically, sugarcane mills in Brazil return residues such as ash, filter cake and vinasse of the ethanol production to the field in various ways, which allows reduced fertilizer application. The vertical integration of the sugarcane industry in Brazil, in which large areas of field crops belong to the mill, makes the distribution of the residues easier because of shorter distances, rights of access of pipelines and trucks, etc. (Magalhães et al. 2012). But residues are bulky materials with low nutrient concentrations and unit value. Industries with other scales, structures and feedstock supply systems may not share these favorable conditions and may require different solutions (Mutton et al. 2010).

Some residues such as vinasse, a by-product of ethanol production, deserve attention. Large amounts of vinasse are produced in the ethanol industry (10 to 13 L/L ethanol, in the case of sugarcane). If dumped in water bodies it will cause environmental problems because of its high biological oxygen demand. Excessive application to the soil also has detrimental effects. However, when adequately returned to soil, vinasse acts as a source of readily mineralizable organic carbon and nutrients, reducing the need for fertilizers.

The bulky nature of residues imposes limits to recycling. In Brazil, it is usually economically feasible to apply fresh vinasse up to 25 to 30 km from the processing plant, through trucks, pipelines and other means. However, the increasing size of mills and continuous application of vinasse in soils close to the plant make it necessary to carry the residue longer distances. Concentrating vinasse by removing water and biodigestion are devised options. The latter generates biogas, an extra source of energy. However, reducing costs for these solutions is a challenge. Vinasse from second generation biofuels will have other properties, such as lower nutrient levels, and may need different solutions. Proper legislation is important in order to stimulate the adequate utilization of residues (Box 5.1).

Box 5.1. Sugarcane vinasse disposal in Brazil (Mutton et al. 2010)

In the past vinasse was considered a nuisance in the ethanol industry and many times it was just dumped in rivers at a time when environmental concerns were less important. Successive rules and regulations changed behaviors and perceptions and today vinasse is seen as a valuable source of nutrients to be recycled:

1978: Directive 323 (Ministry of Internal Affairs): vinasse disposal in water bodies is forbidden. Project for vinasse treatment and use is required.

1980: Directive 158 (Ministry of Internal Affairs): Extend directive 323 to encompass other residual waters and distillery effluents.

1984: Resolution 002 (Conama): stricter projects to control pollution from effluents of ethanol distilleries.

1986: Resolution 001 (Conama): turn mandatory the projects of Environmental Impact Assessment and Environmental Impact Report for approval of new distilleries or expansion of existing ones.

1988: Establish that liquid, solid or gaseous residues from agriculture and other sources shall be disposed of in a way that will not pollute underground water. Additional regulation in 1991 (Decree 32,995).

1991: Law 7.641: industrial effluents of organic origin used for irrigation or fertigation must have evidenced biodegradability in soil and be free of organo-metallic compounds.

2005: Technical Norm P4.231 (Cetesb, São Paulo State): further control of vinasse use in agricultural soils. Establishes detailed rules for the rate of vinasse application based on vinasse and soil composition so that exchangeable K in the 0-0.8 m soil layer does not exceed 5% of the cation exchange capacity or that the K load is compatible with amounts extracted by sugarcane.

Before the technical Norm P4.231 was applied, “sacrifice areas” where overdose of vinasse was applied were common. In some soils, plants could undergo salt stress because of excess K and other nutrients, a problem that is prevented by present legislation.

Plant species and varieties have limitations as far as the soils and climates for which they were bred or selected. Insufficiently tested crops may present poor results and jeopardize bioenergy promoting programs. Some crops were promoted for bioenergy production before they were at a stage where they could be widely cultivated without risk. For instance, Jatropha (*Jatropha curcas*), which is a perennial crop used to produce oil, has been promoted as a drought tolerant oil crop capable of growing in marginal, low fertility soils and yet capable of yielding high amounts of seed and oil. Jatropha has been little studied but its cultivation has been stimulated in many regions. In 2008 an estimated 900 thousand hectares of Jatropha was cultivated worldwide, most of it in Asia (Kant and Wu 2011). Reports of failure to meet expectations are common. In India the Government incentivized small farmers to plant Jatropha but after a short time, most farmers discontinued cultivations because of unsatisfactory results (Openshaw 2000; Kant and Wu 2011; Kumar et al. 2012). Similar unfavorable results were reported in Asia and Africa (Kant and Wu 2011; Mudonderi 2012). In Australia, Jatropha has been declared a noxious weed, because of its propensity to produce masses of seed that can quickly establish new plants in low rainfall areas. Thus, Jatropha, as is the case for many other species, may have potential to become a bioenergy crop but much agronomic work is still necessary before it can be widely recommended.

Key Messages:

- Bioenery production can have either positive or negative impacts on biodiversity, dependent on scale, practice and site conditions.
- Water impact assessment at all levels of the bioenergy value chain should be transparent, with broad stakeholder engagement and included in sustainable certification schemes, using metrics which are consistent with other agricultural and silvicultural activities.
- The use of water footprints and the reliance on WUE, or productive water use, in lieu of proper ecosystem impact analysis should be avoided. Such metrics, while convenient and intuitive, can be highly misleading and irrelevant to achieving sustainable production and environmental security.
- Wherever possible, full water budget analysis should be conducted for the bioenergy system and an appropriate reference state (e.g., other crop, native ecosystem). Water impact assessments for bioenergy must account for changes at the watershed and basin level due to other human activities, climate change, and evolving ecosystem needs.
- The use of irrigation for bioenergy must be subject to a high level of scrutiny. Irrigation of energy crops may need to be avoided, even in instances where it represents the most productive use of available water in terms of output or income per unit water, if there is a risk for serious impacts on local livelihoods and food security. However, there may be some conditions under which irrigation can be compatible with sustaining ecosystem services. Caution, periodic evaluation, and appropriate water pricing and allocation systems can help avoid unwanted effects in water-stressed regions.
- The high nitrogen use efficiency of many bioenergy crops means that they have a better carbon footprint than arable crops. Once perennial cropping systems are established the ground is not cultivated annually and both soil quality and soil carbon stocks can be increased.

- Bioenergy crops also may offer good opportunities for nutrient recycling and strategic planting can help alleviate environmental problems associated with intensive agriculture, such as nutrient run off.

5.4 Climate Security

In this section bioenergy technologies and bioenergy mitigation options, and their potential in climate stabilization are discussed. Modern bioenergy is a highly versatile energy in solid, liquid, and gaseous form for a range of applications including cooking, heating, and transport. It can also be used for electricity generation. Bioenergy can bring about sustainable development by providing energy for many services, promoting particularly rural development, self-reliance, energy security, and finally mitigating climate change. Bioenergy is receiving increasing attention as an opportunity for addressing climate change, as indicated by recent major reports: IPCC – SRREN of 2011 (IPCC 2011), Global Energy Assessment of 2012 (GEA 2012) and the latest IPCC – Assessment Report 5 of 2014 (IPCC 2014a). According to IPCC (2014a), bioenergy deployment offers significant potential for climate change mitigation but it depends on i) Technology used; ii) Land category used and carbon stock on land (Forest land, grassland, cropland or marginal land), iii) Scale of production and iv) Feedstock used and source of feedstock.

Bioenergy conversion technologies: A large number of bioenergy conversion technologies are available to transform biomass into heat, power, liquid and gaseous fuels for application in residential, industrial, transport and power generation. Detailed coverage of the bioenergy conversion technologies is provided in Chum et al. (2011), GEA (2012) and Smith et al. (2014). Some of the recent large scale applications include; increased use of biomass – hybrid fuel systems, direct bio - power generation, combined heat and power, biofuels from multiple sources along with small scale applications of bioenergy technologies such as improved cook stoves, biogas and decentralized biomass power systems in rural areas. Technologies to produce cellulosic, Fisher – Tropsch, algae based and other advanced biofuels are in development and may become available for commercial use in future. Bio- methane from biogas or landfill gas can also be used in natural gas vehicles. BECCS (Bioenergy and Carbon Capture and Storage) is one of the important new opportunities which is capable of not only being a carbon neutral technology but also potentially lead to net removal of CO_2 from the atmosphere. BECCS offers potential for large-scale net negative GHG emissions, but the technology is still in development phase and many technical challenges remain.

Net GHG mitigation benefit from bioenergy technologies: The net GHG or mitigation potential of different bio-energy crops and technologies is highly contentious (Chapter 17, this volume). The IPCC- SRREN report (Chum et al. 2011) provides the end-use lifecycle GHG emissions for corn, oil crops, crop residues, sugarcane, palm oil and grasses, etc. Chum et al. (2011) concluded that the direct CO_2 emissions per GJ (excluding Land Use Change) are lower for most bioenergy technologies compared to electricity from coal and oil. Life-cycle GHG emissions for biogas and biomass are lower than fossil fuel options for electricity and heat generation. Similarly, direct CO_2 emissions for sugarcane, sugar beet, corn and wheat and lignocelluloses for ethanol production are lower compared to gasoline (Horta Nogueira and Capaz 2013; Walter et al. 2014; Wicke et al. 2012).

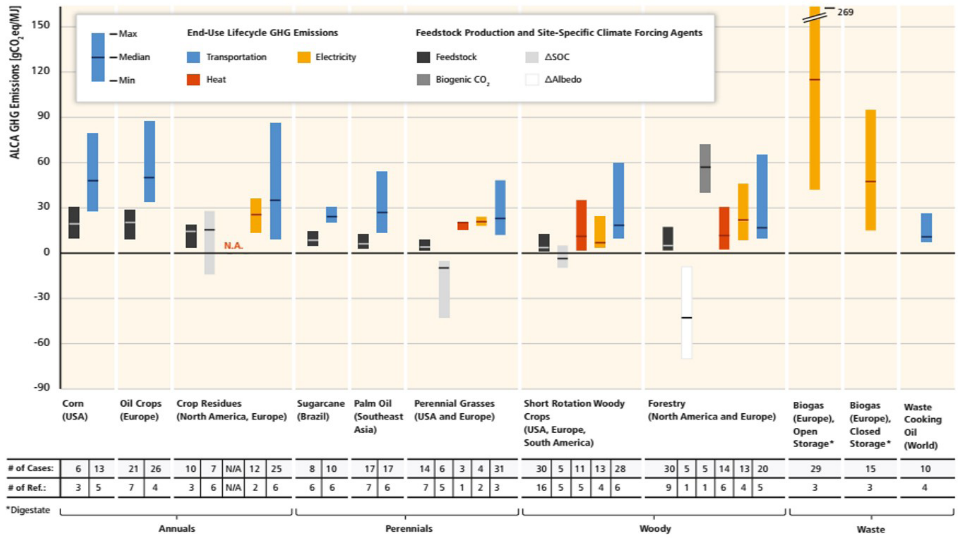


Figure 5.4. Direct CO_2eq (GWP100) emissions from the process chain or land-use disturbances of major bioenergy product systems, not including impacts from LUC (Smith et al. 2014).

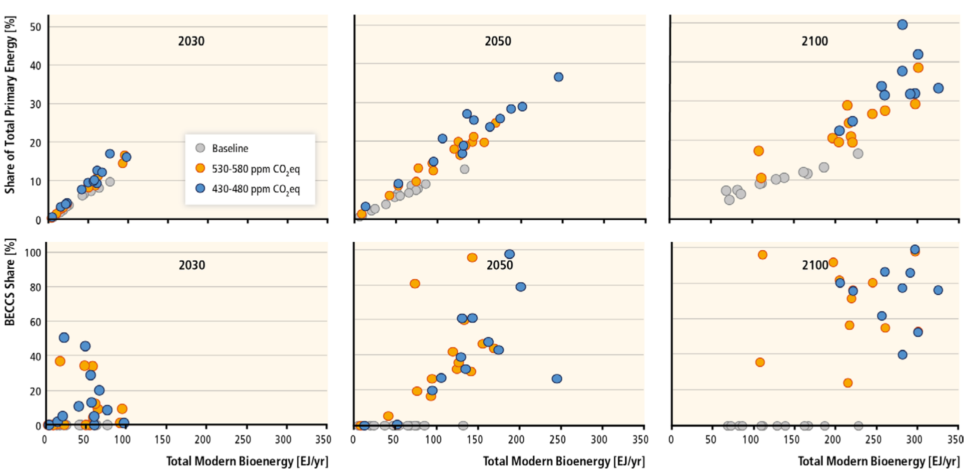


Figure 5.5. Annual global modern biomass primary energy supply and bioenergy share of total primary energy supply (top panels) and BECCS share of modern bioenergy (bottom panels) in baseline, 550 ppm and 450 ppm CO2eq scenarios in 2030, 2050, and 2100. Source: Rose et al. (2014). Notes: All scenarios shown assume idealized implementation. Results for 15 models shown (3 models project to only 2050). Also, some models do not include BECCS technologies and some no more than biopower options.

The IPCC – 2014 report (Smith et al. 2014) presents a comprehensive assessment of a range of lifecycle global direct climate impacts (in g CO_2 equivalents per MJ, after characterization with GWP (time horizon=100 years) attributed to major global bioenergy products reported in the peer-reviewed literature. Results are broadly comparable to those by Chum et al. (2011), who reported negative emissions, resulting from crediting emission reduction due to substitution effects. The results presented in Figure 5.4 do not allocate credits to feedstocks to avoid double accounting.

The assessment shows diverse values depending on the methods and the conditions used in the studies, site-specific effects, and management techniques. It can be observed that fuels from sugarcane, perennial grasses, crop residues, and waste cooking oil provide higher net GHG benefits than other fuels (LUC emissions can still be relevant). Another important result is that albedo effects and site-specific CO_2 fluxes are highly variable for different forest systems and environmental conditions and determine the total climate forcing of bioenergy from forestry. Thus, for the majority of bioenergy crops involving no LUC from high carbon density lands, net GHG benefits are likely.

Bioenergy and mitigation potential: Diverse global estimates of the potential of bioenergy are available. Chum et al. 2011 estimated a technical potential of 300 -500 EJ by 2020 and 2050, respectively and a deployment potential of 100 – 300 EJ globally by 2050. The Global Energy Assessment provides a potential estimate of 160-270 EJ/ year (GEA 2012). However, Smith et al. (2014), suggest a technical bioenergy potential of about 100 EJ possibly going up to 300 EJ.

Rose et al. (2014) project increasing deployment of, and dependence on, bioenergy especially with high climate change mitigation goals. Share of bioenergy in total regional electricity and liquid fuels is projected to be up to 35% and 75%, respectively, by 2050. The availability of BECCS is critical for large-scale deployment of bioenergy. Share of modern bioenergy under Baseline, 430-580 ppm CO_2 eq and 530-580 ppm CO_2 eq is presented in Figure 5.5. The share of modern bioenergy is projected to increase even under Baseline scenario by 2050 and 2100. Under stringent mitigation scenarios, the share of modern bioenergy could be in the range of 20-30 % by 2050 and going up to 30-50% by 2100 of Total Primary Energy for majority of model projections. In scenarios that include BECCS technologies, BECCS is deployed in greater magnitude and even earlier in time and potentially representing 100% of bioenergy in 2050 (Figure 5.5). Rose et al. (2014) further project that bulk of biomass supply for bioenergy and bioenergy consumption will occur in developing and transitional economies. Thus developing countries will play a critical role in promoting bioenergy technologies in the coming decades.

According to the IPCC (2014b), BECCS is critical to scenarios for the stabilization of global warming at <2°C; however, the potential and costs of BECCS are highly uncertain with some integrated assessment models being more optimistic than bottom-up studies.

Apart from large-scale commercial and high technology-based modern bioenergy applications, Smith et al. (2014) also highlight the importance of bioenergy for rural applications and for creating access to modern energy services for the poor. Improved cookstoves, biogas, and decentralized small-scale biomass power could not only improve the quality of life, livelihoods and health of 2.7 billion rural inhabitants, but also reduce GHG emissions.

There are several barriers to large-scale deployment of bioenergy for mitigating climate change. These include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. Sustainability and livelihood concerns might constrain the large-scale deployment of bioenergy production systems. The potential of bioenergy could be adversely impacted by climate change itself. The IPCC (2011) concluded that "the future technical potential of bioenergy can be influenced by climate change through impacts on biomass production such as altered soil conditions, precipitation, crop productivity and other factors. The overall impact of mean temperature change of >2^0 C on the technical potential of bioenergy is expected to be relatively small on a global scale. However, considerable regional differences could be expected." Porter et al. (2014) also conclude that if climate change detrimentally impacts crop yields, the bioenergy potential may decline and costs may rise because more land will be required for food production. Further, biofuel production could also be adversely impacted by climate change, constraining shift to low carbon fuels (de Lucena et al. 2009).

According to IPCC (2014a) achieving high bioenergy deployment levels for mitigating climate change would require, "extensive use of agricultural residues and second-generation biofuels to mitigate adverse impacts on land use and food production, and the co-processing of biomass with coal or natural gas with CCS to produce low net GHG-emitting transportation fuels and/or electricity". Land demand for bioenergy, which is one of the major concerns and a barrier, depends on: (1) the share of bioenergy derived from wastes and residues; (2) the extent to which bioenergy production can be integrated with food and fiber production, and conservation to minimize land use competition; (3) the extent to which bioenergy can be grown on areas with little current production; and (4) the quantity of dedicated energy crops and their yields. The GEA (2012) concludes that extensive use of agricultural residues and second-generation bioenergy is necessary to mitigate adverse impacts on land use and food production, and the co-processing of biomass with coal or natural gas with CCS to make low net GHG-emitting transportation fuels and or electricity.

The IPCC AR-5 approved 'Summary for Policy Makers' (IPCC 2014c) states the following on bioenergy in the context of climate security: "Bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems. Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. The scientific debate about the overall climate impact related to land use competition effects of specific bioenergy pathways remains unresolved. Bioenergy technologies are diverse and span a wide range of options and technology pathways. Evidence suggests that options with low lifecycle emissions (e.g., sugarcane, Miscanthus, fast growing tree species, and sustainable use of biomass residues), some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated ‘biomass-to-bioenergy systems’, and sustainable land-use management and governance. As mentioned above, in some regions, specific bioenergy options, could reduce GHG emissions and improve livelihoods and health in the context of sustainable development”.

Key Messages:

- Bioenergy is critical for climate security and energy security. Bioenergy, particularly BECCS is critical for mitigation of climate change, especially for low climate stabilization scenarios (at <2^{o}C increase in global temperatures).
- The IPCC’s Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC 2011) suggested a sustainable bioenergy potential to be between 100-300 EJ by 2050. The GEA (2012) projects a potential of 80-140 EJ by 2050. The IPCC (2014b) suggested a conservative technical potential of 100 EJ and possibly going up to 300 EJ.
- The share of bioenergy in the global primary energy supply will continue to increase even under Baseline scenario, thus it is necessary to ensure that bioenergy is produced sustainably with no or minimal adverse environmental and socio - economic impacts.
- The negative implications of land deployment for bioenergy can be avoided or minimized by: i) production and utilization of co-products, ii) increasing the share of bioenergy derived from forest, plantation, and crop wastes and residues, iii) integrating bioenergy production with crop production systems and in landscape planning, iv) increasing crop land productivity especially in developing countries, freeing up crop land for bioenergy crops, and v) deploying marginal or degraded lands.
- Achieving high level of deployment of bioenergy requires extensive use of agricultural residues and second-generation biofuels to mitigate the adverse impacts and land use and food production, and co-processing of biomass with coal and biogas with CCS to produce low net GHG emitting transportation fuels and/or electricity.
- Modern bioenergy deployment for meeting rural energy needs (cooking, lighting and mechanical applications) not only creates energy access for rural communities and promotes quality of life, but also reduces GHG emissions, with no or minimal environmental impacts.

5.5 Governance and Policy Guidelines

This Section considers governance perspectives relating to sustainable bioenergy development and pays particular attention to the agriculture-forestry nexus where national and regional integration is required.

5.5.1 Underlying Causes of Deforestation

General underlying drivers of forestland conversion and unsustainable use of forest resources include undervaluation of forest goods and services, poor governance, institutional failures such as inadequate law enforcement, low financial returns on forest use compared to other uses, lack of local user rights and inadequate land tenure arrangements as well as other disincentives to sustainable forest and agricultural resource use. From another governance perspective, there are also negative social impacts of uncontrolled agricultural expansion into forests. Medium- and large-scale forest plantations may stimulate land concentration, which may displace local people and threaten their livelihoods (Pacheco et al. 2012). Furthermore, the evolving, and often growing, global markets for forest products, including feedstock, and the relocation of processing capacity create increased local deforestation in producing countries, *i.e.*, consuming countries are increasing their imports and thus "exporting deforestation" as production of raw material shifts mostly to Africa and South America.

To ensure bioenergy is only developed in sustainable ways, it is important to recognize the general drivers of forestland conversion and put into place governance policies that are designed to avoid unsustainable exploitation of natural forests for biofuels. The linkages between agriculture and mitigating GHG emissions, forestry and bioenergy need to be considered from different yet interdependent governance angles: (a) agriculture and forestry are major sources of GHG emissions, (b) horizontal expansion of agriculture is mostly at the expense of clearing forests, although other alternatives for increasing agriculture production in the tropics exist (Martha Jr. et al. 2012; Pereira et al. 2012); (c) competition among food, fodder, fiber and fuel production often occurs on the same landscape, and (d) socio-economic factors, especially those related to land tenure and rights of indigenous peoples.

The need for a global response to the challenges of climate change, deforestation, biodiversity and food security has already been recognized in international commitments and conventions. The Brazilian Forest Code is a good example of conservative law applied to agricultural landscapes since early last century. Although it lost part of its contents for political pressures recently, it still assures that agricultural landscapes have the mission to keep part - varying according to the biome - of the native vegetation. Although there is no intergovernmental governance mechanism to deal with bioenergy or biofuels policies, several existing treaties and initiatives that touch upon issues related to forests, food security, energy, environment and trade are relevant to bioenergy. In building an international consensus on sustainable forest management and food security-compliant biofuels, the experiences of the existing conventions such as UNFCCC, CBD and CCD as well as the Sustainable Development Goals may prove useful.

5.5.2 Guidelines for Social and Environmental Factors – Biodiversity, Water

The existing environmental impacts caused by LUC can be mitigated by local restrictions in which limits for the expansion of biofuel crops over previously uncultivated ecosystems are established by the producing and/or the importing country. The mitigation of the usual agricultural impacts of biofuel expansions over marginal or annual crops should be based on the maintenance of connectivity among remnants of native vegetation at the landscape level and on the use of wildlife friendly agricultural practices. All these approaches are complementary in terms of public policy (Soderberg and Eckberg 2013) and national and international market (Palmujoki 2009). However, in order to be effective such strategies should include long-term monitoring programs of such environmental impacts (either positive or negative) including water, soil and biodiversity (Verdade et al. 2014a).

Key Messages:

- Climate change-forestry-agriculture-bioenergy nexus are best discussed at intra- and inter-governmental levels in order to develop and implement appropriate governance policies. Sustainable biofuel production must be part of sustainable forest management and sustainable agriculture (food security) where both are needed as integral components of land use with clear understanding of the uniquely complex set of environmental, economic and social issues involved.
- Identifying which eco-regions and countries have the greatest opportunity to use which raw material as a source for bioenergy along with analyzing the full potential and merits of each biofuel source is highly recommended as an environmental and livelihood issue. For example, the new opportunities associated with bioenergy developments may avail a potential to incorporate smallholders of both forest and agriculture communities into bioenergy production schemes, thereby improving their livelihoods.
- In drawing national and regional integrated forestry, agriculture and bioenergy governance policies it is imperative to address the full valuation of forest goods and services, opportunity costs of forestland conversion and alternative cropping systems law enforcement, institutional capacities, safeguarding local user rights and land tenure arrangements.
- Governance policies for investments related to expansion in bioenergy feedstock production through forest conversion should be clear regarding enforcement and compliance of social safeguards and environmental regulations.

5.6 Conclusions

Bioenergy has a key role to play in environmental and climate security. As for any new development, environmental consequences associated with LUC are inevitable but LUC associated with bioenergy can be positive. Many initial concerns regarding rapid expansion of particularly biofuels for example on biodiversity, and of iLUC, have not been substantiated by recent research, indicating these issues are of much less importance than indicated in the previous SCOPE Report (SCOPE 2009). However, this should not be taken to mean that there are no risks associated with bioenergy development. Governments worldwide can influence the deployment of sustainable bioenergy through the use of appropriate assessment practices, governance and policies. Assessment of environmental impacts should recognize the different attributes (both positive and negative) of different bioenergy cropping systems, particularly with regard to the use of arable (food) crops compared with more favorable perennial bioenergy crops, and must be carried out at appropriate scales (farm, landscape, region, country, global) that recognize that impacts may operate at the ecosystem (e.g.,forests, grassland, arable, coastal) level. New bioenergy croplands should be selected and developed following both Strategic Environmental Assessments (at a regional scale) and Environmental Impact Assessments (at a local and site scale) as these provide baselines for monitoring positive and negative impacts and guide adaptive management strategies. Sustainable bioenergy production should be based on, and support, good governance, strong institutions, best available scientific information, marke based voluntary certification, and access to information about appropriate management strategies that support sustainable resource use and benefit biodiversity. Through these approaches bioenergy can realize its potential for mitigation of the unprecedented environmental and climatic change that challenge the future of humankind.

5.7 Recommendations

1. Within the context of climate change and its potentially devastating consequences, policy-makers and governments around the world now share the responsibility to encourage sustainable bioenergy development.
2. Local and global issues should be distinguished when considering the positive and negative impacts of bioenergy systems. New bioenergy croplands should be selected following both Strategic Environmental Assessments (at regional scale) and Environmental Impact Assessments (at local and site scale) and should recognize the spatial heterogeneity of landscapes, ecosystems and species, and landscape level processes dependent on catchment connectivity, fluxes in water-yield and nutrient cycling.
3. There is a clear need for increased coordination of objectives and planning procedures within governments, as well as between governments and concerned

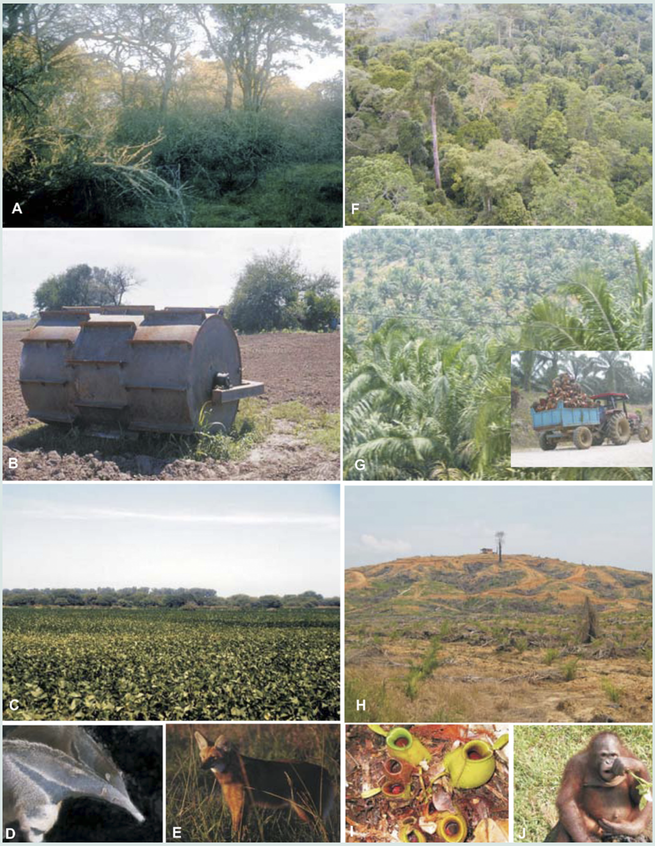
international institutions, NGO's and the private sector. It is particularly important to recognize the interdependencies of forestry and agriculture policies with a view to harmonizing them for the sustainable production and supply of bioenergy.

4. Actions should respond with appropriate land use planning, environmental governance, law enforcement, and strengthening of institutional capacities and the safeguard of local user rights and land tenure arrangements. Incorporation of initiatives such as REDD+ programs and Green Economy into national development strategies will help to strengthen cross-sector forestry and agriculture policies and aligning implementation pertaining to bioenergy.

5. The negative implications of land deployment for bioenergy should be avoided or minimized by i) promoting bioenergy crops with positive attributes with respect to water use, soil impacts and biodiversity; ii) increasing the share of bioenergy derived from wastes and residues; iii) integrating bioenergy production with crop production systems and in landscape planning iv) increasing crop land productivity especially in developing countries, freeing up crop land for bioenergy crops, and v) deploying marginal or degraded lands. Breeding of crops that can maintain productivity on poorer land not suited that is more marginal should also be encouraged. See also Box 5.2.

6. In drawing national and regional integrated forestry, agriculture and bioenergy governance policies, it is imperative to address the full valuation of forest goods and services, opportunity costs of forestland and cropland conversion and alternative cropping systems, law enforcement, institutional capacities, safeguarding local user rights and land tenure arrangements. Governance policies for public and private investments related to expansion in bioenergy feedstock production through natural forests and farmland conversion should be clear regarding enforcement and compliance of social safeguards and environmental regulations.

Box 5.2 A. Lessons Learnt: Bioenergy done wrong

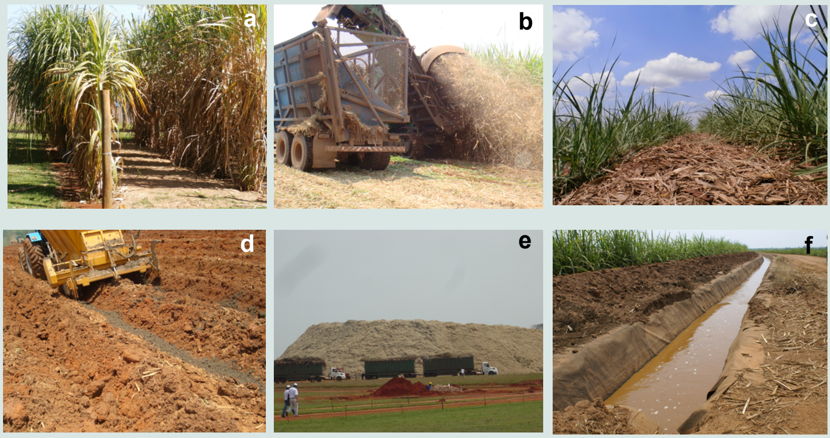


In Argentina and Bolivia, the Chaco thorn forest (A) is being felled at a rate considered among the highest in the world (B), to give way to soybean cultivation (C). In Borneo, the Dypterocarp forest, one of the species-richest in the world (F), is being replaced by oil palm plantations (G). These changes are irreversible for all practical purposes (H). Many animal and plant populations have been dramatically reduced by changing land use patterns, to the point that they could be considered functionally extinct, such as giant anteater in the Chaco plains (D), the maned wolf (E), several species of pitcher plants (I) and and the orangutan (J) in the Bornean rainforest.

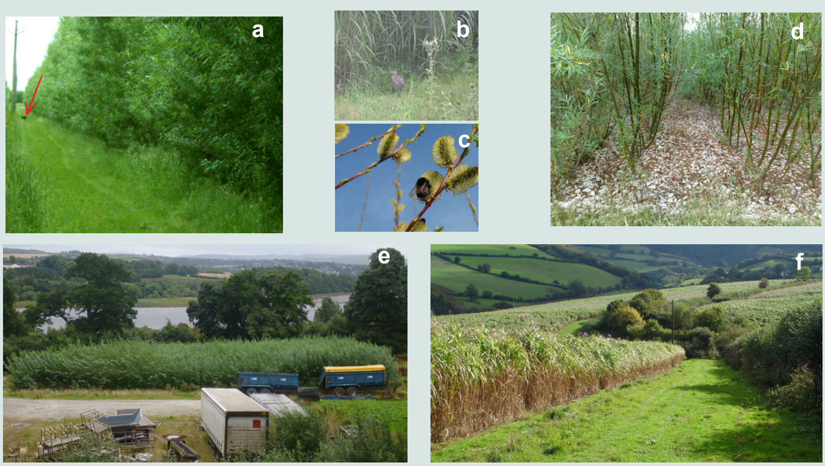
Photos by Sandra Díaz, except (A and C), courtesy by Marcelo R. Zak.

From Citation: Díaz S, Fargione J, Chapin FS III, Tilman D (2006) Biodiversity Loss Threatens Human Well-Being. PLoS Biol 4(8): e277. doi:10.1371/journal.pbio.0040277

Box 5.2 B. Bioenergy done right



Bioenergy done right Sugarcane: (a) Breeding plants with superior traits; (b) Harvesting without burning; (c) Keeping plant residues to protect the soil and recycle nutrients; (d) Recycling industrial residues (vinasse and filter cake) in the field; (e) Bagasse: by product to produce bioelectricity or 2G ethanol; (f) Fertirrigation using vinasse.



Bioenergy done right - Miscanthus and SRC willow: (a-c) Attracting biodiversity: (a) deer (arrow) in willow ride; (b) birdlife on Miscanthus border; (c) bee using early willow pollen source; and (d-f) using marginal land: (d) willow on stony, dryland site; (e) willow alongside river as a riparian filter; (f) Miscanthus in grassland-dominated area.

5.8 The Much Needed Science

- Improved methodologies for the estimating, quantifying, and verifying of LUC;
- Methods for identifying win-win situations as well as trade-offs, e.g. land-sparing pasture intensification with bioenergy crops grown so that overall soil carbon storage and fertility are increased;
- Increased trials of bioenergy crops in environments where bioenergy expansion is anticipated, to provide much needed data on crop performance in target environments before wide spread expansion;
- Breeding of resource-use efficient and “future climate-resilient” bioenergy crops;
- Continued development of integrated, resource-efficient biomass conversion pathways;
- Long-term studies of perennial bioenergy crops and short-rotation forests in relation to ecosystem services, biodiversity, water quality and availability and soil carbon;
- Policy development to encourage sustainable bioenergy development and landscape-level planning.

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