The role of bioenergy in a climate-changing world

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DOI
10.1016/j.envdev.2017.02.008

Publication date
2017

Document Version
Final published version

Published in
Environmental Development

Environmental Development 23 (2017) 57–64

Contents lists available at ScienceDirect

Environmental Development

journal homepage: www.elsevier.com/locate/envdev

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ARTICLE INFO

Keywords:
Bioenergy
Food security
Energy security
Environmental security
Climate Change
Sustainable development
Landscapes

ABSTRACT

Bioenergy has been under intense scrutiny over the last ten years with significant research efforts in many countries taking place to define and measure sustainable practices. We describe here the main challenges and policy issues and provide policy recommendations for scaling up sustainable bioenergy approaches globally. The 2016 Intended Nationally Determined Contributions (INDCs defined under the UN Framework Convention on Climate Change) (UNFCCC) Conference of the Parties (COP21) will not reach global Greenhouse Gas (GHG) emission targets of 2 °C. Sustainable biomass production can make a significant contribution. Substantive evidence exists that many bioenergy cropping systems can bring multiple benefits and off-set environmental problems associated with fossil fuels usage as well as intensive food production and urbanization. We provide evidence that there are many approaches to land use for bioenergy expansion that do not lead to competition for food or other needs. We should focus on how to manage these approaches on a synergistic basis and how to reduce tradeoffs at landscape scales.

Priorities include successful synergies between bioenergy and food security (integrated resource management designed to improve both food security and access to bioenergy), investments in technology, rural extension, and innovations that build capacity and infrastructure, promotion of stable prices to incentivize local production and use of double cropping and flex crops (plants grown for both food and non-food markets) that provide food and energy as well as other services.

The sustainable production of biomass requires appropriate policies to secure long-term support to improve crop productivity and also to ensure environmental as well as economic and social benefits of bioenergy cropping systems. Continuous support for cropping, infrastructure, agricultural management and related policies is needed to foster positive synergies between food crops and bioenergy production.

In comparison to fossil fuels, biofuels have many positive environmental benefits. Potential negative effects caused by land-use change and agriculture intensification can be mitigated by agroecological zoning, best management practices, the use of eco-hydrology and biodiversity-friendly concepts at field, watershed and landscape scales.

Global climate and environmental changes related to the use of fossil fuels and inequitable development make it unethical not to pursue more equitable energy development that includes bioenergy. To achieve sustainable development, competitiveness and costs of bioenergy production need to be addressed in a manner that considers not only economic gains but also development of local knowledge and social and environmental benefits.

1. Introduction

Over the past two years, 137 experts from 24 countries and 82 institutions have collaborated to analyze a range of issues related to the sustainability of bioenergy production and use. The resulting assessment *Bioenergy & Sustainability: Bridging the Gaps* (Souza et al., 2015a) was launched at a symposium at the World Bank on September 28, 2015, in Washington DC, USA. During the symposium, authors highlighted key findings and discussed opportunities and challenges for sustainable energy in developing regions as well as the role of bioenergy in the 2030 and 2050 time horizons. The symposium brought together invited representatives from a range of research institutions, government and non-government agencies and key staff from the World Bank. The report was coordinated by scientists linked to the research programs of the São Paulo Research Foundation (FAPESP) on Bioenergy (BIOEN), Global Climate Change (RPGCC), and

http://dx.doi.org/10.1016/j.envdev.2017.02.008
Received 30 October 2016; Received in revised form 21 February 2017; Accepted 23 February 2017
2211-4645/

Box 1. Some bioenergy policy-relevant issues.

- Is bioenergy really needed, and why?
- Is there enough land to produce bioenergy without jeopardizing food security?
- Can bioenergy be deployed at the scales needed without inducing unintended land-use changes?
- Can we deliver enough biomass, and how?
- Is bioenergy efficient?
- What are the bioenergy impacts for the environment?
- Under what conditions does bioenergy reduce greenhouse gas emissions?
- What happens to food production, biodiversity, water and soils in multi-functional landscapes?
- What evidence is there that sufficient land and resources are available?
- Under what circumstances can bioenergy enhance food security?
- How can biofuels compete with low fossil fuel prices?
- What needs to happen in financing and commercialization schemes?
- What research needs to be conducted to fill in the gaps in understanding how bioenergy contributes with maximum benefits?

Biodiversity (BIOTA) and was supported by FAPESP and the Scientific Committee on Problems of the Environment (SCOPE), an international non- governmental organization. We summarize discussions on policy, challenges and recommendations for scaling up sustainable bioenergy approaches globally (Souza et al., 2015b). Since most of the bioenergy is derived from plant biomass, the scientific knowledge about its production and supply chains needs to be appropriately disseminated to inform policy making. Box 1 lists some of the aspects discussed by policy makers and scientists at the World Bank meeting in 2015.

2. Meeting energy security sustainably

Energy consumption patterns in OECD and non-OECD countries show that most increase in energy use will take place in developing countries. Because there is a direct relationship between energy consumption and economic activity, increased consumption brings opportunities for human development, better education levels and improved public health (Dale and Ong, 2012). With the advent of global trade as practiced in the last 15 years where lowest cost of products was practiced for economic benefits without accounting how damaging to the environment this would be, more critical analysis are looking at the sustainable production and consumption patterns that are beneficial all around and that consider the comparative advantage of nations. For instance, in the case of biomass and bioenergy, developing countries that have adequate land and water may be more suitable to produce bioenergy (Chum et al., 2015). Moreover, increasing energy demand for development in non-OECD countries makes it critical that they have access to sustainable energy sources. Otherwise, they will be pushed to use fossil energy and thereby compromise global efforts to reduce emissions of greenhouse gases (GHG).

Fortunately, several alternatives exist to increase the share of renewables in the energy matrix including various bioenergy options (Foust et al., 2015), and developing countries' investments in renewables surpassed those of developed countries in 2015 (REN21, 2016) representing 19.2% of the share of global final energy consumption. Bioenergy initiatives exist in several countries in the world that contribute to a significant share of their energy matrix providing liquid biofuels, bioelectricity, biogas and heat (Fig. 1). Provided that good management practices are followed and efficient systems are used, bioenergy can have several added benefits besides energy security, including food security, climate security and sustainable development (Osseweijer et al., 2015; Nogueira et al., 2015; Kline et al., 2016), and we now know that based on the 2016 INDCs (Rogelj et al., 2016) even the global GHG reduction targets of 2 °C will not be reached without bioenergy. Sustainable biomass production can make a significant contribution to climate change mitigation while also providing diversification of energy resources in the long term. Major global GHG mitigation scenarios show that a primary energy use average contribution of 25% from bioenergy is possible e.g. International Energy Agency (2011); Global Energy Assessment (2011); IPCC et al., 2014; OECD/IEA (2011) as well as Greenpeace, and the World Wildlife Fund. In the AR5 (IPCC et al., 2014) and the IPCC Synthesis Report (IPCC et al., 2015), bioenergy coupled with carbon capture and storage (CCS) have a major role to play, principally if nations did not start levelling emissions by 2030, very likely with the current pledges

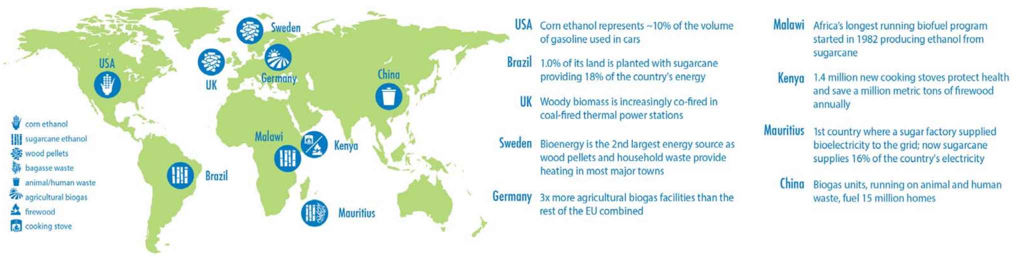

Fig. 1. Examples of biofuels, bioelectricity, biogas and heat from biomass that are increasingly contributing to energy supply around the world. See also the shares of biomass in total final energy consumption and in final energy consumption by end-use sector (REN21, 2016).
Source: FAPESP-SCOPE Bioenergy & Sustainability Policy Brief (Souza et al., 2015c).

(Rogelj et al., 2016). Unconstrained emissions would require significant negative emissions from commodity-scale bioenergy and CCS, among other carbon dioxide reduction technologies. The UN Sustainable Development Goals and its 17 global aspirational goals (United Nations Global Sustainable Development Report, 2015), that include climate action for securing livelihoods for centuries to come, suggest that we have a moral duty to develop and supply large-scale bioenergy in ways that improve social development (Nuffield Council on Bioethics, 2011; European Group on Ethics in Science and New Technologies to the European Commission, 2009) and foster significant sequestration of fossil carbon emissions.

One of the first issues that must be addressed is that of the production of liquid renewable fuels to help mitigate climate change and biofuels is essential for two reasons. First, it represents the only renewable energy source that can provide about 27% of the world transport fuels (predominantly aviation, shipping and long distance road sectors) currently derived from fossil fuels (Meier et al., 2015). Such use of biofuels can lead to a reduction of 2.1 Gton of CO_2 in the atmosphere per year (OECD/IEA, 2011). Second, biofuels provide renewable energy services in a way that can also generate wealth and contribute to sustainably improving human well-being both now and in the longer term in ways that are not observed with other renewable energy options. Besides GHG reduction (Macedo et al., 2015), substantive evidence exists that bioenergy brings multiple benefits that can off-set environmental problems associated with fossil fuels, intensive food production and urbanization (Leal et al., 2015). Examples range from reduction of pollution in urban centers to increased agricultural efficiency in rural areas that benefit from improved energy access and poverty alleviation (Souza et al., 2015c).

Although several feedstock options are already available at commodity scale (Fig. 1), continued efforts are needed to develop and/or improve crop and forestry systems that can produce bioenergy and do so more efficiently (Long et al., 2015). Second-generation biofuels (lignocellulosic biofuels), present a way to achieve the required higher productivity and provide environmental benefits. Advanced biofuels, such as sugarcane ethanol, that are technologically mature and provide high yields per hectare, are already making important contributions that help meet GHG reduction targets (Youngs et al., 2015). Some first-generation biofuels display characteristics that put them on par with second-generation biofuels in terms of emissions, sustainability and positive social impact. That is why the definition of 'advanced biofuels[2]' refers to the resulting characteristics of the fuels in terms of requirements of sustainability and emissions mitigation rather than the technological route in which biofuels are produced or which feedstock is used (Brito Cruz et al., 2014). It is a sustainable outcome that matters, not the specific technology by which the biofuel is produced.

Bioenergy efficiency both affects and is affected by regional development. In developing countries, bioenergy inefficiency is related to infrastructural problems, but positive effects can accrue if technological training and education are provided (De Moraes et al., 2015). In developed countries, where technology and infrastructure are in place, competition becomes the main problem, since commodities are volatile and market dependent (Foust et al., 2015). Currently, conventional technologies to produce bioenergy from agricultural and urban waste and traditional feedstocks such as sugarcane are mature and can be applied to many regions with positive benefits by taking advantage of learning from experience such as the Brazilian Ethanol program or examples of biogas production around the world (Leal et al., 2015). Double cropping for anaerobic digestion of animal manure and crop residues is a conventional technology that is ready to produce much more bioenergy, more sustainably, if it is combined with better farm management practices (Biogas Consortium, http://www.consorziobiogas.it). In an Italian Biogas program, farmers grow their usual food crops in the regular growing season but then produce a second or "double crop" during the period when the land is normally left unplanted. The double crop is harvested and stored on farm and then fed to an anaerobic digester along with various wastes to produce biogas. The biogas is burned on farm to produce electricity for the grid. The liquid fraction of the digester effluent is used to drip irrigate the fields to recycle crop nutrients and the solid fraction of the effluent is incorporated into the soils, thereby potentially sequestering carbon and improving soil fertility. Less dependence on purchased fertilizer improves farm economics, as does the existence of a second "crop" – revenues from the generated electricity that is sold to the grid. The presence of the double crop does much to reduce soil erosion and limit the transport of pollutants to ground water and surface waters. Thus many aspects of sustainability are met: large amounts of renewable energy are produced, carbon is sequestered, rural development is fostered and water quality is improved (Dale et al., 2016). This example shows the power of the circular economy where wastes do not exist (Allwood et al., 2011; Ellen MacArthur Foundation, 2012).

3. Attaining food security alongside bioenergy

Priorities for successful synergies between bioenergy and food security include integrated resource management designed to improve both food and water security and access to bioenergy (Souza et al., 2015a), investments in technology, rural extension, and innovations that build capacity and infrastructure (Souza et al., 2015b), promotion of stable prices to incentivize local production (Dale and Ong, 2012), and use of double cropping and flex crops (plants grown for both food and non-food markets) (Chum et al., 2015) that provide food and energy as well as other services (Osseweijer et al., 2015).

Knowledge acquired through technology development or improved management practices as depicted in the previous session make it possible to move from concerns about risk and negative outcomes into solutions. In terms of land-use change the issue is not how much land we use but how we use the land. Projected land demands for bioenergy fall well within conservative estimates of current and future land availability. From a land area of 50–200 Mha dedicated to producing bioenergy a contribution of around 25% of our future energy matrix could be achieved (Woods et al., 2015). Estimates for the amount of modern bioenergy (which excludes the inefficient burning of biomass for

[2] Bioethanol derived from starch or sucrose has been dubbed a first generation biofuel while lignocellulosic bioethanol, which can be produced from sugar cane bagasse, corn stove, woody crops, grasses and agricultural waste, among others, has been named a second-generation biofuel or advanced biofuel. Advanced biofuels can significantly contribute to decreasing GHG, and in this respect, first-generation sugarcane bioethanol produced in Brazil has also been classified as an advanced biofuel when practiced in conditions similar to Southeast Brazil.

cooking and heat) needed to meaningfully mitigate climate change range from 80 to 200 EJ in the 2050 timeframe. At the upper end of this range, we estimate that about 200 million hectares would be required. Higher estimates of land available for bioenergy have been made using global integrated assessments that range in the order of 240–905 Mha and most estimates exceed 500 million hectares. In reality, many scientists believe that before the world reaches any significant fraction of 200 Mha devoted to modern bioenergy, there will be continued improvement of the science-based (physical and social) guidance, improving projections with data of actual crop production, including double cropping, improvements in crop management and crop rotation in the US and in other countries. Preliminary global general computable equilibrium models projected significant extensification of agriculture and caused major misunderstandings among the various scientific, technological, and social strands as well as policymaker communities. With the appropriate baseline based on actual data, it was shown that intensification instead of extensification was the dominant effect (summarized in Souza et al., 2015c; https://www.usda.gov/oce/climate_change/mitigation_technologies/USDAEthanolReport_20170107.pdf). Additionally, global food supply trends show that a) there is a sizable area of land that is used for agriculture but which makes a small contribution to food production (Woods et al., 2015; Alexandratos and Bruinsma, 2012), and b) FAO predicts that the additional cropland that will be needed to feed the world in 2050 (70 Mha) is only 5% of the amount of land that can be converted to cropland (FAOSTAT, 2014). The Ecofys/World Wildlife Fund land availability analysis concluded that 40% of primary energy supply could be provided from 40% of available land after excluding protected lands, forests, cropland, built up land, and unsuitable land (Woods et al., 2015). These substantive reports corroborate the idea that, done correctly, there is enough land for bioenergy expansion without competition for food or other needs and that the focus is on how to manage it sustainably, improve soils and yields. Results using the Global Calculator (an integrated assessment of the world's energy, explicit land use and food systems to 2050) indicate that managing land is essential to achieving both a low-carbon future, and providing renewable energy (http://www.globalcalculator.org; Climate-KIC and International Energy Agency, 2015). The sustainable production of biomass requires appropriate policies to secure long-term investment for support to improve crop productivity and also to realize the full environmental as well as economic and social benefits of bioenergy cropping systems including food security.

Furthermore with bioenergy production it is possible to enhance food security by focusing on specific contextual problems and opportunities (Kline et al., 2016). Energy security is a prerequisite for sustainable food production and long-term food security, especially in rural areas, where 70–80% of people affected with food insecurity live. Currently there are 1.2 billion people in the world without energy access (World Energy Outlook, 2015). Bringing energy to poor areas results in poverty alleviation and enhances food security by developing trade and providing facilities for storage and packaging. It's clear that efficient bioenergy production in those rural areas can deliver a large portion of energy needs. But continuous support for cropping, infrastructure, agricultural management and related policies are needed to enable the real synergies between food crops and bioenergy production. A strong commitment to bioenergy production is essential considering the long-term investment needed (Osseweijer et al., 2015).

4. Enabling bioenergy contributions to environmental security

The effects of bioenergy production on the environment tend to be context-specific (Karp et al., 2015; Efroymson et al., 2013). In relation to fossil fuels, biofuels (e.g., ethanol) can have lower human health toxicity and reduce GHG emissions (Chum et al., 2015). In addition, biofuels can locally increase evapotranspiration (meaning that when water evaporates and passes into the atmosphere from soil and vegetation, it carries heat away from the land, causing local cooling) and, with improved soil carbon management and practices, also increase soil carbon sequestration (Berndes et al., 2015). Biofuel production that entails by-products such as sugarcane vinasse provide not only water for irrigation but also nutrients such as potassium, saving economic resources.

The negative impacts caused by land-use change and agriculture intensification can be mitigated by agroecological zoning and the use of biodiversity-friendly agricultural management techniques (Verdade et al., 2014). Negative effects of bioenergy, forestry or food production, often related to conventional agriculture, can be avoided or reduced by conservation of priority biodiversity areas, recognizing the context specific effects, adopting location-specific management of production systems and ensuring adequate bioconnectivity across agrosystems to pristine areas at landscape levels (Joly et al., 2015). In fact, the dispute between biodiversity conservation and the production of domesticated species should be viewed as interdependent. There is need to recognize that bioenergy expansion in monitored multi-functional landscapes can be beneficial. A significant amount of biodiversity is present on agricultural landscapes. It is impossible to provide full biodiversity protection only in conservation units like national parks and biological reserves even if they worked properly, which they usually do not. Thus, in real world, evolving agriculture within multi-functional landscapes is necessary to provide complementary biodiversity conservation. In addition, wild varieties and races of domesticated species are among the most endangered world taxa and depend on specialised managed environments to survive. Their conservation is necessary not only to provide genetic resources to draw from for the continual adaptation of their domesticated relatives to environmental changes such as new pathogens and parasites and even the challenges of global climate change (Verdade et al., 2015) but also to be part of ecological processes (Hicks et al., 2016). Multifunctional landscapes include those that provide both food and biodiversity shelter, whilst also conserving nutrient and water cycles (Joly et al., 2015). Resource effectiveness is important throughout the chain. Developing the management strategies needed takes time and effort.

Environmental sustainability indicators that guide certification schemes include soil quality, water quality and quantity, GHG emissions, biodiversity, air quality and productivity (Endres et al., 2015; McBride et al., 2011). In addition, there is now a robust empirical literature on indicators for ensuring resilience to climate change in agroecosystems (Cabell and Oleofse, 2012) that can be incorporated into best management practices. Certification will require sizeable capacity building to operationalize standards meaningfully. To avoid negative environmental impacts, governance and policies are needed in order to address both the local and the global aspects, facilitate development of the sector with simpler criteria and standards, and avoid the one-sided aims of curtailing possible negative impacts, some of which relate to bioenergy very indirectly (Van Meijl et al., 2015).

Box 2. Principles policy-makers should use to evaluate biofuel technologies and guide policy development (Nuffield Council on Bioethics, 2011).

Moral values relevant to current and new biofuels:

1. Biofuels development should not be at the expense of people's essential rights (including access to sufficient food and water, health rights, work rights and land entitlements)
2. Biofuels should be environmentally sustainable.
3. Biofuels should contribute to a net reduction of total greenhouse gas emissions and not exacerbate global climate change.
4. Biofuels should develop in accordance with trade principles that are fair and recognize the rights of people to just reward (including labour rights and intellectual property rights).
5. Costs and benefits of biofuels should be distributed in an equitable way.
6. If the first five principles are respected and if biofuels can play a crucial role in mitigating dangerous climate change then, depending on certain key considerations, there is a duty to develop such biofuels.

(http://www.nuffieldbioethics.org/biofuels-0).

5. Including social aspects in policy planning

One question that needs to be addressed is how to communicate to consumers the positive environmental and socio-economic aspects of bioenergy use and assess the increased acceptance of these clean energy options. Global climate and environmental changes caused by the continued use of fossil fuels and inequitable development makes it unethical not to pursue more sustainable energy development that includes bioenergy (Box 2). A concerted effort must be made to communicate the importance and urgent need to replace fossil fuels and that bioenergy can contribute to this goal. There are good examples of communication strategies that can be used. There are 'best management practices' to be scaled up. In countries where access to energy was limited, bioenergy has improved livelihoods, improved forest protection by avoiding damages of traditional biomass extraction and use, modernized agricultural practices, improved rural development, and revitalized agricultural production (Diaz-Chavez et al., 2015). Significant opportunities for new businesses exist, as the supply chain is made more stable and reliable, but they require advances in logistics and coordination. To make global advances in bioenergy, integrated supply and demand interactions need to be considered at the various scales. Social benefits have been achieved in many initiatives even though this was not their original goal, with stakeholder engagement in this process being crucial (De Moraes et al., 2015; Diaz-Chavez et al., 2015).

6. Competing with low oil prices

To achieve sustainable development, competitiveness and the costs of production are important but not the only goals in the short term. It takes time to develop local knowledge, work ethics and social benefits. Market forces and the commoditization of biofuels and solid biomass pellets contribute to regional and global development. Collaborative governments should promote market development and develop with the private sector a sustainable infrastructure for the distribution of products of the bioeconomy. Again implementation and scale-up of bioenergy poses different challenges in developing and developed countries. While low income and middle-income regions are more vulnerable to impacts such as climate change, the industrialized world is more dependent on global connections and markets. The significant capital loss of the developed countries in the 2010–2013 period is partially due to (public and institutional) rejection of non-sustainable fossil practices (for instance Norway divesting its US$ 9 billion pension fund of coal, oil and gas investments[3]), where sustainable bioenergy can offer a safe haven for institutional investors, pensions funds and the like.

Even though the use of different forms of bioenergy has grown worldwide, this occurred mainly when some special property, i.e. the ethanol high octane number, could be transformed into economic benefit. To compete with oil low prices, which have estimated subsides in the range of over US$ 500 billion/year, it is necessary to put into perspective climate change and add costs for coping with externalities in the use of fossil fuels. Bioenergy alone can play an important role in adaptation to climate change but its continued deployment will require large investments until the technologies reach maturity, representing a high capital risk. Similarly, large investments are needed for carbon dioxide capture and storage in geological sequestration and long-term technological development of the integrated systems. We will not meet energy demands without bioenergy if we want to adapt and mitigate climate change. Even if we do not meet perfectly all five requirements stated by the Nuffield Council on Bioethics (Box 2), we still have a duty to develop bioenergy to adapt and mitigate (Brito Cruz et al., 2014). Science will play a major role to provide new ways to mitigate GHG emissions and overcome negative impacts of bioenergy production as well as to provide knowledge for a well-informed decision making process that will assist participatory governance and public policy development and implementation (Joly et al., 2015). To provide scientific support for high-level decisions while a commodity-scale deployment is taking place, information on the full costs and benefits about bioenergy deployment is needed. The information can be acquired and used via spatially explicit, collaborative plans for management of landscapes and supply chains that build on existing practices to reduce costs and enhance services (Dale et al., 2016). Appropriately applied to a specific context, such landscape design approaches can help

[3] http://www.climatechangenews.com/2015/10/19/norways-oil-rich-capital-first-to-divest-from-fossil-fuels/.

stakeholders assess trade-offs when making choices about locations, types of feedstock, transport, biorefining and distribution of bioenergy products and services.

7. Planning the science for the sustainable expansion of bioenergy

Bioenergy has been under intense scrutiny over the last ten years with significant efforts in many countries taking place to define sustainable practices. As described above, concerns over potential conflicts with food production, over whether or not there is sufficient land and over whether bioenergy can really be delivered sustainably lie at the centre of an ongoing debate that have put development on hold in some regions. The real danger is not that once the bioenergy genie is out of the bottle ruinous land-use change will ensue. The recent investment decline in the bioenergy expansion worldwide provides ample evidence that the growth of bioenergy could be curtailed. Rather, the real danger is that bioenergy development will proceed so slowly and that a key strategy for climate change mitigation and adaptation will be effectively taken off the table. The way forward for the sustainable expansion of bioenergy requires careful planning across multiple agencies of governments since the bioeconomy develops in the nexus of land, water, agriculture, forestry, and related sectors, posing complex questions to policy makers. It is important that science is designed accordingly to deliver the much-needed guidance and technologies to bridge the knowledge gaps (Souza et al., 2015d). There is need for integration of sciences for bioenergy to achieve its maximum benefits and a much deeper analysis of social and environmental benefits. While a lot has been communicated on the potential negative aspects, a stronger effort must be made to communicate the cases of success and good practices (Dale et al., 2013). Bioenergy needs to be considered an integral part of strategic planning for a low carbon economy and can contribute with a large share of the global bioeconomy development if long-term policies are in place. Understanding the dynamics of costs and benefits along the entire production chain in integrated assessments, especially concerning the social implications of bioenergy can help the assessment of risks and contribute to the emergence of appropriate financing schemes. One example was created synergistically by the partnership *Be*low50 of the World Business Council for Sustainable Development (WBCSD), Roundtable for Sustainable Biomaterials (RSB) and Sustainable Energy for All (SE4ALL) for global collaboration to promote the best-of-breed of sustainable fuels that can achieve significant carbon reductions and scale up their development and use (http://www.wbcsd.org/global-companies-unite-in-below50.aspx).

8. Conclusions

Defining, establishing and measuring bioenergy sustainable practices is now occurring in many countries and in multilateral efforts. A noteworthy initial success is the ISO standard 13,065, Sustainability Criteria for Bioenergy (2015). Many sustainable biomass production systems (agriculture, forestry, bioenergy) and their supply chains to various types of products, including a contribution of bioenergy as solid, liquid, and gaseous fuels, have been scoped. We now know that:

- Many approaches to land use for bioenergy expansion do not lead to competition for food.
- Bioenergy cropping systems can bring multiple benefits and off-set environmental problems associated with fossil fuels, poorly managed intensive food production, and urbanization.
- Potential negative impacts caused by land-use change and agriculture intensification can be mitigated by agro-ecological zoning, improved crop yields, use of best management practices, the use of eco-hydrology and biodiversity-friendly concepts at field, watershed and landscape scales.
- The GHG effects of bioenergy have global effects but most other effects are primarily local or regional. Food security and negative land effects are contextual (and not global effects).
- To achieve sustainable development, competitiveness and costs of bioenergy production need to be addressed in a manner that considers not only economic gains but also development of local knowledge and social and environmental benefits.
- Done well bioenergy as well as afforestation can help mitigation of climate change and contribute to the UNFCCC 2016 Intended Nationally Determined Contributions (INDCs).
- Successful approaches focus on exploring synergies between bioenergy and food security and outcomes in multiple sustainability dimensions. Some common characteristics include:

a. integrated resource management designed to improve both food security and access to bioenergy;
b. investments in technology, rural extension, and innovations that build capacity and infrastructure;
c. promotion of stable prices to incentivize local production;
d. use of double cropping and flex crops (plants grown for both food and non-food markets) that provide food and energy as well as other ecosystems services;
e. appropriate policies to secure long-term investment to improve crop productivity and management practices and also to ensure environmental as well as economic and social benefits of bioenergy cropping or agroforestry systems.

In summary, global climate and environmental changes related to the use of fossil fuels and inequitable development make it unethical not to pursue more equitable energy development that includes bioenergy. Biomass as a renewable source of energy is unique in being able to provide local social development hand in hand with improved food security, where it is needed. Moreover, aggressive goals to keep global temperature rises below 2 °C seem to require substantial contributions of bioenergy in large scale, and several options exist to fulfill a significant contribution. Technology development and deployment of all components as integrated systems is ongoing, but long-term efforts (including capital investment during the learning process) is necessary. The need for such integrated strategies is also evidenced by recent global public-private partnerships (e.g., the below50 initiative to reach the UN Sustainable Development Goals in Energy and the Goals in Climate Change) that already frame development on sustainability criteria.

Acknowledgements

This communication is largely based on the results of the SCOPE Bioenergy & Sustainability Project funded by State of São Paulo Research Foundation (FAPESP) under grant # 2012/23765-0. GMS and LMV are recipients of a CNPq Productivity Fellowship. Alfred Hicks (National Renewable Energy Laboratory) contributed with the elaboration of the infographic. VHD, HC and TF's contributions were supported by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy under the Bioenergy Technologies Office. Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725. The National Renewable Energy Laboratory is managed by the Alliance for Sustainable Energy under Contract No. DE-AC36-08GO28308.

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