Advances in Plant Biology 4

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Preface

A nation's vision for developing renewable and sustainable energy resources is typically propelled by three drivers—security, cost, and environmental impact. The U.S. currently accounts for one-quarter of the world's total oil consumption. Technology improvements in the recovery of oil from shale, production of hybrid and electric vehicles, and light vehicle fuel efficiencies have reduced but far from eliminated dependence on foreign oil imports. At the same time, Brazil, because of its embrace of ethanol as an alternative liquid fuel in the 1970s, is today energy independent. Issues of energy security are compounded by increased demand from emerging economies and the supply of that demand from politically unstable parts of the world. Economic growth and development worldwide depend increasingly on secure supplies of reliable, affordable, and clean energy. As easily accessible reserves of oil become exhausted, the energy return on energy invested, currently a ratio of 30:1, will decrease, driving up costs for the consumer, not just of liquid transportation fuels, but of all of the oil-based chemicals and materials supplied by the petrochemical industry. Agriculture itself is an oil-intensive enterprise, with about 2 % of total oil consumption used directly in farm vehicles or indirectly for mechanized processing. As carbon dioxide levels reach an unprecedented 400 ppm, there is an unequivocal imperative to mitigate greenhouse gas emissions by decreasing fossil fuel consumption and transition to carbon-neutral or carbon-negative fuels as well as improving efficiency of fuel use.

It was with the urgency conferred by these three drivers that the American Society of Plant Biologists convened the First Pan-American Congress on *Plants and BioEnergy* in June, 2008, in Mérida, Mexico. This congress was designed to initiate Pan-American research collaborations in energy biosciences and to showcase advances in the development of new energy crop plants, their genetic improvement based on new knowledge of plant growth and development, their fit into regional environments, and the development of a sustainable energy agriculture. Subsequent biennial meetings, one in Brazil and another in the US, have served to connect advances in second and third generation of biofuels with the realities of economic success and sustainability. This edition encompasses specific examples of progress to this goal yet keeps in perspective the realities of the economic drivers and pressures that govern the translation of scientific success into a commercial success.

In Part I, **Social and Economic Impacts of a Bioenergy Agriculture,** we begin with Patricia Guardabassi and José Goldemberg's overview of the prospects of global ethanol production in developing countries and the relevant social and economic issues unique to their environments. Jeremy Woods and Nicole Kalas extend this theme, drawing on the lessons of biofuels policy development concerning direct and indirect land use over the last decade to inform energy policies that will drive sustainable land use. Wally Tyner and Farzad Taheripour discuss the uncertainties, policy options, and land-use impacts in moving from ethanol to advanced fuels. Finally, Gal Hochman and David Zilberman discuss the implementation and economics of algal farming and how economic success hinges on high-value bio-products generation.

In Part II, **Biomass Feedstocks**, we explore the breadth of bioenergy crops and the progress that is being made to introduce them into the agricultural landscape, the underlying biology of bioenergy plants, and new ideas to enhance biomass yield and quality for the energy crops of the future. Andrew Jakubowski and Michael Casler show that improved and locally collected ecotypes of switchgrass, big bluestem, and Indiangrass can coexist on the landscape and help to jumpstart sustainably the shift to a bioenergy-based economy. Cynthia Damasceno, Robert Schaffert, and Ismail Dweikat's article considers how to mine the vast genetic diversity in the sorghum genome and its advantages as an annual crop for use in both tropical and temperate biomes. Angela Karp and her colleagues explore the challenges and prospects for integrative approaches to improve woody biomass species, such as willow, as lignocellulosic feedstocks. Two perspectives consider oil production platforms for advanced biofuels, biodiesel, and bio-based products. Umidjon Iskandarov, Hae Jin Kim, and Edgar Cahoon present the advantages of Camelina as an emerging drought-resistant oilseed suitable for marginal lands that are tractable to genetic improvement, and Janaina Meyer and Antonio Salatino, present their ideas for Brazil's contribution to biodiesel with palm. To conclude this section, Ahmed Faik, Nan Jiang, and Mick Held present a thorough update on our present knowledge of the biochemistry of xylan synthesis, with particular emphasis on the unique aspects of synthesis in grasses. Catherine Rayon, Anna Olek, and Nick Carpita close this section with a perspective on the complexities of cellulose biosynthesis that suggests strategies for how cellulose might be designed for improved bioenergy feedstocks.

In Part III, **Biomass Conversion Technologies** we explore the culmination of the technologies that drive the ethanol industry and the promise for the efficient conversion of biomass into energy-dense liquid fuels and high value co-products. Harry Gilbert begins with an extensive review of how novel enzyme repertories are developed for the efficient deconstruction of plant biomass tailored for the bioenergy industry. Adriana Grandis and her colleagues in the Laboratory of Marcos Buckeridge extend this strategy in their perspective on exploiting natural plant cell wall degradation systems to improve bioethanol production. Rebecca Garlock Ong and colleagues in the laboratory of Bruce Dale present a comprehensive review on how knowledge of the fine structure of the plant cell wall informs better design principles for the biorefinery. Ken Reardon gives some guiding principles for the lignocellulosic refineries of the future for how both the economics and the environmental impacts of biofuel production could be improved by developing processes to obtain a wider range of chemicals with higher value from biomass. The edition concludes with two articles that explore the early successes in the direct conversion of lignocellulosic biomass into advanced biofuels. Basudeb Saha, Nathan Mosier, and Mahdi Abu-Omar show the path to catalytic dehydration of lignocellulosic-derived xylose to furfural, while Joe Bozell identifies pathways for the catalytic oxidation of lignin for the production of low molecular weight aromatics.

In this volume, we bring together perspectives from a wide range of disciplines, recognizing that the grand challenge of displacing a century of global dependence on oil requires a new research paradigm, a "Manhattan Project" for the twenty-first century. Production of carbon-neutral reliable, affordable biofuels for a growing population in a manner that does not compromise food and feed production takes a community that is fully engaged, committed, and international in scope. The success of that community will be measured in our contributions to climate security, economic growth, and self-sufficient energy production for our nations.

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Part I
Economics of Bioenergy

Chapter 1
The Prospects of First Generation Ethanol in Developing Countries

Patricia Guardabassi and José Goldemberg

Abstract There are great perspectives to the development of second-generation technologies to biofuels production, nevertheless its production in large scale is depending on a technological breakthrough to become feasible. The production of ethanol from sugarcane based on first generation technology has evolved in the last decades; however gains of productivity can still be achieved. Latin American and African countries have suitable conditions to the growth of sugarcane. Many of these countries are highly dependent on fossil fuels imports. Thus, the introduction of ethanol blends can reduce the consumption of fossil fuels, while creating jobs and developing local industry. Notwithstanding, first generation ethanol can still contribute to developed countries, especially US and European countries, to commit with biofuels use mandates. The aim of this chapter is to present the state of the art of ethanol production in Latin America and African countries, identifying the main obstacles to the development and discussing policies that could be implemented to overcome such barriers.

Keywords Biofuels • First generation • Developing countries • Barriers

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1.1 Introduction

The economic growth of developing countries and the maintenance of consumption patterns in developed countries continuously increase world's energy consumption. Concomitantly, the depletion of oil reserves has been observed as well as the impacts of climate change caused by human actions, especially due fossil fuels consumption. In the specific case of energy, this topic is of special importance since the projections indicate, in a scenario based on current policies for the energy sector, a growth of the world's energy consumption by 47 % between the years 2008 and 2035 (OECD/IEA 2010), based on increased use of coal and natural gas. In this context it is necessary to develop alternative sources of energy and modern technologies that can replace fossil fuels and mitigate greenhouse gas (GHG) emissions.

The most promising alternatives are those based on renewable sources of energy such as solar panels and wind turbines. However for the transportation sector, which accounted for 13 % of greenhouse gases global emissions of 2004 (IPCC 2007), biofuels are the only worldwide commercially available option, since electric vehicles or hydrogen still demand technological development. Thus, biofuels are gaining an increasingly importance to reduce GHG emissions as well as the dependence of fossil fuels. In view of the impacts from the extensive use of fossil fuels, and the opportunity to reduce their emissions through the adoption of renewable energy in their energy matrixes, developed countries have established targets for use of clean fuels (Goldemberg 2007).

The most ambitious one was established by the European Union, whose goals include a 20 % share of renewable energies in overall Community consumption and, in the transportation sector, at least 10 % biofuels by 2020, equivalent to 14 billion liters. However, alleging aiming to reduce the impact of first generation biofuels on food prices, the EU cut by a half its biofuels target. Within this bioenergy program the European Parliament and the European Union Council established the European Union Directive 28/2009 on the promotion of the use of energy from renewable sources. This Directive sets sustainability criteria that must be accomplished by countries willing to provide biofuels to the European Union country members. In the case of European Union, biofuels are expected to provide a great contribution in the achievement of renewable energy use target and GHG emissions in transport sector (European Expert Group on Future Transport Fuels 2011).

Another initiative that will also be central for the global biofuels market due to its dimensions was taken by the U.S. government in the Energy Independence and Security Act (EISA). Established in 2007, it set a minimum consumption in the country of 45 billion liters of biofuels by 2010, reaching 136 billion liters in 2022. The legislation identifies three types of biofuels, which should account for about 60 % of this volume (equivalent to 88 billion liters), they are: cellulosic ethanol, biomass diesel and "other advanced". To be classified as "advanced" biofuels must reduce by 50 % GHG emissions on a life cycle basis, compared to gasoline. The levels of GHG emissions reduction for biofuels were adopted by the Environmental Protection Agency (EPA), and according to the Agency's calculations, Brazilian ethanol reduces GHG emissions by 61 %. In summary, European and American initiatives together are responsible for the demand of 150 billion liters of ethanol in the year 2022.

However, due to edaphoclimatic conditions and restrictions on land availability, many countries do not produce volumes of biofuels sufficient to supply the domestic market. Consequently, the international trade of biofuels has been growing and more producing countries are likely to be part of it. Ethanol can be produced from a series of feedstocks; however its access to American and European markets will depend on its GHG emissions balance (Worldwatch Institute 2007). Among different raw materials to produce ethanol, sugarcane is the most effective in GHG emissions reduction, because small amounts of fossil fuels are used in its production chain. According to (Smeets et al. 2007), for the year 2050, Sub-Saharan Africa and Latin America and the Caribbean regions have the greatest potential for production of agricultural residues that could be used as bioenergy feedstock.

The "Global Agro-Economic Zones (GAEZ)" system developed by FAO, in conjunction with the International Institute for Applied Systems Analysis (IIASA), identified and quantified areas with potential to produce raw materials for biofuels based on climate and soil conditions. In the case of rain-fed sugar cane, GAEZ identified 135 million suitable or very suitable hectares and 130 million hectares moderately suitable hectares (of which only 22 million are currently planted with sugar cane). For unprotected areas the overall potential is estimated at 87 million hectares suitable or very suitable, of which 26 million hectares are located Africa and 54 million hectares South America (Fischer et al. 2009). The regions with greater aptitude for the cultivation of rain-fed sugar cane are located in South and Central America, the Caribbean, Central Africa and some countries in West and South Africa, South Indian and Southeast Asia. Although suitable for the production of biofuels these regions produce small amounts of ethanol.

From the world's total production of ethanol, in 2010, of 86.8 billion liters; United States and Brazil were responsible for 76.2 billion; and despite its potential the African continent produced only 0.16 billion liters and Latin America and Caribbean 2.6 billion liters (RFA 2011). In fact, there are barriers that must be overcome in order to allow the development of a biofuels production sector. In order to surpass such barriers, it is necessary to settle a legal framework that ensures an appropriate institutional condition, economically attractive to investors and to promote the production minimizing environmental and social impacts.

1.2 The State of the Art of Ethanol Production

Ethanol production has been based in the so-called "first generation technologies" either by direct fermentation (in the case of sugar cane) or saccharification of starch (in the case of corn and wheat) followed by fermentation. New technologies, or second generation technologies, to produce biofuels include the enzymatic conversion of lignocellulosic material. Despite huge amounts invested and the demand created by US Renewable Fuel Standard, there are no commercial plants operating yet. According to the Advanced Ethanol Council “Advanced Ethanol Council (AEC) (2012)”, industry is reaching commercial deployment phase, however the “high capital risk from OPEC-induced price distortions, constrained blending markets and policy uncertainty continues to slow down the rate of deployment”.

Currently, the US is the largest ethanol producer with an annual amount of 49 billion liters, using corn as feedstock, followed by Brazil, which uses sugarcane as feedstock, producing 28 billion liters (REN21 2012). So far, sugarcane ethanol has proved to be the most competitive raw material in use, due to its positive energy balance, and consequently positive reduction of greenhouse gas emissions on a life cycle basis, the lower costs of production and higher production yields when compared to corn (Goldemberg, The Brazilian biofuels industry 2008). Therefore, it is plausible to extend a successful experience, such as the Brazilian ethanol program, to other developing countries.

1.3 Existing Mandates to Ethanol Production and Use

1.3.1 Africa

Ethanol is produced in Africa to replace gasoline since de 1970s, in countries highly dependent on imports, such as Zimbabwe, Malawi and Kenya. Malawi produces ethanol since 1982 and uses E10 blends. The country is running tests with ethanol dedicated engines. The local production reaches 18 million liters, half of it domestically consumed and the rest exported to African countries. There are two distilleries operating in the country with a total producing capacity of 32 million litres. Government aims to estimulate the production of sugarcane in order to use this idle capacity (Janssen and Rutz 2012).

Other nations are introducing policies aiming to leverage the production of biofuels aiming to increase energy security due to energy matrix diversification and reduction of fossil fuels imports. Hence, such policies are also instruments to promote the development of rural areas, through job creation, income generation, local industry expansion and investments in infrastructure. South Africa is the largest market in the region. The country established “The Biofuels Industrial Strategy of the Republic of South Africa”, in December 2007, which aims to develop a biofuels industry that could supply the domestic market of 2 % ethanol blends (equivalent to 400 million liters per year) within 5 years. Sugarcane and sugar beet are edible crops to ethanol production, and sunflower, rapeseed and soybeans to biodiesel. The program will demand about 1.4 % of country’s agriculture land. The country will only adopt mandatory blends when domestic biofuels production is ensured (Department of Minerals and Energy 2007).

In 2009, Mozambique Council of Ministers approved the National Biofuels Policy and Strategy. According to the Minister of Energy, the use of E10 and B3 would started in 2012, and the country's productive capacity to meet domestic demand, but the interest of the government is to continue to promote ethanol production aimed at export in the coming years (Gil 2011). Kenyan biofuel policy aims to reduce oil imports by 25 % by 2030 and to increase access to energy through sustainable biofuels production. The 2009 draft of Biofuels Strategy stress a general capacity to produce ethanol from molasses to supply E10 blends. In 2010, the Kenyan biofuel policy strategy defined an E10 blending mandate (equivalent to 93 million liters). The national installed capacity of 125,000 liters per day is producing only 60,000 litres per day due to the limited current supplies of molasses (GTZ and Ministry of Agriculture Kenya 2008).

In Tanzania, a country that presents suitable climate conditions and available arable land and water, the Biofuels Guidelines of December 2009, addresses key issues related to: institutional framework; application procedure for investors; land acquisition and use; contract farming; sustainability of bioenergy development; avoidance of food versus fuel conflicts and sufficient value creation for the local rural population. In Zambia, energy security and matrix diversification are the main drivers of biofuels introduction. The Sixth National Development Plan defines biofuel blending ratios for bioethanol and biodiesel, for the current period up to 2015: up to E10 and B5. Ethiopia has three state owned sugar factories which have been operational for long time. The country introduced E5 in 2009, then increasing to E10 early 2012. Government says that the country's ethanol blending policy has saved the country $20.5 million in fuel imports since the policy began in 2008 (Biofuels Digest 2012).

1.3.2 Latin America and Caribbean

In the Latin America and Caribbean there are a growing number of nations adopting biofuels. In Argentina, national legislation defines the blend of 5 % ethanol to gasoline and the same percentage of biodiesel to diesel oil. However, regarding ethanol, the mandate must be introduced progressively due the lack of domestic production capacity to attend the demand (Fundación Bariloche 2011). Uruguay has approved Law 18,195/2007 to introduce gradually introduce ethanol blends up to a mixture of 5 % in 2015. Domestic production is not sufficient nowadays to supply the internal market, though a project being developed by the state-owned oil company, is promoting the development of sugarcane crops, especially in least developed regions of the country (Fundación Bariloche 2011). Paraguay defined by Law 2,748/2005, from the year of 2006, the blend of ethanol to gasoline ranging from 20 % up to 24 %. In May 2008, Decree 12,240/2008 determined the reduction of taxes to biodiesel and ethanol e cut out importing taxes on flexible fuels vehicles and E85 new and used vehicles (USDA 2009). In Colombia, the promotion of biofuels initiated in 2001, due Law 693/2001 that stipulates rules to ethanol use and determines incentives to production, trade and consumption of this fuel (CENBIO and CENTROCLIMA 2011).

In Mexico, besides the Bioenergy Promotion and Development Law, which aims to promote the diversification of energy matrix, the use of biofuels is not mandatory (BIOTOP 2009). In Costa Rica, the use of ethanol was initiated in the 1970s aiming at reduce the country's oil dependence, however it had not succeed at that time (Nogueira 2004). In January 2008, the "Biofuels National Program" was launched aiming the increase of country's energy security and greenhouses emissions reduction through the blend of 7.5 % ethanol to the gasoline and 5 % of biodiesel to the diesel in that year, progressively increasing to E10 and B20 blends in 2010. The lack of infrastructure obligated government to postpone the goals (Aguero 2011), however ethanol is available in few regions in the north of the country yet (Villegas e Campos 2011) and apparently government is not interested in expanding ethanol supply. Other countries in the region, such as El Salvador, Honduras, Nicaragua, Guatemala, Peru, Ecuador and the Dominican Republic have legislation stimulating the production and use of biofuels, however there are no mandatory blends and local production is low, absent or devoted to foreign markets (especially European Union and United States under advantageous trade agreements).

1.4 Main Obstacles to the Development of Ethanol Industry

To analyze the production of biofuels two main aspects must be considered, the feedstock production (agricultural side) and its processing into biofuel (industrial side). The current yield of agriculture production in Africa is low due to the lack of adequate agricultural management, derived from the lack of access to fertilizers, seeds, water and training. One of the causes is the lack of access to credit for small holders, that prevents then to buy agriculture supplies such as fertilizers, seeds and equipment hence reducing production costs (Mitchell 2011).

Other aspects contributing to slow down development are related to the risks to investors and include absentee or weak land tenure policies (Cotula et al. 2004) precarious infrastructure for distribution of the final product (Cornland et al. 2001); lack of policies to guarantee the existence of a consumer market (e.g. mandatory blending). Regarding the industrial production there are many technologies to produce ethanol from various feedstocks. The so-called first generation biofuels technologies based on sucrose fermentation are well known and largely used worldwide. The implementation of such technologies requires few adjustments to local operation condition and the main barrier in this case would be the lack of trained personnel.

An additional benefit from the production of biofuels is the possibility of using crops residues, e.g. sugarcane bagasse, as fuel in cogeneration systems. Those units can supply the energy needs of the biofuel facility and even produce surplus electricity to feed the surrounding areas, with the advantage that the feedstock is readily available at low (or no) cost. It can be advantageous in African countries where access to energy services is limited, especially in rural areas. Cogeneration technology is commercially available in a wide range of power capacities. Low technical skills and the lack of a supportive policy and regulatory framework prevent investments in more efficient production. The absence of attractive and pre-determined tariffs are the major barriers to the development of a to sell the exceeding production (Cogen for Africa n.d.).

1.5 Policy Proposals

The development of a stable institutional and political environmental is required in order to attract companies aiming to invest in biofuels production in such markets. To establish a captive market for biofuels through the adoption of mandatory blends is essential, however, in many countries the domestic market can be so small, due to economic conditions and a reduce vehicles fleet, that looking at exporting could present an interesting opportunity. In this case, fuel quality standards have to be carefully considered. A policy of prices that enables ethanol to compete with both gasoline and sugar prices is essential, especially in the initial stages of its introduction into the market. Also, an extensive network for distribution and retail has to be designed in order to easily offer the product to consumers.

Considering the utilization of third parties, such as small farmers, investments in training and equipment tend to be necessary; nevertheless many of these farmers do not have access to credit to invest in its production. This problem could be partially amended through the development of funding policies and tools, such as microcredit and rural credit. There are countries where land tenure rights are unclear, thus the introduction and improvement of land use and ownership legal framework is required in order to protect and guarantee small farmers rights.

Regarding environmental aspects, the development of a zoning that defines edible areas to grow sugarcane crops and those areas that must be protected. In the case of other environmental issues related to the use of fertilizers, pesticides and atmospheric emissions, the use of commercial available technologies can be adopted as best practices. Water use tends to be a more delicate topic, especially in African countries. The reuse of the vinasse (an ethanol production by-product) for fertirrigation can reduce the need of water withdraw.

A fundamental aspect is related to labor conditions. It is well know that usually sugarcane cutters, that represent the largest amount of workforce in this sector, have low education levels, thus continuous training programs are essential to increase productivity and avoid accidents. Also, the endorsement of international working treaties and the correct enforcement must avoid child labor and inappropriate and degrading working conditions.

The promotion of electricity surplus production through cogeneration systems based on sugarcane bagasse still needs the creation of institutional and regulatory policies aiming to minimize market risks for investors. Mechanisms such the definition of standard power purchase agreements and feed-in tariffs can create confidence in the market, and stimulate investments in modern and efficient biomass cogeneration projects.

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References

Advanced Ethanol Council (AEC) (2012) Cellulosic biofuels industry progress report 2012/2013. http://ethanolrfa.3cdn.net/d9d44cd750f32071c6_h2m6vaik3.pdf, 2012

Aguero M (2011) Recope descarta plan de etanol a corto plazo. La Nación. 21 de abril de 2011. www.nacion.com/2010-07-14/ElPais/NotasSecundarias/ElPais2446754.aspx (acesso em 21 de abril de 2011)

Biofuels Digest (2012) Ethiopia's ethanol blending saves $20.5 million in three years. 9 de 7 de 2012. http://www.biofuelsdigest.com/bdigest/2012/07/09/ethiopias-ethanol-blending-saves-20-5-million-in-three-years/ (acesso em 5 de 10 de 2012)

BIOTOP (2009) Biofuel policies and legislation in Latin America. Relatório de projeto, 42

CENBIO and CENTROCLIMA (2011) Bioenergy, rural development and poverty alleviation in Brazil and Colombia. São Paulo, Brazil

Cogen for Africa. Key drivers and barriers for biomass cogeneration development. s.d

Cornland DW et al (2001) Sugarcane resources for sustainabledevelopment: a case study in Luena, Zambia. Stockholm Environment Institute, Stockholm

Cotula L, Toulmin C, Hesse C (2004) Land tenure and administration in Africa: lessons of experience and emerging issues. IIED, Londres

Department of Minerals and Energy (2007) Biofuels industrial strategy of the Republic of South Africa

European Expert Group on Future Transport Fuels (2011) Future transport fuels. European expert group on future transport fuels

Fischer G, Hizsnyik E, Prieler S, Shah M, van Velthuizen H (2009) Biofuels and food security. The OPEC International, Vienna

Fundación Bariloche (2011) Bioenergy for rural development and poverty alleviation—GNESD. San Carlos de Bariloche

Gil F (2011) Biocombustíveis e petróleo: Mistura obrigatória a partir de 2012. Moçambique para todos. 14 de agosto de 2011. http://macua.blogs.com/moambique_para_todos/2011/08/biocombust%C3%ADveis-e-petroleo-mistura-obrigatoria-a-partir-de-2012.html (acesso em 15 de novembro de 2011)

Goldemberg J (2007) Ethanol for a sustainable energy future. Science 315:808–810

Goldemberg J (2008) The Brazilian biofuels industry. Biotechnol Biofuels, 1 de May de 2008: 1–6

GTZ, Ministry of Agriculture Kenya (2008) A roadmap for biofuels in Kenya

IPCC (2007) Fourth assessment report: climate change 2007—synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva

Janssen R, Rutz D (2012) Bioenergy for sustainable development in Africa. Springer, Berlin

Mitchell D (2011) Biofuels in Africa: opportunities, prospects, and challenges. The World Bank, Washington, DC

Nogueira LAH (2004) Perspectivas de un programa de biocombustibles en América. Cidade do México: CEPAL

OECD/IEA (2010) World energy outlook 2010. International Energy Agency, Paris

REN21 (2012) Renewables 2012 global status report. REN21 Secretariat, Paris
RFA (2011) World fuel ethanol production 2011. http://ethanolrfa.org/pages/World-Fuel-Ethanol-Production (acesso em 15 de novembro de 2011)
Smeets EMW, André PC, Faaij APC, Lewandowski IM, Turkenburg WC (2007) A bottom-up assessment and review of global bio-energy potentials to 2050. Prog Energy Combust Sci 33:56–106
USDA (2009) Paraguay biofuels annual. Buenos Aires
Villegas JS, Campos C (2011) Gasolina con alcohol seduce a choferes de Guanacaste. La Nación. 21 de 04 de 2011. http://www.nacion.com/2011-04-19/ElPais/Relacionados/ElPais2753442.aspx (acesso em 25 de maio de 2011)
Worldwatch Institute (2007) Biofuels for transport. Springer, London

Chapter 2
Can Energy Policy Drive Sustainable Land Use? Lessons from Biofuels Policy Development Over the Last Decade

Jeremy Woods and Nicole Kalas

2.1 Introduction

The mandated increase in bioenergy as a means to decarbonise our energy supply, enhance energy security, and promote rural development has raised concerns regarding the impacts biomass feedstock production may have on food security. These national mandates appear to have placed bioenergy feedstock production in competition for resources required to feed a growing global population. In turn, concerns over the direct and indirect impacts of bioenergy, particularly conventional biofuels,[1] have pushed policy makers to try to direct biomass crop production for energy onto marginal, degraded and 'unused' land. Moving bioenergy onto marginal lands will inevitably raise the costs of feedstock production, but it may also be contradictory to food security where sustainable intensification and reduced losses require increased energy inputs into agriculture. This marginalisation ignores the beneficial role that perennial energy crops could play in managing the sustainable intensification of overall agricultural production required to feed over 9 billion people by 2050. Chapter 2, therefore, explores the role and drivers of bioenergy in future world energy production, land use change and wider sustainability issues, and proposes an alternative, integrated approach toward a resource efficient and sustainable provision of agricultural products, including food, feed, biobased chemicals, materials and energy.

[1] Conventional biofuels are produced through the fermentation of sugars or starches to bioethanol from commodity crops such as sugarcane, maize, wheat, and beet, or through the methyl esterification of vegetable oils to biodiesel from palm, soy or oilseed rape.

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2.1.1 Changing Patterns in Global Energy Supplies

Two concurrent developments in energy use are changing the pattern of global energy supplies (see Fig. 2.1). On one side, climate policy and energy security driven increases in efficiency and uptake of renewable energy technologies in the USA, European Union and Japan are slowly reversing the upward trend of oil imports observed to date. In the USA, increased domestic production of oil and the recent intensification in shale gas exploration (hydraulic fracturing) have placed the country on a path to energy self-sufficiency. On the other side, rapid economic growth in China and India, driven primarily by fossil fuels, has led to increased consumption of cheap coal and imported oil. These opposing trends in oil consumption are raising the competition for energy security and shifting the global balance of oil imports from OECD to non-OECD countries, where China is expected to become the world's largest oil importer by 2020.

As Fig. 2.2 illustrates, new coal has provided nearly 50 % of incremental energy supply since 2000 and in increasingly inefficient power plants (to lower capital costs). In the USA, shale gas has started to drive coal out of the electricity generation mix and is also degrading the role for dedicated biomass and other sources of renewable energy. In the UK, power generators are moving rapidly towards large scale biomass co-firing in existing electricity plants and reducing demand for dedicated biomass.

Cheap coal and the 'shale gas revolution' are the biggest challenges to climate change mitigation and the meaningful deployment of renewables. The world is not on track to meet the internationally agreed target to limit the long-term rise in the global average temperature to 2 °C. Over 80 % of global energy consumption is based on fossil fuels, and the energy sector accounts for approximately 2/3 of Greenhouse Gas (GHG) emissions (IEA 2013).

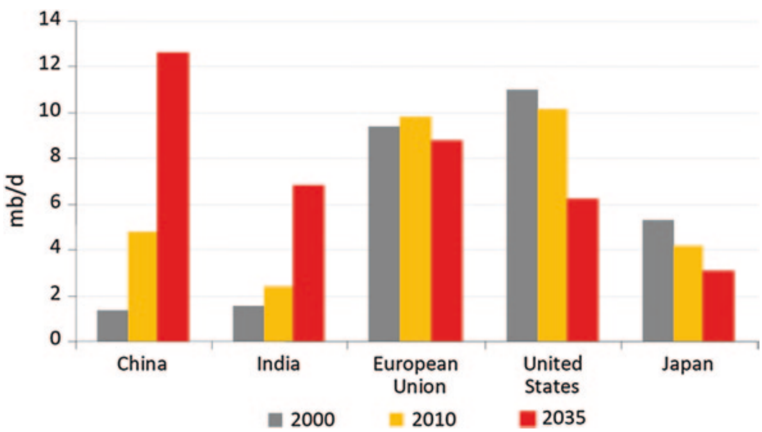

Fig. 2.1 Net imports of oil (2000–2035). *Source* IEA (2011)

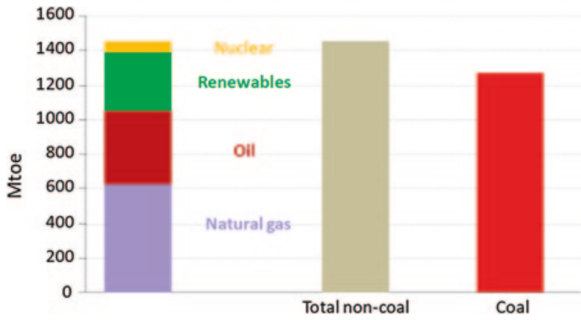

Fig. 2.2 Growth in global energy demand (2000–2010). *Source* IEA (2011)

2.1.2 Future World Energy Production and Price Trends: Is Bioenergy Policy Swimming Against the Tide?

2.1.2.1 World Energy Production and Price Trends

The IEA's Current Policies Scenario[2] shows an increase in world oil production by 26 % from 82.3 mb/d[3] (2007) to 103.8 mb/d in 2030 (see Fig. 2.3) (IEA 2008). To meet demand growth and offset decline, an additional 64 mb/d would be needed, which corresponds to six times Saudi Arabia's current capacity.

Figure 2.4 shows the global trends in prices for fossil fuels ($/GJ) indicating a continued increase in oil prices, and recent decrease in both gas and coal (BP 2012). Gas and coal are expected to resume their upward trend, but stay below oil prices.

2.1.2.2 Global Bioenergy Policy and Consumption

Bioenergy policies are motivated by climate change mitigation targets, energy access and security, and rural development. While global demand for biomass feedstocks is predominantly driven by policies in the EU and USA, at least 33 countries have now implemented mandates for biofuels (blending requirements) (Biofuel Digest 2012).

In the EU's *Renewable Energy Directive* (RED), Member States have committed to reduce their CO_2 emissions by 20 % and to target a 20 % share of renewable energies in the EU energy mix (including 10 % of transport fuels by 2020 as part of the 2007 *The EU climate and energy package* (EC 2009a)). Biofuel demand is projected to be 7,307 ktoe[4] (14,450 million litres) of ethanol, and 21,650 ktoe

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[2] The IEA's Current Policies Scenario (previously called the Reference Scenario) assumes no changes in energy and GHG emission reduction policies (IEA 2010).

[3] mb/d = million barrels/day (1 barrel = 159 litres).

[4] Ktoe = kilo tonnes of oil equivalent (1 ktoe EtOH = 1.978 million litres, 1 ktoe biodiesel = 1.32 million litres).

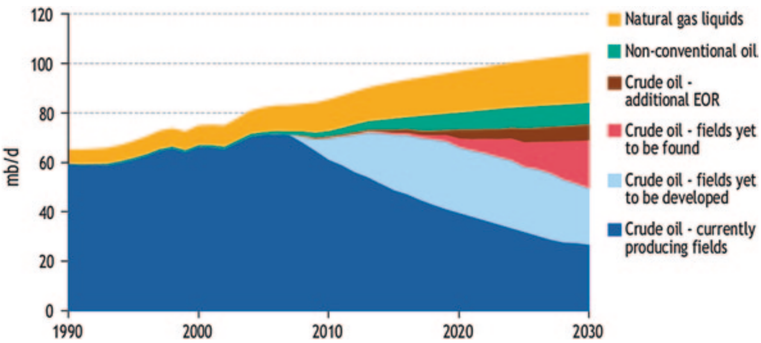

Fig. 2.3 World oil production by source in the Current Policies Scenario (1990–2030). *Source* IEA (2008)

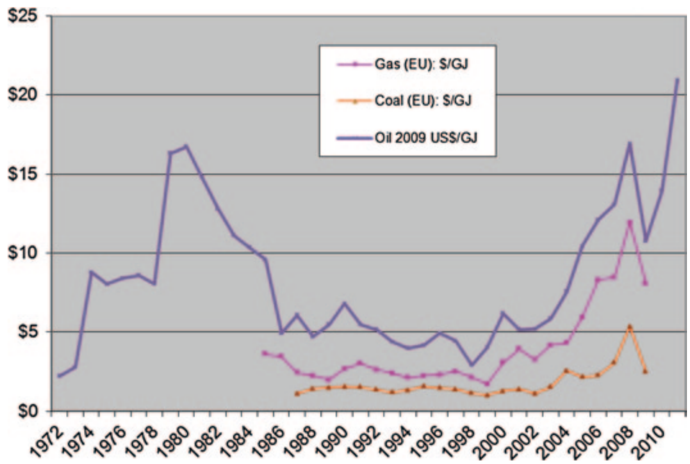

Fig. 2.4 Global trends in fossil fuel prices (1970–2011). *Source* BP (2012)

(28,600 million litres) of biodiesel (Beurskens et al. 2011). The dominant driver for the RED is GHG mitigation, but energy security is also a serious concern. In conjunction with the *Fuel Quality Directive* (FQD), sustainability criteria for GHG emission reductions and biodiversity conversion are applied to each supply chain through assurance and certification schemes (EC 2009a, b, 2012).

In the USA, biofuel blending is mandated by the *Renewable Fuels Standard* (RFS2) to achieve the targets established in *The Energy Independence and Security Act of 2007* (EISA). The RFS2 has laid the foundation for achieving significant GHG emissions in the transport sector and for promoting the development of the US renewable fuels sector. It provides volumetric standards for renewable fuels, including advanced biofuels, and includes GHG emission thresholds producers are

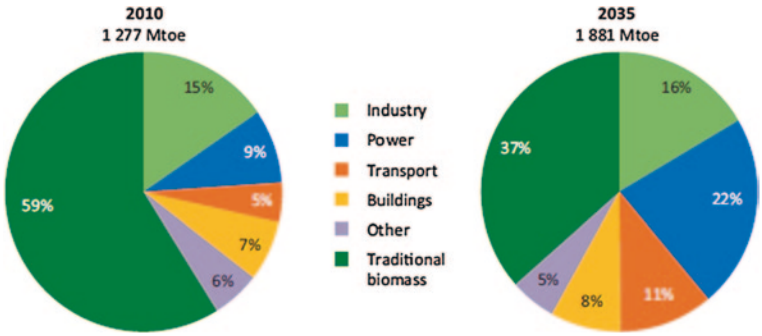

Fig. 2.5 World bioenergy use by sector and use of traditional biomass in the IEA new policies scenario (2010 and 2035). *Source* IEA (2012)

required to meet. Under the RFS2, annual biofuel production, which in the USA is predominantly ethanol, is to increase from currently 13.2 billion gallons (60 billion litres) (2012) to 36 billion gallons (164 billion litres) by 2022 (EPA 2010).

In 2010, total global bioenergy consumption amounted to 1,277 Mtoe,[5] or excluding traditional biomass,[6] 526 Mtoe (see Fig. 2.5). The IEA New Policies Scenario[7] estimates that in 2035 total world bioenergy use will increase to 1,881 Mtoe, or 1,200 Mtoe excluding traditional biomass (at an average annual growth rate of 3.3 %). Currently, the industrial sector is the largest consumer of bioenergy (196 Mtoe), but the power sector will dominate bioenergy consumption in 2035 (414 Mtoe). Together, the power and industrial sector will demand approximately 2/3 of global bioenergy in 2035. The use of traditional biomass will continue to decline, as access to modern and more efficient energy technologies, including modern bioenergy,[8] increases in developing countries. Excluding the use of traditional biomass, the EU will be the single largest consumer of bioenergy, increasing its consumption from 130 Mtoe (2010) to 230 Mtoe (2035), whereas the US will follow closely with 210 Mtoe by 2035 (IEA 2012). Global biofuel (or liquid bioenergy) consumption, dominated by ethanol, is estimated to increase by 250 % to 210 Mtoe during that period, driven primarily by blending mandates (IEA 2012).

[5] Mtoe = million tonnes of oil equivalent (1 Mtoe = 41.9 PJ).

[6] Traditional biomass includes wood, charcoal, crop residues and animal dung and is mainly used for heating and cooking (IPCC 2011).

[7] The New Policies scenario is IEA's central scenario and takes into account the cautious implementation of broad policy commitments and plans to address energy and GHG emission reduction challenges (IEA 2012).

[8] Modern bioenergy is utilised at higher efficiencies than traditional biomass and includes liquids and gases as secondary energy carriers to generate heat, electricity, combined heat and power (CHP), and transport fuels (IPCC 2011).

2.2 What is Sustainable Bioenergy and What to Measure

The main areas of concern for policymakers regarding the sustainability of bioenergy production (in particular that of biofuels) are its impacts on food security and global commodity prices, life cycle GHG emissions reductions, resources depletion, 'land grabbing', ecosystem services and biodiversity. Figure 2.6 shows that sustainability of bioenergy needs to be considered systematically and holistically across the three pillars of sustainability (environmental, social and economic). It also points out the importance of scale and geographic context in the sustainability assessment of bioenergy value chains.

The EU, which depends more on imported feedstocks than the USA, both in terms of amounts and variety, to meet its bioenergy demands has been on the forefront of formulating broad environmental sustainability safeguards into its regulations (FAO 2013). However, the implementation of these criteria is complicated by the fact that many feedstocks have multiple, substitutable end-uses, e.g., wheat is used for food, feed, and fuel production, whereas the criteria apply to a single end-use thus creating the potential for leakage (Frank et al. 2012). Furthermore, at present, social sustainability safeguards are only realised as part of voluntary schemes adopted by selected biofuels producers.

The sustainability of bioenergy in terms of their efficacy to reduce GHG emissions by substituting fossil fuels hinges on two main factors: land use and biomass production practices. Land use change has direct (positive or negative) implications on terrestrial carbon stocks, and management practices encompassing zoning, crop selection and cultivation, energy and fertiliser inputs impact the GHG balance of the end-product. The core of the debate about the efficacy of bioenergy (again, with a particular focus on biofuels) continues to centre on the issue of indirect land use change (ILUC). While some modelling results indicate no ILUC impacts (e.g., Kim and Dale 2011), other studies show significantly lower impacts than previously estimated (e.g., INRA 2013) or very high GHG

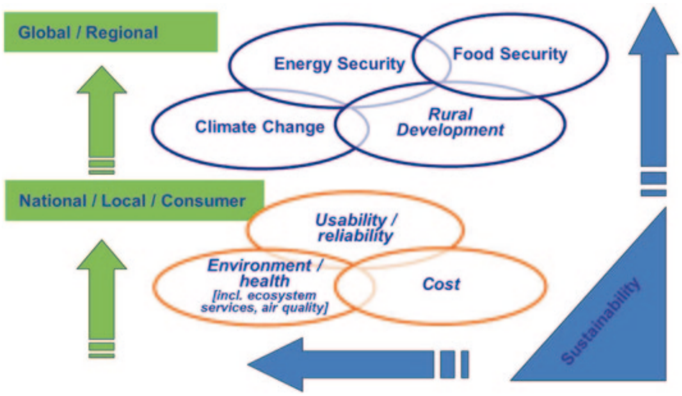

Fig. 2.6 Measures of sustainable bioenergy

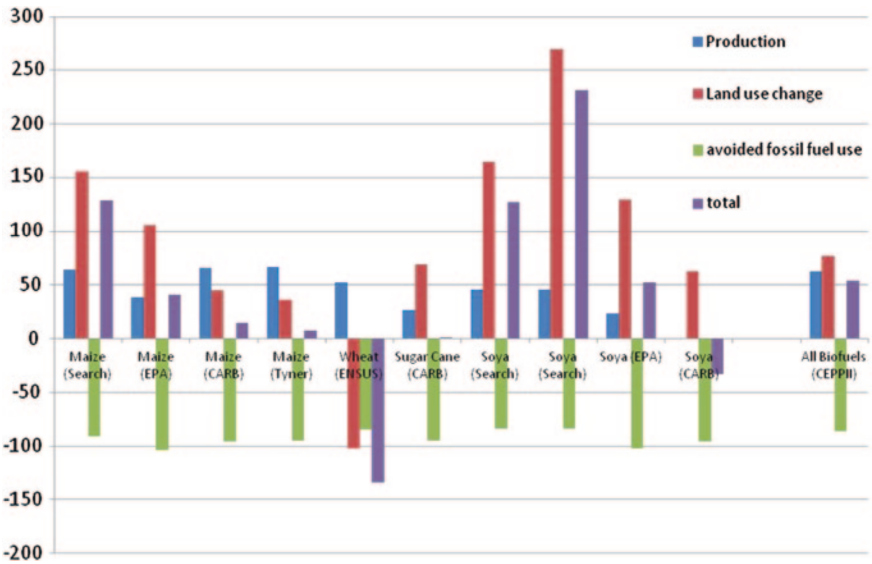

Fig. 2.7 Uncertainties of estimated indirect land use change GHG emission for selected biofuels (g CO_2 eq/MJ). *Source* adapted from EC DG-Tren (2010)

emissions (e.g., Searchinger 2010). Figure 2.7 further illustrates the divergence in the results of different ILUC modelling studies. The debate around the significant scientific uncertainties as to the magnitude and effect of ILUC has slowed down the development of bioenergy supply chains and diverted attention from wider issues of the sustainability of bioenergy and agricultural production more broadly.

'Land grabbing', defined as "the transfer of the right to own or use the land from local communities to foreign investors through large-scale land acquisitions" (Rulli et al. 2012) has also been attributed to the increase in demand for bioenergy feedstocks (GRAIN 2013). While numerous cases of illegal appropriations and human rights violations with disastrous impacts on smallholders and local communities have been reported and must be prevented in the future, a recent analysis by the Land Matrix (2013) suggests that the scale of the problem may have been largely exaggerated. Land Matrix reviewed 950 large-scale land acquisitions (LSLA) of 200 ha or more since 2000. Of the 750 concluded deals, covering a total area of 32.6 Mha, their research concludes that only approximately 5 % (or 1.63 Mha) have gone into agricultural production. Figure 2.8 shows that that while biofuel production has had an impact, food crops accounted for a larger share of deals and area. Forestry and tourism were also important sources of demand for land. A study by IIED on the socio-economic impacts of such land acquisitions concludes that the impact of these investments depends on the way they are structured, and "can either create new opportunities to improve local living standards, or further marginalise the poor (IIED 2009)".

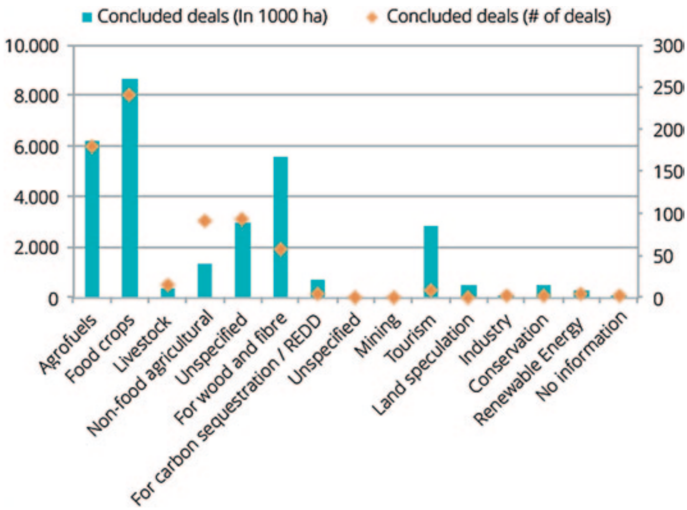

Fig. 2.8 Main drivers of large-scale land acquisitions. *Source* Land Matrix (2013)

Biofuels have also been blamed for the 2008-2009 spikes in food prices (e.g., Pimentel et al. 2009; ActionAid 2010). However, recent studies indicate that the causal relationships are more complex and that the increase in commodity prices can be primarily attributed to high crude oil prices (affecting energy and fertiliser costs), exchange rate movements, stock-to-use ratios, unusually frequent adverse weather events, and only in small part to EU and US demands for conventional biofuel feedstocks (Baffes and Dennis 2013; Oladosu and Msangi 2013). Nevertheless, concerns over global food security have dichotomised the issue and effectively placed the production of food and fuel in opposition (Rosillo-Calle 2012).

Sustainable bioenergy production must also adequately consider the protection of biodiversity. According to the Millennium Ecosystem Assessment (2005), see Fig. 2.9, "current rates of species extinction are at least two orders of magnitude above background rates and are expected to rise to at least three orders above background rates". In the UK, 60 % of monitored species have declined over the past 50 years and 10 % of species are threatened by extinction (UK 2013). Drivers of this unprecedented rate of biodiversity loss are habitat conversion and fragmentation, primarily due to agricultural expansion and urban development; increasingly, climate change, which contributes to habitat change, is becoming the dominant driver of extinction.

To address the aforementioned concerns regarding the sustainability of bioenergy and to provide policymakers and producers with a comprehensive framework to promote and monitor the development of bioenergy supply chains, the Global Bioenergy Patnership (GBEP) Proposed 24 indicators for the sustainable production and use of modern bioenergy (GBEP 2011). Table 2.1 summarises these indicators by pillars and themes. These indicators are thus far the only comprehensive framework for the sustainable development of bioenergy.

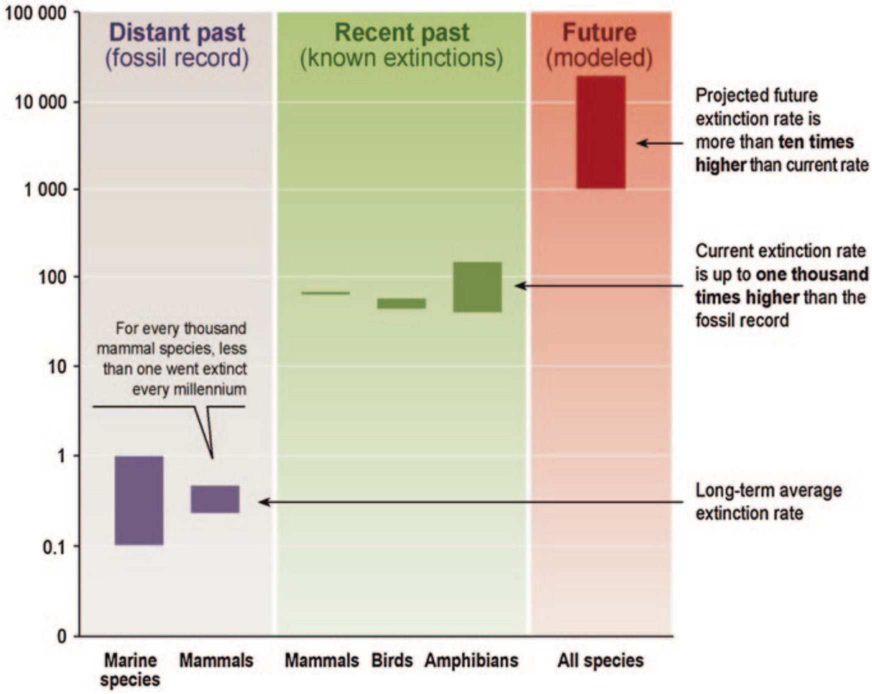

Fig. 2.9 Species extinction (per thousand species per millennium). *Source* MEA (2005)

2.2.1 Sustainable Agricultural Intensification: The Future of Food and Farming: Five Challenges for Global Sustainability

The production of bioenergy sits within a larger system of agricultural production. Bioenergy policies, given their narrow scope and mandate, cannot address the inefficiencies of global agricultural production overall. However, the controversies surrounding the large scale deployment of bioenergy, such land use change, food versus fuel, 'land grabbing', biodiversity loss, etc. may have assisted in recognising the necessity for a profound shift from conventional agricultural practices to a more sustainable, resource efficient and climate-smart, multi-product agricultural production system.

The need to provide food, shelter, energy and other resources for 9.2 billion people in 2050 against the backdrop of climate change requires concerted efforts today to avoid future shocks to global food production (Foresight 2011; Garnett et al. 2013). The Future of Food and Farming report highlights five key challenges for global food system (Foresight 2011):

A. Balancing future demand and supply sustainably—to ensure that food supplies are affordable.

Table 2.1 GBEP sustainability indicators

Pillars		
GBEP's work on sustainability indicators was developed under the following three pillars, noting interlinkages between them:		
Environmental	*Social*	*Economic*
Themes		
GBEP considers the following themes relevant, and these guided the development of indicators under these pillars:		
Greenhouse gas emissions, productive capacity of the land and ecosystems, air quality, water availability, use efficiency and quality, biological diversity, land-use change, including indirect effects	Price and supply of a national food basket, access to lard, water and other natural resources, labour conditions, rural and social development, access to energy, human health and safety	Resource availability and use efficiencies in bioenergy production, conversion, distribution and end use, economic development, economic viability and competitiveness of bioenergy, access to technology and technological capabilities, energy security/diversification of sources and supply, energy security/Infrastructure and logistics for distribution and use
Indicators		
1. Lifecycle GHG emissions	9. Allocation and tenure of land for new bioenergy production	17. Productivity
2. Soil quality	10. Price and supply of a rational food basket	18. Net energy balance
3. Harvest levels of wood resources	11. Change in income	19. Gross value added
4. Emissions of non-GHG air pollutants, including air toxics	12. Jobs in the bioenergy sector	20. Change in consumption of fossil fuels ard traditional use of biomass
5. Water use and efficiency	13. Change in unpaid time spent by women and children collecting biomass	21. Training ard regualification of the workforce
6. Water quality	14. Bioenergy used to expand access to modern energy services	22. Energy diversity
7. Biological diversity in the landscape	15. Change in mortality and burden of disease attributable to indoor smoke	23. Infrastructure and logistics for distribution of bioenergy
8. Land use and land-use change related to bioenergy feedstock production	16. Incidence of occupational injury, illness and fatalities	24. Capacity and flexibility of use of bioenergy

Source GBEP (2011)