Lecture Notes in Energy 27

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Liquid Biofuels: Emergence, Development and Prospects

Springer

Lecture Notes in Energy

Volume 27

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ISSN 2195-1284 ISSN 2195-1292 (electronic)
ISBN 978-1-4471-6481-4 ISBN 978-1-4471-6482-1 (eBook)
DOI 10.1007/978-1-4471-6482-1
Springer London Heidelberg New York Dordrecht

Library of Congress Control Number: 2014943248

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Introduction

The survival of the human species is linked to the exploitation of natural resources, as there is no other known way to provide the essential heat, energy, and food. There has been a great deal of debate regarding how this exploitation can occur, since to exist, organisms need to intervene in natural systems. A superficial analysis might suggest that an irreconcilable dichotomy has been created. Such reasoning may lead to extreme attitudes where, on one side there is the irresponsible use of natural resources, and on the other, the discourse suggesting that nature could be so much better off without the human presence on earth.

The state of well-being achieved by modern societies has increased the rate of unsustainable exploitation of the planet's resources. Our technological choices are based on our understanding that nature's capacity to provide for what we consider to be our needs is unlimited. It follows then that an alternative path must be designed so that those technological choices lead to a process of sustainable exploitation of natural resources. After all we are the only species on the planet that is endowed with a capacity for awareness that is sufficient not only to understand and evaluate our own destructive power, but also with the intelligence required to minimize it.

Therefore, it seems appropriate to move toward new productive systems, whether agricultural or industrial, where growth and development can be achieved without the opposition between capital and nature. For this to happen, we must overcome the economic, social, and political challenges that the technological solutions present.

Thus, understanding the relationships between the natural and social environment seems to be the way forward in the search for a solution to the problems that challenge the planet, since it is from within this society that the answers to those challenges will emerge. However, we must avoid believing in a *panacea*, since there is no single "cure" that can be used to solve modern problems, as there is an intricate set of social, economic, and ecological relationships. As Hippocrates said: "Disease is the result of the airs, waters and places."

There is insufficient space to address all these issues in a single book, so we have chosen just one path, that of energy. This choice is justified by its importance as a factor in development and its condition as one of the key elements in the interaction between society and nature. The production and use of energy determine numerous impacts on the planet and on societies. While it may be an indicator of well-being, its effects may be adverse (Dincer 2002).

Among the adverse effects of the current methods of obtaining and using energy one can include the environmental impacts, price fluctuations, geopolitical risks, and the risks of its nonavailability. Because of these effects, there has been growing interest in the search for alternatives to current patterns of production and consumption of energy throughout the world (Holdren 2006; Hanegraaf 1998). Within the energy sector worldwide, experts have addressed a number of issues, among them one can mention the research into conversion technologies as applied to different inputs in order to produce liquid and gaseous fuels, and into geographical organization for the production of food and energy.

Among the various studies of note, that by David Tilmann (2009) highlights the trilemma of the plant-derived fuel production systems. What he refers to as the trilemma is the need to simultaneously attend the requirements for food, fiber, and renewable fuels. Based on this trilemma and by analyzing initiatives from around the world, one possible conclusion is that with the current level of use of the technologies and services available it will be impossible to reverse the rate of exploitation of the resources required to meet our energy needs according to the criteria of social, economic, and environmental sustainability, considering the rate of world population growth and its impact on the volume of resources that will be required to meet those needs.

Inspired by these issues and based on the structuring of energy matrices in different countries, this book deals with different aspects of the production and use of liquid biofuels, derived from the production and conversion of biomass. Among the primary sources of energy, biomass has come to occupy a growing place in the energy mix worldwide. The concept of biomass can be understood as referring to all living matter on earth that is capable of storing solar energy (Taylor 2008; Goyal et al. 2008). Many researchers consider biomass to be a source capable of contributing to the energy needs of both developed and developing societies (Berndes et al. 2003).

Around the world, different arrangements for the production of bioenergy are being developed, with multiple integrated technologies that either benefit from the concentrated supply of inputs produced in large scale or take advantage of the small-scale production of inputs at the local level. These trends present us with the challenge to find the most efficient use for the natural inputs available.

From a demand and supply perspective, it should be noted that bioenergy is coming to be seen as a priority on the international agenda, with the use of liquid biofuels constituting a key strategy in the attempt to meet both the demand for environmental sustainability and the energy needs of countries. The growth in the production and use of biofuels around the world has led to increased interest and discussion on the subject, lending greater importance to related studies and research, as is the case with this book.

Without claiming to be exhaustive, this book provides a critical and plural discussion of the major issues being raised in the context of research and policies and the alternatives that are being outlined regarding the insertion of bioenergy in the energy matrices of several countries. In this sense the book provides a multidisciplinary and integrated view of the debate on the emergence and diffusion of the liquid biofuels as an energy source, bringing together different elements, such as public policy, industry organization, and the sustainability of different systems for the production of liquid biofuels and technology. The discussion on these different aspects will be illustrated by biofuel researchers and practitioners from a range countries that produce and consume biofuels.

In this book the reader will find that biofuel production, analyzed in relation to its institutional, economic, technological, and environmental aspects, is presented in two parts. The first, consisting of eight chapters, deals with the economic and environmental aspects. The second part of the book, consisting of four chapters, presents and discusses the technological issues. Importantly, almost all the chapters include discussions on the institutional aspects related to biofuel, especially the issue of regulation imposed by governments in order to strategically control the production and distribution of biofuels.

In compiling this book, our intention was to address the main issues and key challenges related to the production and consumption of bioenergy. When the call was issued to researchers from around the world, our main objective was to seek out different perspectives and analyses on the subject, while identifying points of convergence and divergence among several different research centers around the globe.

We hope that this book serves as a "must-read" reference for all those involved in biofuel-related research. We feel sure that it contains valuable material for the library of any biofuel researcher, practitioner, and/or educator. In selecting the contents, we have attempted to provide material that will be of interest to both those with experience in the field of biofuel and those who are setting out to discover its relevance.

"Economic Issues in the Liquid Biofuels Industry" discusses the market distortions that occur when the production costs of the first generation of biofuels compared with those of fossil fuels. In doing so, the relationship between the energy market and the agricultural market is emphasized. The relationship between biofuels and the agriculture and energy markets is dealt with from three perspectives: energy security risk; reduction of greenhouse gas emissions; and rural development. "A Comparison Between Ethanol and Biodiesel Production: The Brazilian and European Experiences" spotlights the Brazilian ethanol and European biodiesel scene in terms of the policies adopted and their production, supply and demand, as well as the environmental impacts of these biofuels.

"Global Market Issues in the Liquid Biofuels Industry" discusses issues such as the supply, demand, exports, imports, prices, and future perspectives of the global market for ethanol and biodiesel by focusing on Brazil and the United States. Both countries are of great importance in the global biofuel market both in terms of their respective production capacities and as consumer markets. "The Biofuel Industry Concentration in Brazil Between 2005 and 2012" deals with the growth and concentration of production capacity in the Brazilian biofuels industry.

"Calculation of Raw Material Prices and Conversion Costs for Biofuels" takes a closer look at the discussion regarding the raw materials in the first generation biofuels, by presenting a forecast of raw material prices, simulating the likely effects on production costs of the economies of scale obtained from scaling-up production and from technological learning. An analysis is provided of various scenarios in which different biofuels and fossil fuels are compared. Regarding raw materials for the production of biodiesel, two chapters present and discuss alternatives to the traditional oilseeds used in biodiesel production, though with an organizational and economic focus. "Governance of Biodiesel Production Chain: An Analysis of Palm Oil Social Arrangements" deals with the governance structure of the biodiesel production chain in Brazil from a social perspective by focusing on the relationship between the farmers and the palm oil industry. "An Economic Assessment of Second-Generation Liquid Fuels Production Possibilities" provides an economic assessment of the possibility of producing the second generation biofuels, more specifically bioethanol production from lignocellulosic materials in the United States.

"Environmental Issues in the Liquid Biofuels Industry" completes the first part of the book and deals with the environmental issues involved in the liquid biofuels industry, presenting the different generations of biofuels and discussing them in relation to their Tailpipe Emissions, life cycle, Ecological Footprint, and Climate Threats and Technological Opportunities.

The second part of the book addresses the technological aspects of biofuel production. The chapters within it highlight the different types of technologies used in biofuel production and the use of new materials such as algae, oleaginous organisms, and waste polymers. Accordingly, "Application of Analytical Chemistry in the Production of Liquid Biofuels" discusses the use of chemical analysis in the production of biofuels with respect to the evaluation of the quality and chemical composition of the raw materials and all materials and by-products in the production process. Also related to the use of chemistry in the production of biofuels, "Technical Barriers to Advanced Liquid Biofuels Production via Biochemical Route" deals with the technical barriers to advanced liquid biofuel production via the biochemical route, focusing on second and third generation feedstocks.

The chapters that follow focus on the use of new raw materials for the production of biofuels as alternatives to mitigate the problems and limitations posed by the use of the raw materials of agricultural origin used in the first generation of biofuels. "New Frontiers in the Production of Biodiesel: Biodiesel Derived from Macro and Microorganisms" highlights the state of the art and the main characteristics of the oil and biodiesel provided by macroorganisms (insects) and microorganisms (bacteria, filamentous fungi, and yeasts). "Algae: Advanced Biofuels and Other Opportunities" looks into the use of algae as an alternative source of biofuels, presenting a review of microalgae cultivation (species, usage, processes, and culture), while highlighting the advantages and challenges of algae-based biofuel. The last chapter is not directly concerned with biofuels, as it focuses on another possible alternative, liquid fuels from waste polymers, thus opening another possible route for the production of alternative fuels to petroleum, and potentially minimizing the environmental impact by using industrial waste from various industries.

Acknowledgments We are very grateful for the support and contribution of so many authoritative biofuel researchers and practitioners in writing chapters for this book. We extend a special thanks to Springer's publication team for their encouragement, help, and patience in compiling this book.

The Editors

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Contents

Economic Issues in the Liquid Biofuels Industry

Hong To, Suman Sen and Michael B. Charles

Abstract Biofuel policies around the world have, in general, been driven by concerns relating to energy security, greenhouse gas (GHG) abatement and regional development. However, in major biofuel markets, these policies have led to market distortions that have problematized the achievement of the longer-term objectives associated with biofuels. In particular, prioritization of certain economic goals, like assisting rural areas, has hindered the achievement of other outcomes, such as decoupling national energy security from fossil fuel prices and achieving the greatest possible emission abatement. A shift towards next-generation equivalents is desirable, but the currently low price of conventional fuel and the high production costs of advanced biofuels currently act as a barrier to commercialization. These barriers are most likely to be overcome as conventional fuel resources become depleted and advanced biofuel technologies mature over time. Until then, government intervention will be crucial in determining the industry's future.

1 Introduction

Today, more than 99 % of all biofuels produced are first-generation biofuels made from edible crops. Yet the long-term viability of these fuels is questionable owing to the following: (1) the use of feedstock optimized for food production, rather than for energy production, thereby resulting in direct competition with food supply; (2) rising prices of certain crops and food stuffs owing to the rapid expansion of global biofuel production and, in return, increasing costs for biofuel production; and (3) the utilization of only a portion of the plant's total biomass, which results in waste, so that land-use efficiency is low from energy supply and/or greenhouse gas (GHG)

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A. Domingos Padula et al. (eds.), *Liquid Biofuels: Emergence, Development and Prospects*, Lecture Notes in Energy 27, DOI: 10.1007/978-1-4471-6482-1_1,

mitigation perspectives.[1] As a consequence, there are growing concerns about the economic, environmental and social sustainability of biofuels if they are to replace a significant proportion of the world's petroleum use. Although biofuel production and support policies are usually expected to reduce dependence on fossil fuels, mitigate anthropogenic climate change and support rural development, arguments for biofuel policies should also be made from an economic perspective, i.e. in the case of market failures that impede a desirable allocation of resources.

The chapter starts by describing the growth of the biofuel industry over the last decade, with emphasis on developments in the United States, Brazil and the European Union (EU), all of which are now significant biofuel markets. It then presents an assessment of the economic impacts of a growing biofuel industry, beginning with production cost issues. In particular, the chapter looks closely at the interrelationships between biofuels and agricultural and energy markets, all of which raise important implications for biofuel production scale, together with food security and biomass prices. The chapter also analyses the cost-effectiveness and competitiveness of biofuels as well as their macroeconomic impacts. To do this, we will look at effects of pro-biofuel policy on the three most commonly touted benefit areas associated with biofuels: (1) promoting energy security; (2) reducing the environmental impact of liquid fossil fuels; and (3) enhancing rural economies.

2 Global Production and Consumption

The biofuel industry has experienced remarkable growth over the last decade. Global production has tripled from about 18 billion litres in 2000 to about 60 billion litres in 2008 and has continued to grow after a slight pause in 2007–2008 (Kristoufek et al. 2012; Mandil and Shihab-Eldin 2010). However, production and consumption of biofuels worldwide returned to growth in 2010. According to US Energy Information Agency (EIA) data, total world biofuel production increased nearly six-fold over the 2000–2010 period, that is, from about 18 billion litres to about 104 billion litres. Supply is currently dominated by bioethanol, which accounted for approximately 75 % of total biofuel production in 2010 (Mandil and Shihab-Eldin 2010; Moschini et al. 2012). Similar figures are also reported for biofuel demand. Despite the growth in the biofuel industry, global consumption of biofuels in 2012 represented 3 % of total fuel consumption (IFPEN 2012), i.e. 55 million tons oil equivalent, of which 73 % is bioethanol consumption. Global production and consumption of biofuels, over the 2000–2011 period, are presented in Fig. 1.

At present, biofuel production and consumption are concentrated in a small number of countries or regions, with the United States, Brazil and the EU being particularly salient. Bioethanol has been the leading biofuel in the United States (from corn) and in Brazil (from sugarcane), whereas biodiesel is the preferred biofuel in Europe (from

[1] These matters are dealt with in detail in chapter "Environmental Issues in the Liquid Biofuels Industry".

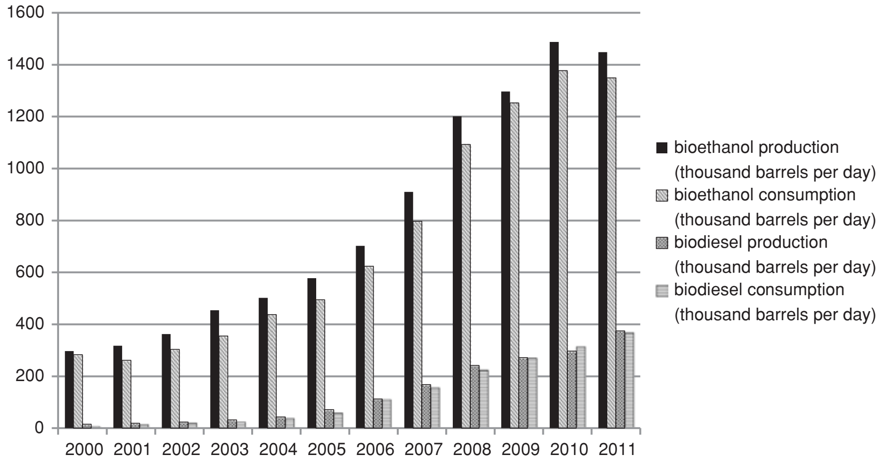

Fig. 1 Global biofuels production and consumption (2000–2011) (US EIA 2013)

Table 1 Global bioethanol production and consumption (US EIA 2013; USDA 2012a, b)

Country	2009 Production	2009 Consumption	2010 Production	2010 Consumption	2011 Production	2011 Consumption
	(billion litres)					
United States	41.6	41.8	50.3	48.67	52.8	48.72
Brazil	26.1	24.5	28.0	24.3	22.9	21.1
World	75.2	72.7	86.3	80.0	84.1	78.3

Table 2 Global biodiesel production and consumption (US EIA 2013; USDA 2012a, b)

Country	2009 Production	2009 Consumption	2010 Production	2010 Consumption	2011 Production	2011 Consumption
	(billion litres)					
United States	1.95	1.2	1.3	1	3.7	3.3
Brazil	1.6	1.57	2.4	2.5	2.7	2.6
EU	9.5	11.9	10.7	13.2	11.7	14.1
World	15.8	15.8	17.2	18.4	21.7	21.4

rapeseed oil) (Moschini et al. 2012). In 2006, the United States surpassed Brazil as the world's largest bioethanol producer and consumer and, by 2010, was producing 57 % of the world's bioethanol output. The EU follows as the third major producer (Mandil and Shihab-Eldin 2010; Moschini et al. 2012). By way of contrast, the EU is the largest producer and consumer of biodiesel. Over the period of 2009–2011, the EU accounted for about 60 % of global biodiesel production and about 70 % of global biodiesel consumption. The production and consumption levels in these three regions over the 2009–2011 period are summarized in Tables 1 and 2.

Of particular importance is that the industry is very much reliant on first-generation fuels (explained in Sect. 2 in chapter "Environmental Issues in the Liquid Biofuels Industry"). While these are generally produced from food crops (such as sugar cane, sugar beet or corn in the case of bioethanol, and vegetable oil derived from oleaginous crops in the case of biodiesel), they also have a variety of other commercial applications (such as stock feed in the case of corn, or use in industrial products such as cosmetics and engine lubricants, in the case of vegetable oils). The cost-effectiveness of first-generation fuels is therefore closely tied to the global price of the feedstock used—a price set not only by demand for these feedstocks for energy, but also for other purposes.

3 Production Costs

First-generation biofuels are relatively cheaper to produce than advanced biofuels (second-generation biofuels and beyond), but they still cost more than equivalent fossil fuels, and are also problematic from a sustainability perspective, as discussed in chapter "Environmental Issues in the Liquid Biofuels Industry". Although advanced biofuels could address the latter issue, commercial production is yet to commence because of the higher start-up and operational costs associated with these production processes. This section will provide a comparison of the production costs of biofuels vis-à-vis fossil fuels.

The feedstock for first-generation biofuels, i.e. edible crops, accounts for nearly 55–70 % of the total production cost (IEA 2008). As a result, first-generation biofuels, in general, are unable to compete effectively with fossil fuels (UN 2008), particularly when government subsidies and other incentives are removed from the equation. Only sugarcane-based bioethanol produced in Brazil, which costs USD 0.25–0.35 per litre of gasoline equivalent[2] (lge), is competitive with gasoline at USD 0.34–0.42 per litre (i.e. USD 40–50 per barrel) (IEA 2007).[3] By way of contrast, the cost of corn-based ethanol in the United States and sugar beet-based ethanol in the EU vary between USD 0.60–0.80/lge (IEA 2007)—much higher than the then price of gasoline. Likewise, the cost of producing biodiesel from animal fat, vegetable oil, tallow fat and palm oil varies between USD 0.40–0.50, 0.60–0.80, 0.60–0.85 and 0.82–0.86/lde,[4] respectively (IEA 2007; RFA 2007), all higher than production costs of petroleum-based diesel. For some feedstocks, such as cooking oil, commercializable by-products could lower its effective cost (Demirbas 2009).

[2] Bioethanol energy content is two-thirds that of gasoline, and therefore is referred to as litre of gasoline equivalent (lge).

[3] India, Pakistan, Swaziland and Zimbabwe have production costs that are broadly similar to those experienced in Brazil (Demirbas 2009; Dufey 2006).

[4] Biodiesel energy content is 10–12 % less than that of diesel, and therefore is referred to as litre of diesel equivalent (lde).

Table 3 Production price of second-generation biofuels in selected countries (adapted from Eisentraut 2010)

Oil price: USD 60/bbl		Feedstock price	Bioethanol	Biodiesel
		USD/GJ	USD/lge	USD/lde
Woody energy crop	Global (IEA analysis)	5.4	0.91	0.84
Straw/stalks	China	1.9–3.7	0.68–0.85	0.66–0.79
	India	1.2–4.3	0.63–0.86	0.62–0.80
	Mexico	3.1	0.79	0.74
	South Africa	0.8–3.1	0.60–0.79	0.60–0.74
	Thailand	2.0–2.8	0.67–0.77	0.67–0.72

Second-generation biofuels are produced from the cellulosic content of inedible plants. While the cost of such feedstock is comparatively lower, it still represents around 36 % of the net production cost of the biofuel (USDA 2010). Processing-related expenses, including chemicals such as enzymes, are substantial. Although technological advances have significantly lowered the cost of cellulosic ethanol (Wyman 2008), the processing technique employed continues to be most significant determinant of the fuel's net production costs. The IEA (2007) estimated the cost of second-generation bioethanol and biodiesel at approximately USD 1.00/lge (assuming feedstock price of USD 3.6/GJ) and USD 0.90/lde (assuming feedstock price of USD 3.6/GJ), with a potential reduction to USD 0.50/lge and 0.70–0.80, respectively, by 2017. Furthermore, the cost of setting up a second-generation biofuel refinery is potentially up to ten times that of establishing an equivalent first-generation production unit (Eisentraut 2010). While this additional outlay partially negates the advantage of using lower-cost feedstocks, larger plants may be able to capture economies of scale and achieve some cost savings (UN 2008). Nevertheless, high capital investments are a major concern, particularly for those plants being proposed in less developed countries (Eisentraut 2010).

Eisentraut (2010) theoretically deduced the cost of second-generation biofuels produced in different countries by assuming capital costs to be 50 % of the total production costs, feedstock 35 %, operation and maintenance, energy supply for the plant, and other expenses between 1 and 4 % each. Table 3 summarizes these estimates.

Eisentraut (2010) also compared the probable production cost of second-generation biofuels if an oil price of USD 120/bbl is assumed. He concluded that bioethanol and biodiesel would cost USD 1.09 and 1.07, respectively, in the short term. In the long term, prices are projected to fall to USD 0.72 and 0.73, respectively, which would be lower than gasoline and rapeseed biodiesel, and also competitive with first-generation bioethanol. The above figures should be considered in tandem with the then price of fossil fuels. This, however, does not greatly change the cost efficiency of biofuels as the cost of biofuels continues to increase with the rise in price of feedstock and other inputs (OECD 2011). In addition, these costs are purely economic and do not include the various environmental costs typically included in life-cycle analyses (LCAs), as explored in chapter "A Comparison Between Ethanol and Biodiesel Production: The Brazilian and European Experiences". Other costs associated with production, and that of first-generation biofuels in particular, relate to storage, especially given the seasonal nature of biofuel production (Moreira and Goldemberg 1999; Karp and Richter 2011).

4 Economic Issues Relating to Energy Security

The oil crises in the 1970s awakened oil-importing countries to their dependency on oil-rich nations. Increasing energy demand, together with finite stock of fossil fuels, has resulted in rising oil prices over time. Since a good deal of global oil production occurs in politically unstable regions, thereby resulting in recurrent shocks, price spikes and general volatility, concerns about national security have escalated during an era of increasing energy demand (Council of Economic Advisers 2008). From an economic perspective, the pursuit of energy security can be related to a number of possible market failures, including the power of OPEC and the unequal distribution of oil wealth around the globe. This results in insufficient competitive conditions, which led to sub-optimal resource allocation (Tsui 2011). From a national perspective, the energy security argument ascribes benefits to reducing oil imports (Delucchi and Murphy 2008; Lapan and Moschini 2012). For example, the hidden cost of oil dependence for the United States is estimated to be about USD 3 per gallon of conventional liquid fuel (Copulos 2007). This cost includes incremental military costs, supply disruption costs and direct economic costs.

Given that the existing mobile energy paradigm relies heavily on liquid fuels, this means, especially in the developed world, exchanging increasingly price-volatile hydrocarbon-based liquids fuels for a proportion of biofuels, the feedstock of which can be grown domestically, or at least sourced from comparatively stable economies. An important issue is that biofuels are generally blended with hydrocarbon-based fuels. In effect, biofuels, especially land- and labour-intensive first-generation biofuels, cannot replace hydrocarbon-based liquid fuels on a one-for-one basis, yet they can extend remaining petroleum supplies and, at a general level, the infrastructure that uses them. But this means that liquid fuels in countries desirous of enhancing their energy security will not be able to divorce themselves completely from the global oil price. Hence, the use of biofuels merely *improves* energy security, but does not result in independence from fossil fuels.

It is necessary to understand the link between energy (i.e. oil and biofuels) and agricultural commodity markets to analyse how biofuels, especially first-generation biofuels, could meet the stated national energy security objective when using feedstock optimized for food production, rather than for energy production. Given that agriculture is an energy-intensive sector, one can draw a direct linkage from oil prices to agricultural commodity prices. The emergence of biofuel markets has raised another linkage between oil prices, biofuel prices and the prices of feedstock crops (and the prices of agricultural commodities in the end).[5] Biofuels have a direct effect on the agricultural sector because they use biomass as an input that, together with agricultural commodities, is produced on a fixed area of agricultural land. The increase of agricultural commodity prices could be significant owing to

[5] de Gorter and Just (2010) have shown that crop prices, i.e. corn prices in the case of the United States, are directly linked to that of bioethanol. A theoretical framework with regard to the relationship between sugar cane prices and bioethanol prices in Brazil or between palm oil/soybean prices and biodiesel prices in the European Union can be formulated easily in a similar way.

price inelasticities of food demand and land supply. For example, markets for corn, wheat and rice in the United States, the world's reserve supplier of grains, saw a drastic increase in related food prices (AgMRC 2009). Corn prices rose from USD 2.20 per bushel in 2006 to above USD 5.20 per bushel in 2007 and reached a high of USD 7.60 per bushel in the summer of 2008. A casual observation also suggests a direct link between these price rises and biofuel output.

However, the potential impact of the expansion of first-generation biofuel production on food crop prices remains controversial. Some argue that biofuel production has an adverse impact on food prices and poverty, especially in developing countries (Runge and Senauer 2007; Mitchell 2008). The World Bank has shown that up to 75 % of the increase in food prices could result from biofuel expansion (Mitchell 2008), while the IMF estimated that the increased demand for biofuels accounted for 70 % of the increase in corn prices and 40 % of the increase in soybean prices (Lipsky 2008). Likewise, the FAO (2008) and the OECD (2009) have argued that biofuel expansion was a substantial factor in causing food price rises. Yet some, like Hassouneh et al. (2011), Mallory et al. (2012) and Du and McPhail (2012), have played this down. Indeed, according to the USDA, the biomass demand for biofuels has little impact on food commodity prices (i.e. biofuel production generating only 3 % of the 40 % rise in global food prices) (Reuters 2008). Similarly, the European Commission (2008) argues that the impact of biofuel on food crop prices is likely to be very small. Alexandratos (2008) found that increases in the demand for food in emerging countries, particularly China and India, together with weather issues, poor harvests, speculation and financial crises, are the dominant factors behind demand shocks. Yet he acknowledges that the addition of biofuels results in food crop demand growing faster than in the past, which could prevent the current commodity prices trending back towards pre-surge levels.

According to the theoretical framework developed by Gardner (2007), de Gorter and Just (2008b, 2009a), together with empirical work by Ciaian and Kancs (2011), increased bioethanol production results in increasing corn prices, which in turn substantially increases bioethanol prices. Yet an increase in bioethanol prices does increase the price of corn and of other crops because corn competes for land with other crops, while other crops are substitutes in consumption. Thus, the circular impact of high corn and bioethanol prices continues until the opportunity cost of corn for other uses is above the marginal benefit derived from converting corn to bioethanol when high-cost biofuel feedstocks are present. Above this point, bioethanol would cease to be produced unless there are substantial production subsidies. The inefficiency of production subsidies owing to high taxpayers' costs and the cost of interaction effects between existing policies (de Gorter and Just 2009a, 2010) implies that, with rising feedstock prices over time, no additional bioethanol would be produced in the longer term when subsidies are no longer enough to induce production. Indeed, a direct link between rising agricultural commodities prices and biofuel output raises concerns about the viability of biofuel production at a scale sufficient to replace a significant proportion of a nation's use of petroleum. This is because biofuel production and costs are uncertain and vary with the feedstock available, together with price volatility. This is especially the case when feedstocks need to be imported.

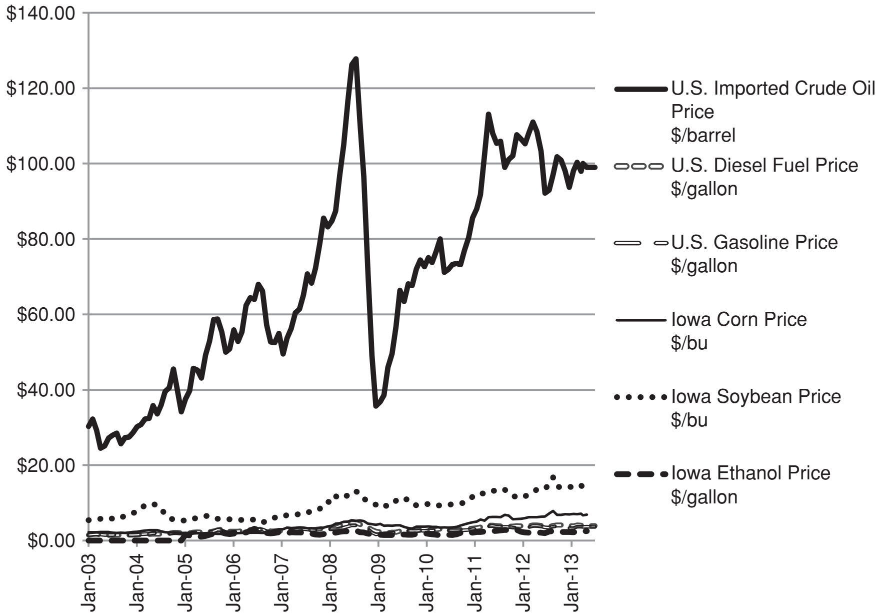

Fig. 2 Agricultural commodity and crude oil price trends in the United States (AgMRC 2013) (monthly price data from January 2003 to May 2013 for two main agricultural commodities corn and soybeans along with energy prices for imported crude oil, diesel, gasoline and ethanol are sourced from AgMRC 2013.)

The limitation of direct food-versus-fuel competition therefore favours the development of later-generation biofuels derived from non-edible biomass. Although these biofuels have addressed some of the problems associated with first-generation biofuels, the issues of competing land use and required land-use changes with regard to second-generation biofuels' feedstock production are still relevant (Brennan and Owende 2010). Since food demand and land supply are price inelastic, the price increase of agricultural commodities owing to competition with second-generation biofuels' feedstock production may still be substantial. Figures 2 and 3 show the price trends of agricultural commodities and energy in the United States and at a global level, respectively. Prices of agricultural commodities have been volatile and are rising over time. Although the surge in the sugar price during 2010–2011 stemmed from weather shocks and poor yields in the two largest sugarcane-producing nations (NREL 2013), i.e. Brazil and India, sugarcane-based bioethanol production was arguably another contributing factor (Alexandratos 2008). At a global level, the prices of palm oil and soybean are even more volatile. The explanation could be that both palm oil and soybean are not only used as feedstocks for biodiesel, but also are in demand for other purposes.

Furthermore, the trends of these agricultural prices are very much similar to those of energy prices, and crude oil prices in particular. The link between crude

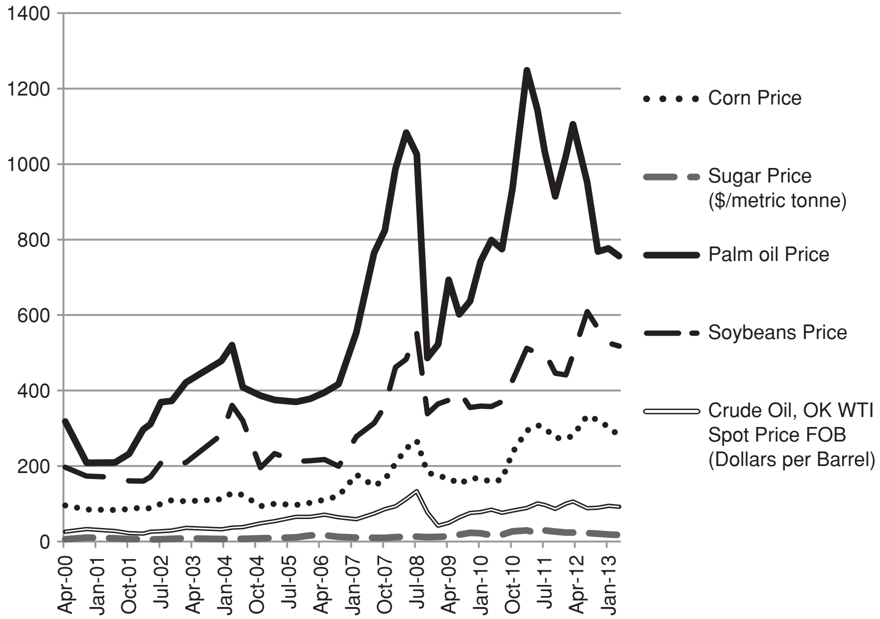

Fig. 3 World agricultural commodity and crude oil price trends (AgMRC 2013; World Bank 2013) [*Note* that crude oil, corn, sugar, soybean and palm oil prices are from markets located in major world trade centres that can represent world prices. Monthly price data from April 2000 to April 2013 with oil prices are sourced from the AgMRC (2013). Other price data are collected from the World Bank (2013)]

oil prices and those of agricultural products works via the following: (a) the effects of crude oil prices on agricultural commodity production costs given agriculture's heavy reliance on energy-intensive inputs (fertilizer, fuel and, in irrigated agriculture, electricity) and (b) the macroeconomic effects of crude oil prices, e.g. on inflation, incomes, interest rates, exchange rates and foreign trade, all of which have impacts on the agricultural commodity demand–supply balance affecting the prices (Alexandratos 2008). The implication from Mitchell's estimates (2008) is that the increased petroleum costs caused food prices to increase by 15–20 %. Thus, the use of pro-biofuel policies to improve national energy security becomes questionable. This is because a nation cannot entirely escape from oil price volatility by moving to biofuels derived from edible crops because these remain linked to global oil prices. The difficulty of escaping from oil price volatility is exacerbated with first-generation biofuels, but also might apply when a market is created for non-edible feedstocks, the production of which will also, in some cases, be affected by crude oil prices. Although later-generation biofuels could limit market distortions relating to the direct food-versus-biofuel competition, they may not escape volatility relating to fossil fuel prices. This would especially be the case for grass crops, but perhaps not for milling residue.

5 Economic Issues Relating to Reducing Emissions

Biofuels are expected to enhance sustainability and minimize GHG emissions. The argument in favour of biofuels with respect to reducing emissions is that biofuels, especially cellulosic-based biofuels, emit much less carbon dioxide than conventional petroleum fuels. Yet there are many economic issues that currently work against these interests, these being (1) the high production costs of biofuels, particularly advanced (second-generation onwards) biofuels and (2) the comparatively low conventional fuel prices that do not yet internalize the cost of GHG emissions associated with its extraction, production and combustion. This section provides an insight into the economic issues relating to shifting towards a biofuel regime that intends to realize GHG abatement goals.

As discussed earlier in Sect. 3, the production costs of biofuels, except for sugarcane-based bioethanol produced in Brazil, are much higher than those of fossil fuels (IEA 2007; UN 2008). Furthermore, the substitution of fossil fuels with first-generation biofuels raises concerns with respect to social and ecological sustainability, and also the scope to reduce net GHG emissions (Searchinger et al. 2009). Advanced biofuels could overcome the disadvantages associated with first-generation biofuels, but they are yet to be produced en masse. The technologies employed for advance biofuel work very well at a laboratory scale, but the most significant challenge is to find ways to produce these biofuels at a commercial scale, and at a competitive price (EMBO 2009). The EMBO report added that biofuel companies are often too optimistic with their biofuel plans given that they tend to look at projected production costs based on the availability of mature technology at commercially feasible prices.

Let us consider the case of Shell and its advanced biofuels projects. In 2008, Shell was working on ten such projects, most of which have now been shut down (Shell 2013). Furthermore, none of those that remain is ready for commercialization. Shell has admitted that bringing these biofuels to the market will take longer time than expected (Economist, 2013). Acknowledging the issues of producing advanced biofuels at a competitive price, and consequently the limited incentive for biofuel producers, the United States Environmental Protection Agency (EPA) revised its target for cellulosic biofuels from about 76 million litres between 2010 and 2012 to 53 million litres for 2013 (IEC 2013). The two potential drivers of a truly sustainable biofuel regime thus appear to be the following: (1) an increase in the price of fossil fuels as we move towards a post-peak oil period, or as conventional fuel becomes depleted and the cost of extracting unconventional fuel (from oil sands or shale) becomes uneconomical and (2) the potential decrease in the costs of biofuel production (mainly advanced) as technology slowly matures.

First, we discuss the likelihood of the former, i.e. an increase in the price of fossil fuels. Since the golden age of oil discovery in the 1950s and 1960s (Fleay 1995), the rate of oil consumption has risen steeply (Grant 2007; Leder and Shapiro 2008). Kilsby (2005) reported that the world is consuming oil four times faster than the rate at which it finds new petroleum sources. Although the quantity of world's oil reserves and the end of the fossil fuel age are highly debatable (Hirsch 2005; Leder and Shapiro 2008), there is little doubt that this point will eventually be reached. This does not mean that the stock of fossil fuels will run out; rather, 'cheap oil' will certainly come to an end (Kilsby 2005). To illustrate, let us look at the post-peak oil period, when oil reserves and overall supply begin to shrink. In the face of rising demand, this situation would create a substantial imbalance between oil supply and demand (Grant 2007), and the price of oil would rise rapidly as a consequence (Hirsch 2005; Leder and Shapiro 2008). Furthermore, as the world's stocks of fossil fuels decrease, exploration and extraction activities of the remaining reserves will become increasingly uneconomical, while the energy costs associated with doing so will also rise (Hall et al. 2008; Bardi 2009). These costs could conceivably push the oil price high enough to enable the global biofuel market to evolve sustainably. From an economic perspective, one of three possibilities may occur: (1) oil is the only source of energy supplied in the economy when the price of oil is lower than the price of backstop energy; (2) both oil and backstop energy are supplied in the economy when the price of backstop energy becomes competitive vis-à-vis the price of oil; or (3) backstop energy dominates energy supply in the economy when backstop energy technologies mature and the price of oil is high. At present, with pro-biofuel policies favouring first-generation biofuels, we are experiencing the case of both fossil and subsidized biofuels being supplied in the market.

The second potential driver is the technological advances in the production of advanced biofuels, such as cellulosic-based biofuels. The three main technological conversion pathways for cellulosic biofuel production are selective thermal processing, hydrolysis and gasification (Baker and Keisler 2011; Bosetti et al. 2012). Each of these pathways consists of two major steps. The first step involves breaking down the biomass into an intermediate product consisting of simpler substances, while the second step involves processing the same intermediate product into a commercial fuel. The technologies involved in the latter process, such as biooil and biocrude refining, are similar to those used in fossil oil refining. These technologies are relatively mature compared to the technologies involved in the first step. Fischer–Tropsch is worth mentioning here as it is one of the most cost-effective and established technologies used in the second step. The overall cost efficiency of cellulosic biofuels therefore mainly depends on technological advances for the first step of primary biomass conversion, in particular gasification and hydrolysis (Mandil and Shihab-Eldin 2010; Bosetti et al. 2012). With growing public and private funding towards research and development of advanced biofuels, these technologies are expected to mature by 2030 (Bosetti et al. 2012). Future projected costs (USD/lge) for these technological paths are summarized in the following Table 4, where it is assumed that the feedstock used is switchgrass costing USD 70/tonne.

Given that the increasing demand for biofuels cannot fully be met by first-generation biofuels derived from food crops, the market for advanced biofuels seems to be large enough to accelerate the development and commercialization of advanced biofuel technologies. At present, most of the market demand for biofuels is policy driven. For example, the recently introduced Renewable Fuel Standard 2

Table 4 Projected costs for the different cellulosic biofuel technology paths (adapted from Baker and Keisler 2011)

Technology path	Fuel	USD/lge
Selective thermal processing with pyrolysis	Gasoline	0.6
Selective thermal processing with liquefaction	Gasoline	0.73
Hydrolysis followed by aqueous phase	Diesel	0.69
Hydrolysis followed by fermentation	Bioethanol	0.74
Gasification followed by Fischer–Tropsch	Diesel	0.59
Gasification followed by syngas to bioethanol conversion	Bioethanol	0.67

(RFS2) in the United States and the Renewable Energy Directive (RED) in the EU both require a reduction in GHGs emission by at least 20–35 %. This can only be achieved by increasing the share of advanced biofuels, which, in turn, creates significant demand for these fuels. Furthermore, demand comes from industries pursuing an interest in biofuels for enhancing a socially responsible image, or because they recognize that their business will need to shift to a cost-effective renewable fuel in the future if it is to survive. For example, the US Navy has announced that it wants to source half its nonnuclear fuel from renewables by 2020 (DofNavy 2010), and particularly advanced biofuels, since these avoid the controversial food-versus-fuel issue. Likewise, major commercial airlines (e.g. United, British Airways, Lufthansa and Qantas) that are aiming to become carbon neutral by 2020 have expressed their interest in including cellulosic biofuels within their fuel mix. With the increasing costs of conventional jet fuels owing to the implementation of carbon taxes (e.g. Australia's carbon tax requires airlines to pay more than AUD 20 per emitted ton of carbon) and increasingly stringent climate change regulatory policies around the world, the airline industry sees renewable energy as a key to its continuing growth (Qantas 2013; IFPEN n.d.).

Despite the market potential discussed above, a neoliberal approach, where only market forces prevail, will not allow advanced biofuels to reach sufficient global market penetration at the required level so as to meaningfully combat GHG emissions from the transport sector. This is because it is unlikely that conventional fuels will ever be priced—at least in the immediate future—at a level that internalizes all external costs, including the cost of GHG emissions associated with their extraction, production and combustion. It is therefore desirable that some form of government intervention takes place so as to ensure the growth of the biofuel industry, particularly if the projected GHG emission reductions are to be realized at a lower cost than would be the case in a business-as-usual scenario.

Thus, an increased adoption of biofuels at a global level will largely depend on the position that governments take on the trade-off between the environmental and economic justification of biofuels, more so given that current pro-biofuel policies are claimed to be very costly and have a negligible net effects on emissions. For example, taking the US biofuel market into consideration, Jaeger and Egelkraut (2011) found the then approach to be 14–31 times more costly than alternatives such as increasing the gasoline tax or promoting energy efficiency improvements.

In addition, RFS2 and RED have sparked a debate over their effectiveness in reducing GHG emissions owing to potential ‘carbon leakage’ that may occur in other sectors and countries not covered by the same sustainability standards. For example, these standards would provide incentives to bioethanol producers to use relatively clean inputs (e.g. natural gas), while the dirtier inputs (e.g. coal) that might otherwise have been used are shifted to other uses not covered by the sustainability standards. Carbon leakage also happens at an international level when Indonesia exports sustainable biodiesel and consumes unsustainable biodiesel at home, or when the United States purchases Brazilian bioethanol to comply with its RFS2, while Brazil imports emission-intensive corn-based ethanol from the United States that does not meet RFS2. Significant volumes of bilateral trade of bioethanol between the United States and Brazil driven by their different biofuel policies have been seen in recent years, but no global changes to emissions were achieved (de Gorter and Just 2010; Meyer et al. 2013).

In the end, of course, the two potential drivers signalled above will have a more important role. In other words, for advanced biofuels to be sustainable in the long term, they will need to be economically competitive vis-à-vis conventional fossil fuels without government subsidies, especially if one takes into account an appropriate credit allocation for emissions reduction. When the above two driving forces become more entrenched, partially as a result of strategic government intervention, the biofuel industry will be ready to operate independently and according to the precepts of free-market economics.

6 Economic Issues Relating to Rural Development

Biofuels have often been seen as a way to enhance the agricultural sector. This is especially the case in the developed world, where locally produced food crops find it increasingly difficult to compete at a global level because developing and underdeveloped nations produce the same at a much lower cost. In these cases, governments provide considerable subsidies, promote low-interest loans and impose various trade barriers to incentivize farmers to produce these crops at a competitive price and thereby sustain their agricultural sector. Given that biofuels, especially first-generation biofuels, rely on edible crops as a feedstock, they create an alternative market for such agricultural products as a valuable input for the energy sector. In this section, we look at the degree to which rural economies, where farming is the livelihood for most people, are influenced by the burgeoning biofuel industry.

One of the central arguments in favour of biofuels is its contribution to rural development through increased employment opportunities and higher income. It has been estimated that the biofuel industry requires approximately 100 times more labour than the capital-intensive fossil fuel industry to produce the same energy output (Renner and McKeown 2010). This is because there is a wider array of jobs associated with biofuel production. These positions can relate to farming through to biotechnological research. Scaramucci and Cunha (2007) estimated that more than 5 million jobs could be generated in Brazil by the year 2025 if 5 % of global gasoline demand is replaced by sugarcane-based bioethanol from Brazil. Jobs also result from indirect employment, such as those involved in the sales of biofuels and transport of biomass. In 2006, all types of biomass operation in the United States employed about 136,999 people directly and another 310,000 across the supply chain (Domac et al. 2005). While the numbers are substantial, rationalizing pro-biofuel policies simply based on potential job creation can be problematic. This is because the net economic benefits depend on a multitude of factors.

For example, production capacity and level of mechanization can influence the scope for job creation. While a heavily mechanized production system increases labour productivity, it also minimizes employment opportunities. Likewise, a large refinery may achieve higher economies of scale, but the number of workers required per unit of output is low. Brazil's policy to control the rate of mechanization and provide support for small-scale refineries has assisted with controlling unemployment and poverty in the region (APEC 2010). In 2006, 351 plants were able to provide employment for approximately 700,000 people to produce 17,900 million litres of ethanol from 5.9 million hectares of land. In this context, the Brazilian Social Fuel Seal (Selo Combustível Social)[6] initiative, which supports biofuel producers through tax incentives, is worth mentioning here as it promotes diversification of jobs within biofuel-producing regions and encourages the ongoing participation of family-based feedstock production firms in the nation's biofuel industry (Padula et al. 2012). However, large-scale production is crucial for biofuels to compete with fossil fuels (DfID 2007). This may negate the expectations of regional development emanating from the biofuel industry. Indeed, potential benefits from new or expansion of existing biofuel facilities are often overestimated. This is because refinery building or expansion provides construction-related jobs to those generally living outside the local area. As a result, most of the initial impact is not felt locally (APEC 2010; Hillebrand et al. 2006; Moreno and López 2008).

Net employment may also vary depending on the land displacement effect. Switching from existing food crops for biofuel production does not always result in additional employment (Jaeger and Egelkraut 2011). Rather, it simply exchanges one market for another. With regard to the impacts of biofuel policy on employment, analysis based on dynamic and long-term general equilibrium adjustments, including shifts in jobs in agriculture among biomass-producing regions, has found that biofuel policies would not provide any additional economic activity. This is because the increase in bioethanol output would be offset by a reduction in livestock production (Dicks et al. 2009), especially because land-use changes take effect. Furthermore, de Gorter and Just (2010) claim that higher fuel prices induced by biofuel subsidies magnify the inefficiency of the preexisting wage tax by reducing real wages and thus discouraging work. This would reduce labour supply and generate deadweight costs because the tax base becomes eroded as consumers move away

[6] This seal is awarded to biofuel producers who buy a minimum percentage of feedstock from family farmers, provide technical assistance, and enter into contracts with these farmers.

from the taxed good and use substitutes. On the contrary, if the land used for biofuel production was not in use or was abandoned, any job created would potentially increase net employment and foster economic growth (Diop et al. 2013).

As with employment expectations, it is perceived that biofuels increase the income levels of those engaged in the industry. Parcell and Westhoff (2006) found that, in 2006, the average annual salary of ethanol-related salary was much higher than the average US salary. However, this may not always be the case as earnings and job security can vary significantly across a number of factors. Skilled labour working in technical roles has a much higher income potential than unskilled labour working in the field or in the refinery. In fact, there are fewer white-collar jobs compared to blue-collar jobs. Depending on the type of feedstock, employment opportunities may vary. In the case of Brazil, the high seasonality of sugarcane production means that the ratio between the number of temporary and permanent workers is significant (DfID 2007). As a result, many workers do not have a biofuel job throughout the year. Failures of biofuel projects are becoming increasingly common, and these failures adversely affect the livelihood of many vulnerable farmers in regional areas (APEC 2010).

While one objective of biofuel policies is to help farmers, landowners stand to benefit the most from increases in crop prices. Crop growers who lease land therefore only benefit until higher profits associated with rising feedstock prices are captured by higher land values and land rents. Take corn for example. Though disputed by Ajanovic (2010), as corn prices rise, domestic pork and poultry producers reliant on this crop to feed their livestock will potentially reduce their international competitiveness, thereby causing a reduction in production levels if higher prices are not absorbed by consumers (Brown 2008). Although the flow of profits from these facilities may initially stimulate rural economies, a rise in crop prices over time owing to demand has the potential to minimize these benefits. There will also potentially be a reduction in livestock farming in these same areas (Dicks et al. 2009), especially as land-use changes take effect. This could eventually work to offset this advantage.

To understand how the biofuel industry has influenced rural development, we look at the employment data of three major biofuel markets, these being the United States, Brazil and the EU (it must be understood, however, that income may vary significantly within the sector itself). If one takes into account that absolute numbers of employment may only tell part of the story, unemployment and employment data in the agricultural sector are presented in the form of percentage of total labour force and of total employment, respectively. As can be observed from Fig. 4, bioethanol production/consumption does not seem to have increased employment in agriculture in the United States. Employment in agriculture is relatively stable during the observed period, despite the substantial increase in domestic biofuel production, and has even slightly declined. With respect to the overall impact on employment, the unemployment rate has increased in recent years. Figure 5 illustrates the case for Brazil. Once again, bioethanol production/consumption has not had the effect of increasing employment in the agricultural sector. Indeed, the employment in agriculture has declined significantly in recent

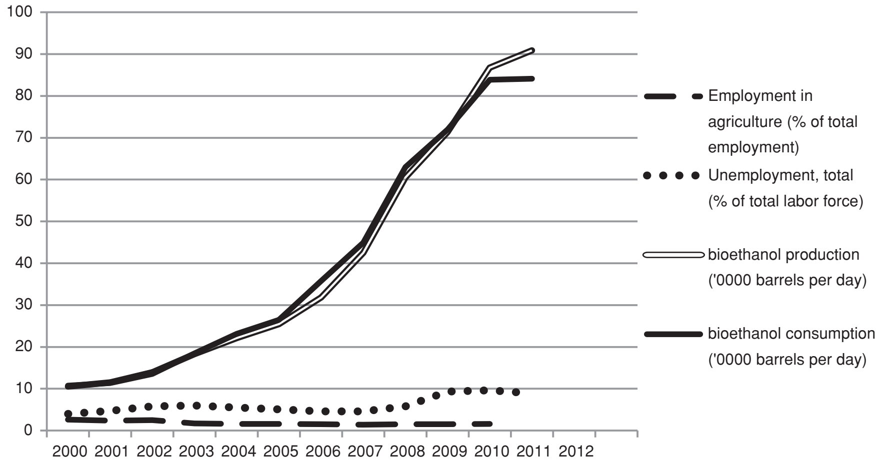

Fig. 4 Bioethanol production/consumption and employment trends in the United States (US EIA 2013; World Bank 2013) (Data for employment in agriculture are available from 2000 to 2010. Other data are available from 2000 to 2011. Bioethanol production/consumption data are sourced from the US EIA (2013). Employment data are sourced from the World Bank (2013))

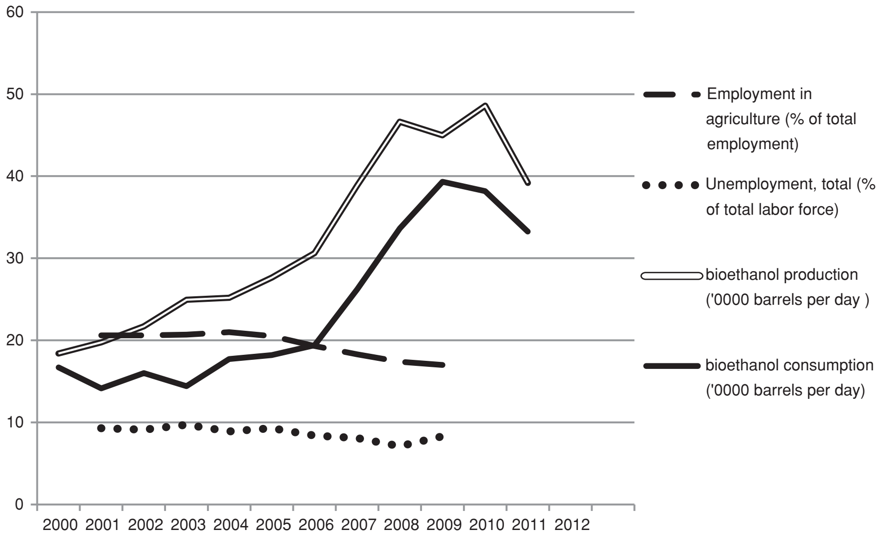

Fig. 5 Bioethanol production/consumption and employment trends in Brazil (US EIA 2013; World Bank 2013) (annual bioethanol production/consumption data from 2000 to 2011 are sourced from the US EIA (2013). Employment data are sourced from the World Bank (2013) and are only available at present up to 2009)

times, even though biofuel production/consumption has increased sharply. The reason may be that a greater use of mechanical harvesting has resulted in fewer jobs being generated. Yet there seems to be some positive impacts on overall

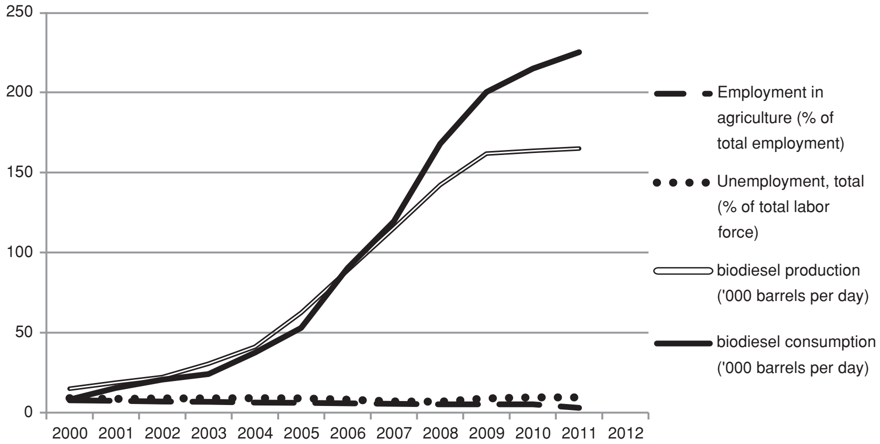

Fig. 6 Biodiesel production/consumption and employment in agriculture trends in the EU (US EIA 2013; World Bank 2013) (annual bioethanol production/consumption data from 2000 to 2011 are sourced from the US EIA (2013). Annual employment data from 2000 to 2011 are sourced from the World Bank (2013))

employment as a drop in the unemployment rate has been observed since 2006. As in the United States and Brazil, biodiesel production/consumption does not increase employment in agriculture in the EU. Like the United States, employment in agriculture has also slightly declined, despite a significant observable jump in biofuel production and consumption. Furthermore, biofuels seem to have a neutral impact on overall employment (Fig. 6).

So, despite the fact that first-generation biofuels use crops currently grown by farmers within the respective domestic biofuel markets investigated, there is no clear overall benefit with respect to the number of people employed in the agricultural sector. While jobs are obviously being created in terms of biofuel processing, the same positive effects do not seem to flow through to the agricultural sector in the economies discussed.

The observations made above have significant implications. As it is eventually realized that more sustainable forms of biofuel production beyond first-generation processes are necessary, this will arguably also have significant impacts on local or regional economies reliant on the growing and processing of particular feedstocks. In many cases, food crops currently being used for biofuel production will not be optimum for later-generation bioethanol production, which can use all manner of biomass (Blottnitz and Curran 2007). Once demand for biofuels grows, the cost equation of producing biofuels from these less energy-intensive crops will undoubtedly force producers to look for crops that can produce the most energy at the least cost (McCormick-Brennan et al. 2007). In many cases, this might mean that regions currently producing biofuel feedstocks will not be well placed to grow the preferred types of biofuel crops. This will clearly have detrimental impacts on economies that are closely tied to long-held agricultural traditions, especially if