Renewable and Sustainable Energy Reviews 61 (2016) 41–52

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

# A review of the ecological and socioeconomic effects of biofuel and energy policy recommendations

Xi Ji*, Xianling Long

*School of Economics, Peking University, Beijing 100871, PR China*

ARTICLE INFO

*Article history:*
Received 6 April 2015
Received in revised form
14 January 2016
Accepted 4 March 2016
Available online 25 March 2016

*Keywords:*
Biofuel
Ecological effect
Socioeconomic effect
Energy policy
Demand side management

ABSTRACT

Many countries have attached great emphasis on biofuel because it is universally acknowledged renewable and sustainable. However, there remain doubts regarding biofuel's renewability, cleanliness, and ecological friendliness. In addition, its impacts on income, employment, and food security have been widely discussed. Therefore, the effect of developing biofuel as an important method of resolving the energy crisis and climate change is questioned. Based on the rocketing concern on the multiple effects of biofuel, this paper provides a comprehensive and updated review of the literature on biofuel's ecological effects and socioeconomic effects. The literature included in this paper is selected English language papers being published since 2004. We find that existing studies have not arrived at a consensus regarding the ecological or the socioeconomic effects of biofuel. There remain uncertainty and doubts toward biofuel's renewability and cleanliness. Biofuel's impacts on water and biodiversity are also questioned. Although biofuel is widely regarded to have positive impacts on income and employment, many studies prove that biofuel influences food security negatively. Besides, biofuel's economic cost is likely to be the barrier to its promotion. Because of the uncertainty of biofuel's impacts, this study recommends cautious attitude toward biofuel development, especially for those countries where biofuel development would be inappropriate, and suggests that policy makers engage in "demand side management" instead of unsustainable "supply side management".



**Contents**

1. Introduction . . . 42
2. Material and methods . . . 42
3. The ecological effects of biofuel . . . 43
   3.1. Biofuel renewability . . . 43
   3.2. Biofuel cleanliness . . . 43
   3.3. Impact on water resources . . . 44
   3.4. Impact on biodiversity . . . 44
4. The socioeconomic effects of biofuel development . . . 45
   4.1. Impact on income and employment . . . 45
   4.2. Impact on food security . . . 46
      4.2.1. Impact on food supply . . . 46
      4.2.2. Impact on food accessibility . . . 46
   4.3. The economic costs of biofuel development . . . 47
5. Results and discussion . . . 47
   5.1. Results . . . 47
   5.2. Discussion on the policy of developing biofuel . . . 48

* Corresponding author. Tel.: +86 10 62755283; fax: +86 10 62754237.
*E-mail address:* jixi@pku.edu.cn (X. Ji).

http://dx.doi.org/10.1016/j.rser.2016.03.026
1364-0321/

6. Conclusions and energy policy recommendations . . . 49
6.1. Conclusions . . . 49
6.2. Energy policy recommendations . . . 49
Acknowledgments . . . 50
References . . . 50

## 1. Introduction

Energy is not only a strategic national resource but also an important material foundation for a country's social and economic development. Recent decades have witnessed scarcity in coal, oil and other fossil energy, along with environmental problems caused by the use of fossil energy, both of which have seriously hindered global development. Many countries have regarded the development of new energy both as a primary method of resolving the energy crisis and as an important development strategy.

Renewable energy is the key to new energy development [1]. Biofuel is widely regarded as a renewable energy[1] [2,3]. As seen in Fig. 1, biofuel production in developed and developing countries such as the United States and China is experiencing a rising trend. Global biofuel production has jumped from the equivalent of 10,021 thousand tons of oil in 2001 to the equivalent of 58,457 thousand tons of oil in 2010, an increase of nearly 500%.

There seems to be a global consensus that biofuel has advantages such as renewability, cleanliness, or economic efficiency, which not only can resolve fossil energy supply problems, optimize energy structure and ensure national energy security but also can lower greenhouse gas emissions, reduce ecological degradation, promote regional economic growth, and increase farmers' income. However, problems and conflicts caused by its development continue to emerge. Skepticism about the advantages of promoting biofuels has grown [10]. Biofuel policies based on the idea of supply side management also show drawbacks and potential risks.

The volume of published literature on biofuel has been increasing in recent years. Multiple effects of biofuel have been analyzed in these studies, ranging from its impacts on the environment and natural resource, to its impacts on economy and society. In this paper, the biofuel's impact on the environment and natural resource is defined as ecological effect, and its social and economic impact is regarded as socioeconomic effect. The selected literature concerning both the two aspects is reviewed in this paper. The objective of this paper is threefold: First, to provide a comprehensive literature review of the ecological and socioeconomic effects of biofuel; Second, based on the results of literature review, to discuss the effects of biofuel policies as an energy strategy based on supply side management, comparing with the thinking of demand side management; Third, based on the overview of biofuel, to propose strategic suggestions for rational biofuel development and scientific energy management.

The remainder of this paper will be structured as follows: Part 2 presents the material and methods applied in this review, including the search sources, search methods and search results; Part 3 provides the literature review of biofuel's ecological effects, mainly from four aspects of biofuel's renewability, cleanliness, its impact on water resources, and its impacts on biodiversity; Part 4 reveals the literature review of its socioeconomic effects, and its impact on income and employment, the impact on food security, and its economic costs are involved; Part 5 summarizes the results and make further discussions on the effect of biofuel development as a energy strategy based on the thought of "supply side management" accordingly; Part 6 draws conclusions based on the results and proposes energy policy recommendations, and detailed suggestions on improving rational biofuel development and proposals on scientific energy management based on the thinking of "demand side management" are put forwarded.

## 2. Material and methods

The search platform *Web of Knowledge* and search engine *Google Scholar* are primarily used to collect the relevant literature. In addition, backward searches through bibliographies of academic studies and reviews as well as hand searching websites of academic projects and conferences on biofuel are also applied. Only literature in English is included in this paper so as to ensure accessibility. Since the rapid progress of this research filed, literature is also limited to the papers published in or after 2004. The literature reviewed is selective and critical. Highly rated journals in scientific indexes are the preferred choice. We carefully select 124 papers which are considered as important or innovative studies, or comprehensive reviews offering us a big picture of biofuel. The literature review is categorized into two topics:

- *Ecological effects* (see Section 3): Biofuel's ecological effects refer to its renewability as an alternative energy, its cleanliness measured by its $CO_2$ and other pollutants emissions, its impacts on water resource and biodiversity.
- *Socioeconomic effects* (see Section 4): Biofuel's impacts on income and employment, food security and its economic cost are the main socioeconomic focuses the existing studies paid attention to. Among these aspects, food security is always a key in the field of biofuel. This paper summaries the biofuel's impacts on food security from two perspectives of food supply and food accessibility.

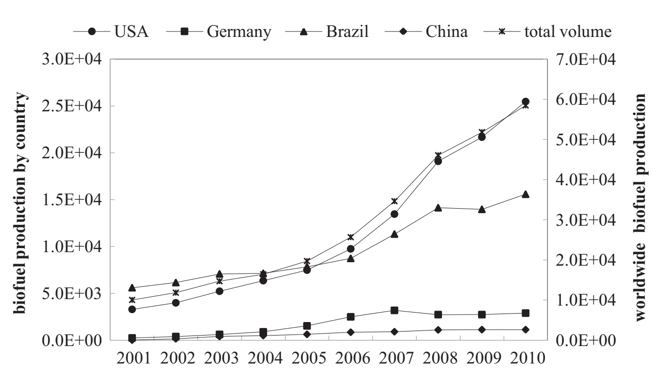


**Fig. 1.** Biofuel production in selected countries and global production in 2001–2010 (unit: thousand tons of oil equivalent).
*Source*: BP Statistical Review of World Energy 2012.

[1] According to different sources and technical methods, biofuel can be divided into three generations: the first generation biofuels refer to conventional biofuels such as biodiesel and ethanol [4]; the second generation biofuels, also known as advanced biofuels, refer to biofuel produced from a wide array of feedstock, ranging from lignocellulosic feedstocks to municipal solid wastes [5,6]; the third generation biofuels are derived from algae [7–9].

**Table 1**
Amount of literature examined in this paper classified by topic and publication year.

| Topics | Year of 2004 to 2010 | Year of 2011 to present |
|---|---|---|
| Renewability | 7 | 11 |
| Cleanliness | 4 | 16 |
| Water Resource | 4 | 3 |
| Biodiversity | 5 | 5 |
| Income and Employment | 4 | 7 |
| Food Security | 13 | 25 |
| Economic Cost | 5 | 14 |

Table 1 shows the material in the literature set, classified by topic and publication year.

## 3. The ecological effects of biofuel

This section will analyze the ecological effects of biofuel from several aspects, including its renewability, cleanliness, and its impact on water resources and biodiversity.

### 3.1. Biofuel renewability

Strictly speaking, the renewability of energy should be dependent on the level of fossil energy (nonrenewable energy) used in the energy life cycle, including exploration, production, transportation, use, pollution treatment and other processes [11]. Accordingly, energy renewability can be categorized into absolute renewability (no consumption of fossil fuels in any life cycle process), partial renewability (consumption of fossil-fuel energy during the entire life cycle is lower than the energy it contains) and non-renewability (consumption of fossil-fuel energy during the entire life cycle is higher than the energy it contains) [12].

Some scholars believe that biofuel is a renewable energy that provides sustained energy through photosynthesis, and so therefore an effective biofuel development mechanism is a basis for sustainable development [2,13]. Based on energy life cycle analysis (ELCA), Shrestha and Pradhan [14] proposed the concept of the net energy ratio (NER, which is identical to FER (Fossil Energy Ratio)), that is, the amount of energy that can be produced when consuming per unit of energy, thus estimating the renewability of biofuel. If the FER is equal to 0, then the biofuel cannot produce energy; if the FER is higher than 0 but less than or equal to 1, then it is not renewable; if the FER is higher than 1, then it is renewable, at least to some extent. Kumar et al. [15] adopted a life cycle approach to assess the renewability of Jatropha biodiesel, and showed that its NER values range from 1.4 to 8.0, depending on the method used for energy and emission distribution between product and co-products as well as irrigation applied. Rajaeifar et al. [16] assessed the energy life cycle of soybean-based biodiesel and estimated that its FER is 1.97. Renó et al. [17] assessed the FER to be 9.4 for the methanol production from sugarcane bagasse. When analyzing biofuel in the United States, Pimentel and Patzek [18] found that the FER of extracting ethanol from food and vegetation is higher than 1. Mohammadshirazi et al. [19] found the energy output/input ratio was 1.49 in biodiesel production, and the shares of renewable and non-renewable energy were 77.31% and 22.69%, respectively from total energy input. García et al. [20] estimated the energy balances for sugarcane ethanol fuel production in Mexico with five modalities. The energy ratios ranged from 1.1 to 4.8. Timmons et al. [3] also found in a simulation of a scenario in New Hampshire that the diesel used to produce and transport woody biomass contained less than 2% of the potential energy in wood chips.

However, some studies question the renewability of biofuel. Yang and Chen [21] found that nonrenewable energy cost was 1.7 times that of corn-ethanol energy produced. Chen and Chen [22] showed that the overall energy cost of rapeseed-based biodiesel was 1.1 times that of biodiesel energy output.

Bureau et al. [23] attributed the two different conclusions set forth above to two causes. First, because of large differences such as resource endowments, natural conditions, economic conditions and technology, certain inputs involved in biofuel production might be different, including, e.g., the input of labor and raw materials such as nitrogen. Second, different research methods adopted by different researchers could lead to differences in the final analysis; for example, the fossil fuel consumed by the byproducts generated in the life cycle process of biofuel development would be included (to some extent) in biofuel's consumption of fossil fuels. Some researchers included all of the fossil fuels consumed by byproducts as energy consumed by biofuel production, but some did not, resulting in findings of different FERs for biofuel or different net energy estimations. In addition, the research border chosen for the life cycle assessment resulted in different outcomes [24,25]. For example, Heller et al. [26] studied the process of generating power from raw willow and found that if one merely considered the cultivation and mining of raw materials, then the FER was 55; however, if one considered the cultivation, mining and transportation of raw materials, then it was 35.7; whereas if considered planting, mining, transportation, and electricity generation from raw materials throughout the process, then the FER decreased further to 13.3.

### 3.2. Biofuel cleanliness

The controversy about biofuel cleanliness mainly focuses on its greenhouse effect. The scientific community has not yet concluded whether biofuel is clean.

It is generally believed that the formation of biofuel is the result of plant assimilation, light and $CO_2$ fixation, which is a reverse process of fossil energy action that releases $CO_2$. Many studies have shown that biofuel has a low carbon-biofuel ratio, and therefore it can effectively reduce $CO_2$ [27–29]. For example, Highina et al. [30] compared the carbon footprint of the first and second generation of biofuel and the carbon footprint of the first generation biofuel was found to reduce the greenhouse gas effect by 78% while the second generation biofuel reduced greenhouse gas by 94% compared to fossil fuels. Holma et al. [31] built a life cycle assessment model to estimate the environmental impacts of forest residue and microalgae biofuel production chains. Biodiesel from forest residues was able to reach the 60% emission reduction compared with fossil fuels, while the emission reduction of microalgae biodiesel was lower.

However, there is evidence that the mitigating effect of biofuel on greenhouse effect is questionable. First, the production phases of biofuel, ranging from plant cultivation, processing to waste treatment phases, will produce greenhouse gases, which are especially serious in developing countries. For example, Yang and Chen [32] found that in China, when corn cultivation, ethanol conversion and wastewater treatment phases were included, the production of bioethanol per kilogram would produce 11.61 kg $CO_2$-equivalent (carbon dioxide equivalent), 5.99 times that of gasoline combustion emissions. More specifically, the sewage treatment process was the main cause of biofuel's production of greenhouse gases—59 percent of total emissions—and the planting stage was another major cause. In addition, cutting down rainforests and reclaiming grasslands to grow energy crops would release large amounts of carbon sequestered. In an assessment using global models, Searchinger et al. [33] found that because the high price of biofuel encouraged people to turn forests and pastures into farmland, corn ethanol doubled greenhouse gas emission in 30 years. In addition, the substitution between fossil fuels and biofuel may have unexpected results. The increase in biofuel consumption will lower oil price and therefore lead to higher oil consumption, which is called positive rebound effect [34]. The positive rebound effect may significantly lower the effectiveness of biofuels in reducing greenhouse gas emissions, thus offsetting the GHG emission saving effect of biofuel [34]. Chen et al. [35] also found a decrease in fuel price in the US due to the production of the second generation biofuels. A study by Popp et al. [36] found that to maintain demand for fossil fuels and avoid a severe decline, producers would reduce the price of fossil energy, which would stimulate more economic activity, thereby leading to 10–40% increases in fossil energy consumption. On the contrary, many studies have reviewed the rebound effect of Renewable Fuel Standard 2 (RFS2) and revealed negative rebound effect. According to Rajagopal et al. [37], because of the increase in mixed fuel price of biofuel and fossil fuel, less fuel was consumed. The negative rebound effects were also revealed in Thompson et al. [38], Laborde [39] and Taheripour and Tyner [40]. The positive and negative rebound effects always coexist, and the negative rebound effect sometimes partially offset the positive rebound effect.

Studies on biofuel cleanliness should also focus on emissions of particulate matter and nitrogen oxides. For example, most studies suggest that compared with conventional diesel fuel, biodiesel can significantly reduce emissions of particulate matter. Biodiesel was estimated to reduce 87.7% emissions of particulate matter [41]. For nitrogen oxides, however, the situation is the opposite. Most studies suggest not only that biodiesel emits more $NO_X$ because biodiesel has more oxygen but also that both cetane number and different fuel injection characteristics will affect biodiesel's $NO_X$ emissions [41]. Timilsina and Shrestha [42] proved that biofuels, particularly biodiesel, generated up to 70% increase in $NO_X$ compared with diesel.

There are four primary reasons that the studies have arrived at different conclusions. First, studies are performed in different countries that are at different stages of development and therefore their technology levels vary. Study shows that currently, substandard sewage treatment processing technology is a primary reason for the emission of large quantities of greenhouse gases. If we can establish an environmentally friendly sewage treatment system, we can significantly reduce greenhouse gas emissions and even realize zero emissions of greenhouse gases [32]. Therefore, greenhouse gases generated during the biofuel production process in developing countries are much higher than in developed countries. Second, studies select different biofuel. Popp et al. [36] found that the first generation of biofuel, such as bioethanol extracted from corn, produced more GHGs because food crops required more fertilizer and pesticides, which polluted land, resulting in more carbon dioxide emission in the land-use process. However, the second and third generations of biofuel can alleviate the greenhouse effect because their primary raw material consists of cellulose products. Hammond and Seth [43] found that carbon footprint for first generation biofuels was high, while the use of the second generation biofuels could reduce the impacts. Third, cultivation methods of biofuel vary. Fargione et al. [44] found that converting rainforests, peatlands, savannas and grasslands to arable land for growing biofuel would create a “biofuel carbon debt[2]” by releasing 17 to 420 times more $CO_2$ than the annual greenhouse gas reductions that these biofuels would provide by displacing fossil fuels; conversely, if biofuel was extracted from waste biofuel or degraded or abandoned agricultural land, little or no carbon debt would result. Danielsen et al. [45] assessed changes in carbon stocks caused by changing land use as well, and they found that it would take over 600 years for carbon emissions saved through use of biofuel to compensate for the carbon lost through forest conversion if the original habitat was peatland, while it would take within 10 years if original habitat was degraded grassland. Fourth, researchers may use different tools for biofuel $CO_2$ calculations. Hennecke et al. [46] compared tools for biofuel $CO_2$ calculations under the Renewable Energy Directive (RED), and found that results for the same biofuel differed up to 21% between tools.

### 3.3. Impact on water resources

The impact of biofuel on water resources is another controversial problem, which has two aspects: water consumption and water pollution [47].

Cambero and Sowlati [25] analyzed principles of the impact of biomass on water quantity and quality. They found that as forest biomass (dry rot trees, forest residues, etc.) could adjust the size and rate of runoff, affect the ability of conserving and transferring water resources, so also could it have an impact on the quality, flow and distribution of water resources. Consequently, biofuel development might cause adverse effects on both forest surface water and groundwater.

Recently, many scholars have assessed water consumption consumed by biofuel production. Yang et al. [48] evaluated China's water consumption in producing biofuel from corn and predicted that by 2020, China's annual water consumption would be 32–72 $km^3$, equivalent to the Yellow River's annual total volume. From the estimation of Yang et al. [49], 3726 kg water was required to generate 1 kg microalgae-based biodiesel if freshwater used without recycling. Recycling harvest water reduced the water usage by 84%. Using sea/wastewater decreased 90% water requirement. Dominguez et al. [50] found that in the United States, water consumption of fuel ethanol-powered cars was 118 L/km, which suggested that if the United States continued to vigorously promote bioethanol development, freshwater resources would be seriously threatened. Gerbens-Leenes et al. [51] estimated the global water footprint related to increasing biofuel use for road transport. They found that the global blue biofuel water footprint would grow to 5.5% of the totally available blue water in 2030. The study of Wu et al. [52] revealed that irrigation water used to grow biofuel feedstocks varied significantly from one region to another, and water consumption for biofuel production varied with processing technology. Water requirements for corn ethanol production varied from 10 to 17 l for each liter of ethanol produced, while water requirements for switchgrass ethanol production varied from 1.9 to 9.8 l. By contrast, only 2.8–6.6 l water was consumed for each liter of gasoline produced from conventional onshore sources in the U.S and 5.2 l water was consumed for each liter of gasoline from Canadian oil sands.

### 3.4. Impact on biodiversity

There are few positive influences of biofuel on biodiversity, which are of limited spatial and taxonomic scale [53]. These positive influences occur only when degraded lands are rehabilitated with non-native feedstocks to support native flora and fauna [53].

The negative influences of biofuel on biodiversity include effects on genetic diversity, species diversity and ecosystem diversity. According to the study of Liu et al. [54], influences of biofuel on biodiversity are different at multiple scales.

[2] Carbon debt refers to indirect greenhouse gas emissions caused by the transition of forests, grasslands, and other types of land to arable land for biofuel production, compared to the effect of greenhouse gas emissions resulting from biofuels. It is negative, so it is called carbon debt.

At the genetic level, primary risks are introgression and contamination by aggressive genotypes [54]. Struebig et al. [55] showed that depauperate species richness was mirrored by concomitant declines in population genetic diversity in the most susceptible taxon in a rainforest undergoing a conversion to oil palm.

At the species level, habit fragmentation and bio-invasion may result in habitat pollution, degradation and disturbance [54]. To promote biofuel production, some countries used excessive fertilizer, which then caused adverse environmental impacts [56]. Based on previous studies, Cambero and Sowlati [25] believed that forest biomass provided a variety of forest organisms with food and cover and therefore, biofuel consumption would reduce forest productivity, affect the growth of scavengers, introduce invading organisms, and ultimately lead to biodiversity reduction. In addition, large quantities of water consumption in biofuel production process will adversely affect plant diversity.

At the ecosystem level, biofuel crops plantation means large-scale homogeneous landscape, leading to simplified ecosystem, which is vulnerable to damage [54]. Biofuel is the alternative energy that creates the greatest demand for land. For example, a great deal of biofuel feedstock is fit to grow in tropical environments [57], which has resulted in a forest-clearing phenomenon in tropical forests (such as the Amazon) to produce sugar cane, soybean and other biomass. In Asia, palm oil biomass production is a major cause of deforestation [55,58].

Biofuel's impact on biodiversity is not identical when using different feedstock. Holma et al. [31] found forest-residue biofuel production caused more negative environmental impacts on biodiversity than microalgae biofuels, because the intensified use of forest resources might impair ecosystem services including utilization of non-forest productions, soil carbon stock and support for biodiversity.

Some institutions have come to realize the adverse effects of biofuel development on biodiversity. In 2007, 11 British organizations (including the Royal Society for the Protection of Birds (RSPB), the National Trust, the Consortium for Policy Research in Education (CPRE), the Council for British Archaeology, and the Wildlife Trusts) issued a report titled "Bioenergy could do more harm than good". They suggested that if plants used in biofuel production such as willows, rapeseed, elephant grass, etc., were not properly and effectively managed, their use to provide heat, electricity and vegetable oil could reduce the number of wild animals in their fields and destroy landscapes, historical sites and soil and water quality [59].

However, Cornelissen and Dehue [60] found no information was available on the magnitude of indirect impacts on biodiversity.

## 4. The socioeconomic effects of biofuel development

This section will analyze and assess three aspects of the socioeconomic effect of biofuel: its impact on income and employment, its impact on food security, and its economic costs.

### 4.1. Impact on income and employment

Crops are raw materials for producing biofuel, and biofuel development can both explore the industrial value of agricultural products and enhance their added value. Experience has shown that biofuel development and economic growth can affect one another. On the one hand, economic growth will stimulate national demand for energy, which will have an impact on the biofuel production since biofuel plays an increasingly critical role. On the other hand, because the government has increased efforts to develop biofuel, biofuel chain (production, transportation, etc.) can provide many employment opportunities and increase people's income [28,61,62]. Cambero and Sowlati [25] believed that countries engaged in forest biomass development could increase employment and achieve energy independence, but the number and quality of jobs depended on the strategic layout of the biomass supply chain, especially on the industrial scale. Amigun et al. [63] proposed that biofuels development could enhance local economy and generate more job opportunities in Africa. The impact of biofuel on the economy is attributable not only to biofuel development's need for more labor input but also to the fact that using crops as biofuel feedstock for production has both increased farmers' income and mobilized farmers to grow feedstocks for biofuel production. For example, the Food and Agriculture Organization's (FAO) report titled “The state of food and agriculture” [64] noted that the growth of demand for fuel ethanol would lead to an increase in the prices of relevant agricultural products used for making ethanol and would increase farmers' income in developing countries, especially countries that produced a large quantity of biofuel feedstocks. Moreover, the reuse of abandoned crops reflects the idea of a recycling economy, improves the efficiency of resource use, and therefore saves resources related to production process. For example, in a study of Argentina, Bolivia, Brazil, Chile, Colombia, Guatemala and Jamaica, Bildirici [65] found that except for Argentina and Jamaica, biomass energy consumption and economic growth were closely related. Bildirici [65] believed that cointegration existed because biomass energy met many countries' demands for energy and therefore biomass energy development could both stimulate economic growth and alleviate poverty in developing countries.

Many studies quantified the economic effects of biofuel. Parcell and Westhoff [66] summarized studies on economic effects of biofuel production, and found that given the production level in 2006 in US, the ethanol industry annually employed 3500 workers, paid out $132 million in salaries, generated $110 million in taxes. Gohin [67] used a computable general equilibrium model of the EU-15 economy to estimate the impacts of European biofuel policy on farm sector, and found that farm-income would increase by 3.2 billion, with 43,000 farm job opportunities.

However, Deppermann et al. [68] found negative but small effects of abolishing EU biofuel policies on agricultural income in the long run, indicating a limited transfer efficiency of biofuel policy. Similarly, Jaeger and Egelkraut [69] thought there was little evidence proving biofuels would have significant, long-term positive job impacts in rural areas. They indicated that some proponents who estimated substantial indirect job creation were based on static and regional input-output models.

Since the global oil crisis in 1970s, biofuel and other new energies have entered a golden age of development. Many countries have launched research and development programs, such as Brazil's ethanol energy plan, the United States' energy farms and the EU biofuel directive programs. However, following the global oil crisis, coupled with international oil organizations' deliberate suppression of the oil supply, oil prices have returned to their original levels, making it difficult to determine the advantages of biofuel. Currently, the market is dominated by fossil energy over the short term. Now, many new-energy programs, projects, and related economies are finding it difficult to survive.

Faced with the fragility of the biofuel market, many countries must adopt a government-directed approach to protect biofuel's market share and the benefits of stakeholders. The renewable portfolio standard (RPS) is one such approach. More specifically, the government establishes mandatory provisions related to renewable energy's market share, stipulating that electricity must contain a minimum proportion of renewable energy. In September 2014, the China Energy Bureau's draft “Renewable portfolio standard assessment methods (Trial)” was already at a stage in which it could solicit opinions. The draft put non-hydro renewable electricity within the scope of RPS, of which biofuel was one of the focuses. Thus, the long-term development of biofuel cannot be separated from government protection, and market vulnerability will become a serious impediment to biofuel development.

### 4.2. Impact on food security

Whether biofuel development affects food security is a hot topic that has attracted increasing attentions. Some studies have developed assessment framework for the impact of biofuel on food security. At national and international level, Global Bioenergy Partnership Sustainability Indicators [70] and High Level Panel of Experts on Food Security and Nutrition Review [71] have proposed conceptual frameworks [72]. At local level, UN-Energy [73], ActionAid [74], Beall et al. [75] provided broad frameworks that could guide analyses of the relationship between biofuels and food security.

There are two ways to measure food security: changes in food consumption and changes in intermediate variables (e.g. changes in food price and changes in availability of food) [72]. Since capturing food consumption is costly and difficult, most studies try to estimate food security through supply side and demand side. The supply side emphasizes the importance of food availability, and the demand side focuses on the access to food.

#### 4.2.1. Impact on food supply

The first concern about food security issue is that biofuel production increases the competition between biofuel feedstocks and food production for land, water and labor. Popp [76] proposed that biofuel led to an increasing competition for natural resources, including land and water, especially in the short run. Clancy [77] and Elbehri et al. [78] thought farmers would choose between growing food crops and biofuel crops, which resulted in a decrease in cultivation areas and yields. Koizumi [79] studied the relationship between biofuel and food security, and showed that both the feedstock of agricultural product-based biofuel and cellulose-based biofuel competed with food production in China and Japan. In the United States, the RFS requires the amount of total renewable fuel to reach 36 billion gallons by 2022, with 21 billion gallons advanced biofuel[3] and 15 billion gallons "conventional" biofuel[4] [80]. In 2014, the U.S. used 5.2 billion bushels of corn to produce 14.3 billion gallons of ethanol fuel [81]. In order to reach 15 billion gallons "conventional biofuel" from corn, about 5.5 billion bushels of corn are needed. The proportion of cropland used for biofuels varies across countries and regions, and [36]. According to Popp et al. [36], the global proportion was about 2.5% (Cropland in the US: 8%; Corn and soybean area in the US: 20-35%; Cropland in the EU: 5-6%; Cropland in Brazil: 3%), and declined to 1.5% when adding by-products substituted for grains and oilseeds because some grains were returned to the feed sector in the form of co-products, which was the net land requirement.

The second concern is biofuel production may damage the ecosystem and thus reduce yields. Anderson et al. [82] found biofuel production resulted in soil organic carbon losses. Popp et al. [83] indicated that pesticides, required by first generation biofuels, had environmental cost if pesticides were not used correctly.

Of course, there are different views about the impact of biofuel on food supply. First, some scholars believe that the "food versus fuel" problem is exaggerated. As for the first generation biofuels, double crops grown between growing seasons of food crops and biofuel crops, as well as mixed crop systems have the potential to produce biofuel feedstocks without decreasing food production and without clearing wild lands [84–86]. As for the second and third generation biofuels, Liew et al. [4] and Leite et al. [9] thought they did not become involved in the "food versus fuel" issue as the second and third generation biofuels did not require agricultural land. Second, food production may even expand when the spillover effects of technology occur. The introduction of biofuel could increase the availability of technical knowledge and the availability of inputs for farmers who can imitate similar techniques and apply inputs (i.e. fertilizers) to food crops plantations [87]. Negash and Swinnen [88] also found in Ethiopia that spillover effects could improve food productivity that offset the amount of land diverted to biofuel.

#### 4.2.2. Impact on food accessibility

The potential negative impact of biofuel on the access to food refers to lower households' purchasing power through decreasing households' income and increasing food prices.

First, some biofuel companies will displace land without sufficient compensation, thus reducing people's income [72]. Second, some institutions and researchers believe that biofuel development is one of the primary causes of the continuous increase in world food prices [89–93]. Study by Naylor et al. [94] showed that biofuel production would have both a direct and an indirect impact on the prices of agricultural products. The direct impact is that the price of corn will accompany the rising demand, and the indirect impact is that the expansion of corn acreage will squeeze acreage available for other crops, thereby reducing food supply and increasing food prices. But there is still significant uncertainty about the magnitude of food price response to biofuels production because of different assumptions regarding demand and supply elasticities for agricultural commodities [95]. According to Ajanovic [62], no significant impact of biofuels production on feedstock prices could be observed until 2011. Similarly, Zhang et al. [96] thought rising fuel prices were not directly causing increase in agricultural commodity prices. Kgathi et al. [86] argued that local biofuel production might not necessarily lead to a substantial increase in food prices because land availability was not a major issue.

The potential positive impact of biofuel on the access to food refers to stimulating employment opportunities and rural economy [86,97].

Opportunities to generate income through biofuel development may provide welfare gains that can improve purchasing power and decrease vulnerability to price shocks for food [98]. Moreover, Escobar et al. [99] believed that the areas most vulnerable to food security issue were impoverished regions whose pillar industry was agriculture. One method of changing the poverty situations of those areas would be to develop biofuel and increase farmers' income, bringing them out of poverty and reducing the impact of food crisis [77]. Okiyama and Tokunaga [100] estimated the income change of farming household, and showed that in the case of biofuels as domestic goods and exports, the growth rate of income was 3% to 5% higher than the income of other households. Biofuel companies also can improve local infrastructure such as roads and electricity, and this may reduce the distance local members travel and time spent on collecting food, which can increase food accessibility [72].

In addition to the opponents and proponents of biofuel, some studies found that the impact of biofuel on food security is mixed and uncertain [101], depending on the consumption status of

[3] Any fuel derived from cellulosic or advanced feedstocks. This may include sugarcane or sugar beet-based fuels; biodiesel made from vegetable oil or waste grease; renewable diesel co-processed with petroleum; and other biofuels that may exist in the future. Advanced biofuels are two sub-categories: cellulosic biofuel and biomass-based diesel.

[4] Any fuel derived from starch feedstocks (e.g., corn and grain sorghum).

household or country [102]. According to Verpoorten et al. [103], net importing countries and urban consumers reported worsening food security while net exporting countries and urban consumers reported improving food security.

### 4.3. The economic costs of biofuel development

There are three costs related to producing biofuel: feedstock cost, conversion cost and opportunity cost. Opportunity cost mainly refers to land opportunity cost. Land opportunity cost includes the income of land-grown edible foods and therefore represents the loss of land value caused by pure energy crops [104].

Duer and Christensen [105] commented that biofuel cost was more expensive than the cost of fossil fuel despite the credit obtained from greenhouse gas emission reductions.

However, Lensink and Londo [106] showed that biodiesel produced from oil crops would be a cost-effective way of biofuel production in the medium term at moderate consumption target levels. According to the result of economic analysis of biodiesel production by Mohammadshirazi et al. [19], the benefit to cost ratio was 2.081, the gross return and net return were \$1.302/L, \$1.298/L respectively. Saygin et al. [107] performed a cost-benefit analysis of biomass and believed that biomass had economic potential, but they also suggested that whether biomass had long-term economic benefits could not be generalized.

First of all, the cost depends on feedstock and technology. Sims et al. [108] found that some "good" first generation biofuels such as sugarcane ethanol were cost effective, while other "less good" first generation biofuels needed generous government support to remain competitive. For the second generation biofuels, production costs are uncertain and vary with the feedstock and conversion process. It was thought to be above \$ 0.80/litre of gasoline equivalent [108]. Carriquiry et al. [109] compared the cost share of the first generation and second generation biofuels. The feedstock cost accounted for over 2/3 of the total costs for the first generation biofuels, while the share of feedstock was relatively lower (30–50%) for the second generation biofuels. Therefore, feedstock cost needed to be reduced for biodiesel, while biomass conversion cost needed to be reduced for cellulosic ethanol. Festel et al. [110] and Liang et al. [111] found the use of lignocellulosic biomass as feedstock to bioethanol (second generation biofuels) could reduce the production cost by 50% than the use of corn-based and sugar-based feedstocks. Kuhad et al. [112] also showed that bioethanol produced from lignocellulosic biomass was more cost-efficient than bioethanol produced from conventional food crop of sugarcane. Some studies showed that the process integration of the first and second generation biofuels could optimize the overall production cost of bioethanol [113,114]. Tey et al. [115], Dassanayake and Kumar [116] and Ng et al. [117] all proved that technological development could improve biofuel's economic performance.

In addition, the economic benefit depends on many external factors, such as the fluctuation of energy market, extreme weather and variation in subsidy policy [4,118]. Besides, cost is closely related to production scale [119]. Apostolakou et al. [120] indicated that base-catalyzed transesterification on vegetable oil was economically profitable only when production rate was greater than 50 kt/y.

## 5. Results and discussion

### 5.1. Results

Based on the review of selected literature, this paper summarizes the synthesized effects of biofuel, mainly from two perspectives of ecological and socioeconomic effects. Main results are described as follows:

First, renewability and cleanliness are two hot topics in the area of biofuel's ecological effects. There remain controversies regarding the biofuel's renewability and cleanliness. Although some researchers have paid attention to biofuel's impact on water and biodiversity, the literature on these two aspects are comparatively insufficient.

- Renewability: The renewability of biofuel depends on the consumption of nonrenewable energy in the life cycle process, which is largely dependent on conditions such as resource endowment, geographical and natural conditions, economic situation and technology level. Accordingly, the existing studies have not arrived at an agreement. However, numerous studies have shown that the wider the boundaries of life cycle assessment, the lower the renewability of biofuel. In some developing countries, biofuel is a nonrenewable energy.
- Cleanliness: There also remains considerable controversy regarding the cleanliness of biofuel. Some scholars believe that biofuel is a clean energy. There is also evidence showing biofuel is not as clean as expected. Furthermore, the greenhouse gas produced by biofuel development in technologically disadvantaged countries is much higher than that produced by technologically advantaged countries. In addition, some biofuel (such as biodiesel) will lead to increased nitrogen oxide emissions. Finally, the competition between fossil fuels and biofuel will reduce the price of fossil fuel, thereby stimulating increased economic activity, which will lead to more pollution.
- Impact on water: Almost all the selected literature on biofuel's impact on water has shown that biofuel negatively influences both water consumption and water pollution.

- Impact on biodiversity: The overwhelming majority of the selected studies have shown that biofuel development will occupy space, as well as damage land and water, thereby destroying their biodiversity.

Table 2 depicts the literature summary of biofuel's ecological effects.

Second, this paper analyzes the socioeconomic effects of biofuel development, focusing on three aspects: impact on income and employment, food security, and economic costs. There also remains controversy regarding the impacts of biofuel on economy and society.

- Impact on income and employment: On the one hand, biofuel development improves farmers' income in the short term, mobilizes them to grow food, and provides them with employment opportunities. On the other hand, some evidence shows that the positive effect of biofuel is limited and unstable.
- Impact on food security: From food supply and food accessibility perspectives, researchers have been debating biofuel's impact on food security. Some people believe that biofuel production increases the competition between feedstocks and food production for land, water and labor, and biofuel development would lower households' purchasing power through decreasing households' income and increasing food prices. By contrast, other people hold views that biofuel will not reduce food production, but generate income, and increase food accessibility.
- Economic costs: Most of the selected studies have shown that the economic costs of biofuel depend on technology and feedstock.

The review results are summarized as Table 3.

**Table 2**
Literature summary of ecological effects.

| | Positive impact | Negative impact | It depends | N.A. |
|---|---|---|---|---|
| Renewability | [15–20,3] | [21,22,26] | [23–25] | [11,12,2,13,14] |
| Cleanliness | [27–31,37–41] | [32–36,41,42,44,45] | [43,46] | |
| Water Resource | | [47,25,48–51] | [52] | |
| Biodiversity | [60] | [55,54,56,25,58,31,59] | [53] | [57] |

*[41]: On the one hand, biofuels could reduce particulate matter (Positive impact). On the other hand, biofuels had negative impacts on $NO_X$ emissions (Negative impact).

**Table 3**
Literature summary of socioeconomic effects.

| | Positive impact | Negative impact | It depends | N.A. |
|---|---|---|---|---|
| Income and Employment | [61,28,62,25,63–67] | [68,69] | | |
| Food Security | [4,9,62,77,84–88,96–100] | [76–79,82,83,72,89–94] | [36,95,101–103] | [70,71,73–75,80,81] |
| Economic Cost | [19,106,107] | [105] | [4,108–120] | [104] |

*Although [4,9,62,84–86,96] in "Positive Impact" of "Food Security" did not prove there existed positive effect, but they indicated that the negative impact on food security was not observed.
*[77]: On the one hand, biofuels increased farmers' income (positive impact), on the other hand, biofuels resulted in Negative Impact: Biofuels resulted in a decrease in cultivation areas and yields.

**Table 4**
Contrasting features of SSM and DSM.
*Source:* [122,123].

| | SSM | DSM |
|---|---|---|
| Principle | Deciding supply according to demand | Deciding demand according to supply |
| Objective | Increasing supply | Controlling and managing demand |
| Means | (1) Alternative energy: Developing new energy<br>(2) Alternative trade: Importing energy and transferring industry | (1) Improving energy use efficiency<br>(2) Economical use of energy |
| Decision-making | Top–down | Bottom–up |

Because various biofuels, methods, scenarios are studied in the literature, it is unrealistic report results quantitatively in summary table. Therefore, we classify literature by their results about biofuel's ecological or socioeconomic effects. It is helpful to have a clear idea about the debates on biofuels.

### *5.2. Discussion on the policy of developing biofuel*

Obviously, there remains uncertainty and controversy regarding the ecological effects and the socioeconomic effects of biofuel development in existing studies, so we have a cautious attitude toward the energy policy that use biofuel development as an important method of resolving the energy crisis and climate change in developing countries.

Energy management can be categorized into supply side management (SSM) and demand side management (DSM). SSM influences energy producers to ensure sufficient supply of energy and to focus the solutions of the supply and demand contradiction on the supply side. The primary form of SSM is alternative energy and alternative trade. Alternative energy primarily refers to seeking alternative energy to achieve diversification of energy use; alternative trade is primarily conducted in two ways: importing energy and transferring industries [121]. In general, under energy constraints, DSM comprehensively employs economic, legal, technical and other measures to regulate users' behavior, to improve the efficiency of energy use and to reduce dependence on energy-intensive industries. Specific features of SSM and DSM that contrast with one another are shown in Table 4.

Biofuel is an alternative energy, so therefore developing biofuel to solve the problem of shortages in the fossil energy supply is one approach of SSM. SSM has been widely used in many countries because its feature of energy management can quickly and effectively satisfy the energy needs of energy-intensive industries in the short term. However, SSM is not a long-term management tool: developing biofuel to compensate for the lack of fossil energy supply has obvious limitations.

First, energy management that uses biofuel as an alternative energy is often uncertain: it cannot guarantee an effective energy supply. Affected by regional climate, soil, water and other natural conditions, along with natural endowments, the stability and sustainability of the biofuel supply largely depends on uncontrollable natural factors.

Second, the use of biofuel as an alternative energy cannot meet people's expectations, and there are diversified issues related to biofuel development that involve the environment, resources, society and the economy. In this paper, based on the analysis of both the ecological effects and the socioeconomic effects of biofuel development, biofuel development has many uncertainties. Its renewability, cleanliness, resource and environmental friendliness are not as positive as people expect. Moreover, because of the fragility and complexity of the energy market, the impact of biofuel industry on farmers' income and employment is unstable, and it may pose a threat to global food security, depending on global grains output.

Third, SSM's primary method of decision-making is top-down because it is "deciding supply according to demand." Accordingly, the supply amount is likely to go awry in the absence of an understanding of real energy needs. In particular, because supply-side managers often ignore the possibility of saving energy, they tend to overestimate actual demand. For example, since China's "Eleventh Five-Year" plan, the state has promulgated the "Renewable Energy Law", the "Long-term Development Plan of Renewable Energy", the "Twelfth Five-Year Plan of National Energy Technology", the "Twelfth Five-Year Special Plan of Biofuel Technology Development," and other regulations and policies, but biofuel development has long been hobbled. More than half of China's biofuel electricity generation companies are in a state of semi-shutdown.

Fourth, SSM such as biofuel development constitutes an extensive management approach to meeting energy needs. This approach would encourage all industries to consume energy without scruples, which is not conducive to creating a mechanism to promote energy-intensive industries' use of institutional and technological innovation to improve their energy efficiency. It is key to be aware that if energy demand is not controlled, all resources will be limited, and we will eventually transform from a situation of relative scarcity to one of absolute scarcity. Because renewability of alternative energy such as biofuel is affected by many factors, it will ultimately reach the supply limit. If energy supply depends on imports, on the one hand, the importing country will experience a huge financial burden over a long period, and on the other hand, the country will risk having its economy restricted by the international energy market.

## 6. Conclusions and energy policy recommendations

### 6.1. Conclusions

This paper aims at providing a comprehensive literature review of biofuels from the perspectives of ecological and socioeconomic effects. We searched for and selected relevant literature, and eventually there are 124 pieces of material discussed in this paper, which have covered most important studies in the area.

There remains uncertainty and controversy regarding biofuel's impacts on environment, society and economy. Although biofuel is considered as a renewable and clean energy, it is still questioned regarding its impacts on energy use, pollutants emission, water and biodiversity. Moreover, although biofuel may has positive impacts on income and employment, many researchers think that biofuel influences food security negatively. Besides, its economic cost is likely to be the barrier to its promotion.

Accordingly, we think it is helpful to be cautious toward biofuel development, especially for developing countries. As a supply side management strategy, biofuel production seems to be a second choice as supply side management has disadvantages when compared with demand side management.

### 6.2. Energy policy recommendations

Biofuel development is a systematic project. Based on the conclusions of this paper, biofuel development as an energy strategy is not a universal method of solving the energy crisis. States should develop rational policies toward biofuel development, assess those policies systematically according to their own merits, adjust measures to local conditions, and make decisions both calmly and carefully.

- First, make full use of "marginal land" and mixed crop systems to grow energy crops. Use saline, wasteland and fallow fields together with other unutilized or underutilized lands that are unsuitable for food production but that can support energy crops with high resistance. Plant energy crops that have a lower demand for water and organic soil contents.
- Base biofuel production primarily on raw materials of non-food energy, such as straw and manure, to avoid the impact of excessive development on food security. In the current situation of global biofuel development and utilization, many countries primarily produce food-based fuel ethanol and rapeseed-based biodiesel, and biofuel electricity generation primarily requires straw, forestry processing waste, manure, etc. as raw materials. This is a development path worth promoting.
- Strengthen the balance and the combination of farming industry and cultivation industry. The raw materials of biofuel derive not only from agriculture and forestry but also from animal husbandry. A virtuous ecosystem circle can be achieved according to the basic ecological principles of material recycling and energy flow, along with combining farming and cultivation.
- Taking into account the geographical dispersion of biofuel resources, the use of biofuel has not formed into a scale that involves low equipment-utilization levels. Therefore, enterprises' layouts should be combined with the regional distribution of agricultural regions, measures should be adjusted measures to local conditions, and scientific planning of the biofuel development region should be performed.
- To reduce market risks to enterprises and farmers caused by biofuel, on the one hand it is important to further improve biofuel's market mechanism. On the other hand the government should establish a quota system and other supportive and incentive mechanisms to protect the basic interests of both small and medium enterprises (SMEs) and farmers.

Even with various advantages of biofuel development, we recommend countries to be cautious. Against the background of the energy supply shortage, SSM is not the optimal energy strategy. Blindly pursuing alternative energy is only "robbing Peter to pay Paul". It will eventually lead to another energy crisis in the long term and could lead to a series of economic and political crisis. Unlike SSM, DSM is a type of intensive management that operates in accordance with the principle of "deciding demand according to supply". In addition, it is a type of energy management that by improving the efficiency of energy use, reduces dependence on energy-intensive industries, thus conserving energy, which can effectively prevent many issues created by SSM, such as those related to the social and economic environments. DSM represents a long-term plan to manage the energy crisis.

Therefore, we recommend that policymakers should integrate economic, administrative and technical approaches, gradually transform from SSM to DSM, and implement future energy strategies over the long term.

- Economic instruments: Economic methods involve the immediate and underlying impetus of adjusting energy demands. Energy consumption behavior should be adjusted using prices, taxes and other economic levers, prompting industries to improve their energy use efficiency and progressively rationalizing energy consumption.
- Administrative measures: For some industries with excess capacity or high energy-consumption and high emissions, monitor their energy consumption processes, supplemented by administrative tools such as fixed consumption. Compared to economic methods, administrative tools are simple and easy to implement and can have significant short-term results. However, they require the government to strengthen and improve its regulatory mechanisms; otherwise, such results will be difficult to maintain.
- Technical methods: In the long term, technical methods are fundamental to improving the efficiency of energy development and enterprise productivity. Achieving upgraded industrial and export structures through technological advances and reducing the dependence of economic development on energy is DSM's fundamental goal.

However, technical methods require investment, which is largely subject to market and institutional environment. In general, companies are reluctant to engage in technological innovation, and it is only through subsidies or enforcement or market forces engineered by the government that technological transformation can be effected. Therefore, economic instruments, administrative measures and technical methods must be combined to effectively implement DSM.

Developing countries are confronted by additional challenges related to DSM. For many developing countries, energy-intensive industries are an important support for economic growth. Blindly eliminating or limiting them will inevitably lead to an inadequate supply of key industrial products that provide national economic lifelines, directly influencing all aspects of national development. Therefore, developing countries cannot achieve an energy management transition from SSM to DSM overnight. Instead, they must combine mandatory measures with induced measures for institutional change. In practice, the government may provide opportunities for profit, prompting stakeholders to pursue new opportunities. According to the implementation effect of induced institutional change, mandatory institutional change can be gradually achieved from the point to the surface, constantly summarizing and searching for norms.

Overall, economic growth's strong demand for energy will continue. If SSM means are the only ones adopted, there will be many energy, environmental, economic and societal crises in the near future. Therefore, even if SSM meets current requirements for economic growth, all countries' national energy strategies should be based on a longer-term future. DSM compensates for SSM's shortcoming through the approach of "deciding demand according to supply" to promote industries' self-renovation, which can not only solve energy problems effectively but also improve the efficiency of production, thus injecting long-term momentum for economic growth.

## Acknowledgments

This paper is jointly supported by the Research Project of Humanities and Social Sciences Funded by the Ministry of Education of PRC (Grant no. 14YJAZH037) and the Key Project of the National Social Science Fund (Grant no. 14AZD010). We are grateful to the reviewers' constructive comments on this paper, and the help of Dr. John Coulter in language editing is also highly appreciated.

## References


[1] Omer AM. Energy, environment and sustainable development. Renew Sustain Energy Rev 2008;12(9):2265–300.
[2] Hepbasli A. A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future. Sustain Energy Rev 2008;12(3):593–661.
[3] Timmons D, Mejía CV. Biomass energy from wood chips: Diesel fuel dependence? Biomass Bioenergy 2010;34(9):1419–25.
[4] Liew WH, Hassim MH, Ng DK. Review of evolution, technology and sustainability assessments of biofuel production. J Clean Prod 2014;71:11–29.
[5] Lee RA, Lavoie JM. From first-to third-generation biofuels: challenges of producing a commodity from a biomass of increasing complexity. Anim Front 2013;3(2):6–11.
[6] Koçar G, Civaş N. An overview of biofuels from energy crops: Current status and future prospects. Renew Sustain Energy Rev 2013;28:900–16.
[7] Brennana L, Owendea P. Biofuels from microalgae-A review of technologies for production, processing, and extractions of biofuels and co-products. Renew Sustain Energy Rev 2010;14:557–77.
[8] Demirbas MF. Biofuels from algae for sustainable development. Appl Energy 2011;88(10):3473–80.
[9] Leite GB, Abdelaziz AE, Hallenbeck PC. Algal biofuels: challenges and opportunities. Bioresour Technol 2013;145:134–41.
[10] Serra T, Zilberman D. Biofuel-related price transmission literature: A review. Energy Econ 2013;37:141–51.
[11] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proc Natl Acad Sci USA 2006;103(30):11206–10.
[12] Pradhan A, Shrestha DS, McAloon A, Yee W, Haas M, Duffield JA. Energy life-cycle assessment of soybean biodiesel revisited. Am Soc Agric Biol Eng 2011;54(3):1031–9.
[13] Höök M, Tang X. Depletion of fossil fuels and anthropogenic climate change—A review. Energy Policy 2013;52:797–809.
[14] Shrestha DS, Pradhan A. Energy life-cycle analysis of a biofuel production system. Bioenergy and Biofuel from Biowastes and Biomass; 2010, p. 411–33.
[15] Kumar S, Singh J, Nanoti SM, Garg MO. A comprehensive life cycle assessment (LCA) of Jatropha biodiesel production in India. Bioresour Technol 2012;110:723–9.
[16] Rajaeifar MA, Ghobadian B, Safa M, Heidari MD. Energy life-cycle assessment and $CO_2$ emissions analysis of soybean-based biodiesel: a case study. J Clean Prod 2014;66:233–41.
[17] Renó ML, Lora EE, Palacio JC, Venturini OJ, Buchgeister J, Almazan O. A LCA (life cycle assessment) of the methanol production from sugarcane bagasse. Energy 2011;36(6):3716–26.
[18] Pimentel D, Patzek TW. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Nat Resour Res 2005;14(1):65–76.
[19] Mohammadshirazi A, Akram A, Rafiee S, Kalhor EB. Energy and cost analyses of biodiesel production from waste cooking oil. Renew Sustain Energy Rev 2014;33:44–9.
[20] García CA, Fuentes A, Hennecke A, Riegelhaupt E, Manzini F, Masera O. Life-cycle greenhouse gas emissions and energy balances of sugarcane ethanol production in Mexico. Appl Energy 2011;88(6):2088–97.
[21] Yang Q, Chen GQ. Nonrenewable energy cost of corn-ethanol in China. Energy Policy 2012;41:340–7.
[22] Chen H, Chen GQ. Energy cost of rapeseed-based biodiesel as alternative energy in China. Renew Energy 2011;36(5):1374–8.
[23] Bureau JC, Disdier AC, Gauroy C, Tréguer D. A quantitative assessment of the determinants of the net energy value of biofuels. Energy Policy. 2010;38(5):2282–90.
[24] Cherubini F, Bird ND, Cowie A, Jungmeier G, Schlamadinger B, Woess-Gallasch S. Energy-and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resour Conserv Recycl 2009;53(8):434–47.
[25] Cambero C, Sowlati T. Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives–A review of literature. Renew Sustain Energy Rev 2014;36:62–73.
[26] Heller MC, Keoleian GA, Mann MK, Volk TA. Life cycle energy and environmental benefits of generating electricity from willow biomass. Renew Energy 2004;29(7):1023–42.
[27] Budzianowski WM. Negative carbon intensity of renewable energy technologies involving biomass or carbon dioxide as inputs. Renew Sustain Energy Rev 2012;16(9):6507–21.
[28] Havlík P, Schneider UA, Schmid E, Böttcher H, Fritz S, Skalský R, Aoki K, De Cara S, Kindermann G, Kraxner F, Leduc S. Global land-use implications of first and second generation biofuel targets. Energy Policy 2011;39(10):5690–702.
[29] Čuček L, Klemeš JJ, Kravanja Z. Carbon and nitrogen trade-offs in biomass energy production. Clean Technol Environ Policy 2012;14(3):389–97.
[30] Highina BK, Bugaje IM, Umar B. A review on second generation biofuel: a comparison of its carbon footprints. Europ J Eng Technol 2014;Vol(2):2.
[31] Holma A, Koponen K, Antikainen R, Lardon L, Leskinen P, Roux P. Current limits of life cycle assessment framework in evaluating environmental sustainability–case of two evolving biofuel technologies. J Clean Prod 2013;54:215–28.
[32] Yang Q, Chen GQ. Greenhouse gas emissions of corn–ethanol production in China. Ecol Model 2013;252:176–84.
[33] Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319(5867):1238–40.
[34] Smeets E, Tabeau A, van Berkum S, Moorad J, van Meijl H, Woltjer G. The impact of the rebound effect of the use of first generation biofuels in the EU on greenhouse gas emissions: a critical review. Renew Sustain Energy Rev 2014;38:393–403.
[35] Chen X, Huang H, Khanna M. Land-use and greenhouse gas implications of biofuels: role of technology and policy. Clim Chang Econ 2012;3(03):1250013.
[36] Popp J, Lakner Z, Harangi-Rákos M, Fári M. The effect of bioenergy expansion: Food, energy, and environment. Renew Sustain Energy Rev 2014;32:559–78.
[37] Rajagopal D, Hochman G, Zilberman D. Indirect fuel use change (IFUC) and the life cycle environmental impact of biofuel policies. Energy Policy 2011;39(1):228–33.
[38] Thompson W, Whistance J, Meyer S. Effects of US biofuel policies on US and world petroleum product markets with consequences for greenhouse gas emissions. Energy Policy 2011;39(9):5509–18.
[39] Laborde D. Assessing the land use change consequences of European biofuel policies. International food policy institute (IFPRI); 2011.
[40] Tyner WE. Induced land use emissions due to first and second generation biofuels and uncertainty in land use emission factors. Econ. Res. Int. 2013; 2013.
[41] Xue J, Grift TE, Hansen AC. Effect of biodiesel on engine performances and emissions. Renew Sustain Energy Rev 2011;15(2):1098–116.
[42] Timilsina GR, Shrestha A. Biofuels: markets, targets and impacts. World bank policy research working paper series, vol. 2010.
[43] Hammond GP, Seth SM. Carbon and environmental footprinting of global biofuel production. Appl Energy 2013;112:547–59.
[44] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319(5867):1235–8.
[45] Danielsen F, Beukema H, Burgess ND, Parish F, Brühl CA, Donald PF, et al. Biofuel plantations on forested lands: Double jeopardy for biodiversity and climate. Conserv Biol 2008;23(2):348–58.
[46] Hennecke AM, Faist M, Reinhardt J, Junquera V, Neeft J, Fehrenbach H. Biofuel greenhouse gas calculations under the European Renewable Energy

Directive–A comparison of the BioGrace tool vs. the tool of the Roundtable on Sustainable Biofuels. Appl Energy 2013;102:55–62.
[47] Wu Y, Liu S. Impacts of biofuels production alternatives on water quantity and quality in the Iowa River Basin. Biomass Bioenergy 2012;36:182–91.
[48] Yang H, Zhou Y, Liu J. Land and water requirements of biofuel and implications for food supply and the environment in China. Energy Policy 2009;37(5):1876–85.
[49] Yang J, Xu M, Zhang X, Hu Q, Sommerfeld M, Chen Y. Life-cycle analysis on biodiesel production from microalgae: water footprint and nutrients balance. Bioresour Technol 2011;102(1):159–65.
[50] Dominguez-Faus R, Powers SE, Burken JG, Alvarez PJ. The water footprint of biofuels: A drink or drive issue? Environ Sci Technol 2009;43(9):3005–10.
[51] Gerbens-Leenes PW, Van Lienden AR, Hoekstra AY, Van der Meer TH. Biofuel scenarios in a water perspective: The global blue and green water footprint of road transport in 2030. Glob Environ Chang 2012;22(3):764–75.
[52] Wu M, Mintz M, Wang M, Arora S. Water consumption in the production of ethanol and petroleum gasoline. Environ Manag 2009;44(5):981–97.
[53] Joly CA, Huntley BJ, Dale VH, Mace G, Muok B, Ravindranath NH. Biofuel impacts on biodiversity and ecosystem services. Scientific Committee on problems of the environment (SCOPE) rapid assessment process on bioenergy and sustainability; 2015. p. 555–580.
[54] Liu Y, Xu Y, Zhang F, Yun J, Shen Z. The impact of biofuel plantation on biodiversity: a review. Chin Sci Bull 2014;59(34):4639–51.
[55] Struebig MJ, Kingston T, Petit EJ, Le Comber SC, Zubaid A, Mohd-Adnan A, Rossiter SJ. Parallel declines in species and genetic diversity in tropical forest fragments. Ecol Lett 2011;16(6):582–90.
[56] Requena JS, Guimaraes AC, Alpera SQ, Gangas ER, Hernandez-Navarro S, Gracia LN, Martin-Gil J, Cuesta HF. Life Cycle Assessment (LCA) of the biofuel production process from sunflower oil, rapeseed oil and soybean oil. Fuel Process Technol 2011;92(2):190–9.
[57] Reinhardt GA, Von Falkenstein E. Environmental assessment of biofuels for transport and the aspects of land use Competition. Biomass Bioenergy 2011;35(6):2315–22.
[58] Zhou A, Thomson E. The development of biofuels in Asia. Appl Energy 2009;86:S11–20.
[59] Bioenergy could do more harm than good; 2007. ⟨http://www.sciencedaily.com/releases/2007/07/070722220325.htm⟩.
[60] Cornelissen S, Dehue B. Summary of approaches to accounting for indirect impacts of biofuel production. Summary of approaches to accounting for indirect impacts of biofuel production; 2009.
[61] Openshaw K. Biomass energy: employment generation and its contribution to poverty alleviation. Biomass Bioenergy 2010;34(3):365–78.
[62] Ajanovic A. Biofuels versus food production: does biofuels production increase food prices? Energy. 2011;36(4):2070–6.
[63] Amigun B, Musango JK, Stafford W. Biofuels and sustainability in Africa. Renew Sustain Energy Rev 2011;15(2):1360–72.
[64] Food and Agriculture Organization the United Nations. The state of food and agriculture; 2008.
[65] Bildirici ME. The relationship between economic growth and biomass energy consumption. J Renew Sustain Energy 2012;4(2):023113.
[66] Parcell JL, Westhoff P. Economic effects of biofuel production on states and rural communities. J Agric Appl Econ 2006;38(2):377.
[67] Gohin A. Impacts of the European biofuel policy on the farm sector: a general equilibrium assessment. Appl Econ Perspect Policy 2008;30(4):623–41.
[68] Deppermann A, Offermann F, Puttkammer J, Grethe H. EU biofuel policies: income effects and lobbying decisions in the German agricultural sector. Renew Energy 2016;87:259–65.
[69] Jaeger WK, Egelkraut TM. Biofuel economics in a setting of multiple objectives and unintended consequences. Renew Sustain Energy Rev 2011;15(9):4320–33.
[70] Secretariat, GBEP. The Global Bioenergy Partnership Sustainability Indicators for Bioenergy; 2011.
[71] Nelson G, Cai Z, Hassan R, Santos M, Swaminathan H. Food security and climate change. A report by the High Level Panel of Experts (HLPE) on Food Security and Nutrition of the Committee on World Food Security; 2012.
[72] Locke A, Henley G. A review of the literature on biofuels and food security at a local level. Overseas Development Institute (ODI), London; 2014.
[73] UN-Energy. 2007. Sustainable bioenergy: A framework for decision makers. ⟨http://www.fao.org/docrep/010/a1094e/a1094e00.htm⟩.
[74] Dahlbeck A. Fuel for thought: Addressing the social impacts of the EU biofuel policies; 2012:13.
[75] Beall E, Cadoni P, Rossi A. A Compilation of tools and methodologies to assess the sustainability of modern bioenergy. Rome: FAO; 2012.
[76] Popp J. Global responsibility of food, energy and environmental security. Stud Agric Econ 2009(110):.
[77] Clancy J. Biofuels and rural poverty. London: Routledge; 2013.
[78] Elbehri A, Segerstedt A, Liu P. Biofuels and the sustainability challenge: a global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. Food and Agriculture Organization of the United Nations (FAO); 2013.
[79] Koizumi T. Biofuel and food security in China and Japan. Renew Sustain Energy Rev 2013;21:102–9.
[80] USDA. 2016. ⟨http://www.ers.usda.gov/media/866543/cornusetable.html⟩.
[81] EIA. 2015. ⟨https://www.eia.gov/todayinenergy/detail.cfm?id=21212⟩.
[82] Anderson Teixeira KJ, Davis SC, Masters MD, Delucia EH. Changes in soil organic carbon under biofuel crops. Gcb Bioenergy 2009;1(1):75–96.
[83] Popp J, Pető K, Nagy J. Impact of pesticide productivity on food security. In: Sustainable agriculture reviews. Springer International Publishing; 2014, p. 19–33.
[84] Heggenstaller AH, Anex RP, Liebman M, Sundberg DN, Gibson LR. Productivity and nutrient dynamics in bioenergy double-cropping systems. Agron J 2008;100(6):1740–8.
[85] German L, Schoneveld GC, Gumbo D. The local social and environmental impacts of smallholder-based biofuel investments in Zambia. Ecol Soc 2011;16(4):12.
[86] Kgathi DL, Mfundisi KB, Mmopelwa G, Mosepele K. Potential impacts of biofuel development on food security in Botswana: a contribution to energy policy. Energy Policy 2012;43:70–9.
[87] Arndt C, Msangi S, Thurlow J. Are biofuels good for African development? An analytical framework with evidence from Mozambique and Tanzania Biofuels 2011;2(2):221–34.
[88] Negash M, Swinnen JF. Biofuels and food security: micro-evidence from Ethiopia. Energy Policy 2013;61:963–76.
[89] Mondiale B. Rising food prices: policy options and World Bank response; 2008.
[90] FAO. Biofuels: Prospects and opportunities; 2008.
[91] Gallagher E. The Gallagher review of the indirect effects of biofuels production. London: Renewable Fuels Agency; 2008.
[92] Westhoff P. The economics of food: How feeding and fuelling the planner affects food produce. 1st ed.. New Jersey: FT Times; 2010.
[93] De Gorter H, Drabik D, Just DR. The perverse effects of biofuel public-sector policies. Annu Rev Resour Econ 2013;5(1):463–83.
[94] Naylor RL, Liska AJ, Burke MB, Falcon WP, Gaskell JC, Rozelle SD, Cassman KG. The ripple effect: biofuels, food security, and the environment. Environ Sci Policy Sustain Dev 2007;49(9):30–43.
[95] Persson UM. The impact of biofuel demand on agricultural commodity prices: a systematic review. Wiley Interdiscip. Rev.: Energy Environ; 2014.
[96] Zhang Z, Lohr L, Escalante C, Wetzstein M. Food versus fuel: What do prices tell us? Energy Policy 2010;38(1):445–51.
[97] Huang J, Yang J, Msangi S, Rozelle S, Weersink A. Biofuels and the poor: Global impact pathways of biofuels on agricultural markets. Food Policy 2012;37(4):439–51.
[98] Ewing M, Msangi S. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. Environ Sci Policy 2009;12(4):520–8.
[99] Escobar JC, Lora ES, Venturini OJ, Yáñez EE, Castillo EF, Almazan O. Biofuels: environment, technology and food security. Renew Sustain Energy Rev 2009;13(6):1275–87.
[100] Okiyama M, Tokunaga S. Impact of expanding bio-Fuel consumption on household income of farmers in Thailand: utilizing the computable general equilibrium model. Rev Urban Reg Dev Stud 2010;22(2–3):109–42.
[101] Oladosu G, Msangi S. Biofuel-food market interactions: a review of modeling approaches and findings. Agriculture 2013;3(1):53–71.
[102] Swinnen J, Squicciarini P. Mixed messages on prices and food security. Science 2012;335(6067):405–6.
[103] Verpoorten M, Arora A, Stoop N, Swinnen J. Self-reported food insecurity in Africa during the food price crisis. Food Policy 2013;39:51–63.
[104] Khanna M, Chen X, Huang H, Önal H. Supply of cellulosic biofuel feedstocks and regional production pattern. Am J Agric Econ 2011;93(2):473–80.
[105] Duer H, Christensen PO. Socio-economic aspects of different biofuel development pathways. Biomass Bioenergy 2010;34(2):237–43.
[106] Lensink S, Londo M. Assessment of biofuels supporting policies using the BioTrans model. Biomass Bioenergy 2010;34(2):218–26.
[107] Saygin D, Gielen DJ, Draeck M, Worrell E, Patel MK. Assessment of the technical and economic potentials of biomass use for the production of steam, chemicals and polymers. Renew Sustain Energy Rev 2014;40:1153–67.
[108] Sims RE, Mabee W, Saddler JN, Taylor M. An overview of second generation biofuel technologies. Bioresour Technol 2010;101(6):1570–80.
[109] Carriquiry MA, Du X, Timilsina GR. Second generation biofuels: economics and policies. Energy Policy 2011;39(7):4222–34.
[110] Festel G, Würmseher M, Rammer C, Boles E, Bellof M. Modelling production cost scenarios for biofuels and fossil fuels in Europe. J Clean Prod 2014;66:242–53.
[111] Liang S, Xu M, Zhang T. Unintended consequences of bioethanol feedstock choice in China. Bioresour Technol 2012;125:312–7.
[112] Kuhad RC, Gupta R, Khasa YP, Singh A, Zhang YH. Bioethanol production from pentose sugars: Current status and future prospects. Renew Sustain Energy Rev 2011;15(9):4950–62.
[113] Furlan FF, Costa CB, de Castro Fonseca G, de Pelegrini Soares R, Secchi AR, da Cruz AJ, de Campos Giordano R. Assessing the production of first and second generation bioethanol from sugarcane through the integration of global optimization and process detailed modeling. Comput Chem Eng 2012;43:1–9.
[114] Dias MO, Junqueira TL, Jesus CD, Rossell CE, Maciel Filho R, Bonomi A. Improving second generation ethanol production through optimization of first generation production process from sugarcane. Energy 2012;43(1):246–52.
[115] Tay DH, Ng DK, Sammons Jr NE, Eden MR. Fuzzy optimization approach for the synthesis of a sustainable integrated biorefinery. Ind Eng Chem Res 2011;50(3):1652–65.
[116] Dassanayake GD, Kumar A. Techno-economic assessment of triticale straw for power generation. Appl Energy 2012;98:236–45.

[117] Ng RT, Tay DH, Ng DK. Simultaneous process synthesis, heat and power integration in a sustainable integrated biorefinery. Energy Fuels 2012;26(12):7316–30.
[118] Kou N, Zhao F. Techno-economical analysis of a thermo-chemical biofuel plant with feedstock and product flexibility under external disturbances. Energy 2011;36(12):6745–52.
[119] Wright MM, Daugaard DE, Satrio JA, Brown RC. Techno-economic analysis of biomass fast pyrolysis to transportation fuels. Fuel 2010;89:S2–10.
[120] Apostolakou AA, Kookos IK, Marazioti C, Angelopoulos KC. Techno-economic analysis of a biodiesel production process from vegetable oils. Fuel Process Technol 2009;90(7):1023–31.
[121] Warren P. The use of systematic reviews to analyze demand-side management policy. Energy Effic 2014;7(3):417–27.
[122] Devine-Wright H, Devine-Wright P. From demand-side management to demand-side participation: Tracing an environmental psychology of sustainable electricity system evolution. J Appl Psychol 2005;6(3-4):167–77.
[123] Petit O, Baron C. Integrated water resources management: From general principles to its implementation by the state. The case of Burkina Faso. In: Natural Resources Forum, Blackwell Publishing Ltd; 2009, p. 49–59.