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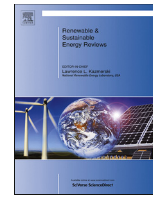

The effect of bioenergy expansion: Food, energy, and environment

J. Popp [a,*], Z. Lakner [b], M. Harangi-Rákos [a], M. Fári [c]

[a] Debrecen University, Faculty of Applied Economics and Rural Development, Institute of Economic Theory, 4032 Debrecen, Böszörményi Street 138, Hungary
[b] Budapest Corvinus University, Faculty of Food Sciences, Department of Food Economics, Budapest, Hungary
[c] Debrecen University, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Animal Science, Biotechnology and Nature Conservation, Hungary

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A B S T R A C T

The increasing prices and environmental impacts of fossil fuels have made the production of biofuels to reach unprecedented volumes over the last 15 years. Given the increasing land requirement for biofuel production, the assessment of the impacts that extensive biofuel production may cause to food supply and to the environment has considerable importance. Agriculture faces some major inter-connected challenges in delivering food security at a time of increasing pressures from population growth, changing consumption patterns and dietary preferences, and post-harvest losses. At the same time, there are growing opportunities and demands for the use of biomass to provide additional renewables, energy for heat, power and fuel, pharmaceuticals and green chemical feedstocks. Biomass from cellulosic bioenergy crops is expected to play a substantial role in future energy systems. However, the worldwide potential of bioenergy is limited, because all land is multi-functional and land is also needed for food, feed, timber, and fiber production, and for nature conservation and climate protection. Furthermore, the potential of bioenergy for climate change mitigation remains unclear due to large uncertainties about future agricultural yield improvements and land availability for biomass plantations. Large-scale cultivation of dedicated biomass is likely to affect bioenergy potentials, global food prices and water scarcity. Therefore, integrated policies for energy, land use and water management are needed. As biomass contains all the elements found in fossil resources, albeit in different combinations, therefore present and developing technologies can lead to a future based on renewable, sustainable and low carbon economies. This article presents [1] risks to food and energy security [2] estimates of bioenergy potential with regard to biofuel production, and [3] the challenges of the environmental impact.

Contents

Abbreviations: GHG, Greenhouse GasEJ Exajoule; TOE, ton oil equivalent; GJ, Giga Joule; FFV, flex-fuel vehicle; LUC, land use change; DDGS, dried distillers grains with solubles; CGF, corn gluten feed; CGM, corn gluten meal; EPA, Environmental Protection Agency; RED, Renewable Energy Directive

* Corresponding author. Tel./fax: +36 525 08482.
E-mail address: poppj@agr.unideb.hu (J. Popp).

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1. Introduction

This paper provides a comprehensive review on global bioenergy, especially biofuels production and potentials, including different feedstock sources, technological paths, financing and trade. The impacts on food production, environment and land requirements are also discussed. It is concluded that the rise in the use of biofuels is inevitable and that international cooperation, regulations, certification mechanisms and sustainability criteria must be established regarding the use of land and the mitigation of environmental impacts caused by biofuel production. Finally, the impact of substitution of traditional animal feed with co-products of biofuel production on the land use of feedstocks is also addressed.

The world's population continues to grow and, over the next 40 years, agricultural production will have to increase by some 60% [1]. Meanwhile a quarter of all agricultural land has already suffered degradation, and there is a deepening awareness of the long term consequences of a loss of biodiversity with the prospect of climate change. Higher food, feed and fiber demand will place an increasing pressure on land and water resources, whose availability and productivity in agriculture may themselves be under threat from climate change. The additional impact on food prices of higher demand for crops as energy feedstock is of real concern. Since biomass can substitute for petrochemicals too, higher oil prices will trigger new non-energy demands on bio-resources as well. In the last 35 years global energy supplies have nearly doubled but the relative contribution from renewables has hardly changed at around 13% [2]. Global energy demand is increasing, as is the environmental damage due to fossil fuel use. Continued reliance on fossil fuels will make it very difficult to reduce emissions of greenhouse gases that contribute to global warming. Bioenergy currently provides roughly 10% of global supplies and accounts for roughly 80% of the energy derived from renewable sources [2]. The "new" renewables (e.g., solar, wind, and biofuel) have been growing fast from a very low base. Although their contribution is still a marginal component of total global renewable energy supply, they are continuously growing. Bioenergy was the main source of power and heat prior to the industrial revolution. Since then, economic development has largely relied on fossil fuels. A major impetus for the development of bioenergy has been the search for alternatives to fossil fuels, particularly those used in transportation.

In the past, burning fossil fuels, deforestation and other human activities have released large amounts of greenhouse gases into the atmosphere. Today, almost all of the commercially available biofuels are produced from either starch- or sugar-rich crops (for bioethanol), or oilseeds (for biodiesel). Recent research has found that these bioenergy sources have their drawbacks [3,4] and turned attention to the use of ligno-cellulosic feedstocks, such as perennial grasses and short rotation woody crops for bioenergy production [5,6]. Removing CO_2 from the atmosphere (negative emissions) implies that human-induced uptake of CO_2 would have to be larger than the amount of human-induced GHG emissions. One of the few technologies that may result in negative emissions is the combination of bioenergy and carbon capture and storage (CCS) [7].

Based on this diverse range of feedstocks, the technical potential for biomass is estimated in the literature to be possibly as high as 1500 EJ/year by 2050 [8]. Estimates of global primary bioenergy potentials available around 2050 published in the last 5 years span range from 30 to 1300 EJ/year [9,10]. Dornburg et al. [11] analyzed a number of projections and pointed out that studies on the potential of biomass as an energy source are in the range of 0–1500 EJ. A sensitivity analysis conducted by Dornburg et al. narrows that range to approximately 200–500 EJ/year in 2050 when taking into consideration water limitations, biodiversity protection and food demand. Recently, the IPCC Special Report on Renewable Energy [12] reported a huge range of 50–500 EJ/year. Also important are the results reached in the Global Energy Assessment [13], which concludes on a potential equal to 160–270 EJ/year in 2050. Such a wide range is due to differences in methodology as well as assumptions on crop yields and available land. The higher value resulting from an optimistic approach assumes a highly developed agricultural system, the lower is the result of a pessimistic approach with high population growth and extreme measures to avoid biodiversity loss [14]. Batidzirai et al. [15] present a very comprehensive overview of bioenergy potentials, also discussing the different types of potential. The differences in bioenergy resource assessment estimates are due to the broad variety of approaches, methodologies, assumptions and datasets.

The total annual aboveground net primary production (the net amount of carbon assimilated in a time period by vegetation) on the Earth's terrestrial surface is estimated to be about 30–35 Gt carbon of biomass growth with a gross energy value of 1100–1260 EJ/year, assuming an average carbon content of 50% and 18 GJ/t average heating value, which can be compared to the current world primary energy supply of about 550 EJ/year [16,17]. All harvested biomass used for food, fodder, fiber and forest products, when expressed in equivalent heat content, equals 219 EJ/year. The global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers and pulses) corresponds to about 60 EJ/year. In order to produce that biomass, humans affect or even destroy roughly another 70 EJ/year of biomass in the form of plant parts not harvested and left on the field and biomass burned in anthropogenic vegetation fires. The global industrial roundwood production corresponds to 15 to 20 EJ/year [17–19]. Hence, some 800–900 EJ/year worth of biomass currently remains in the aboveground compartment of global terrestrial ecosystems. In order to meet their biomass demand, humans affect approximately three quarters of the Earth's ice-free land surface with huge implications for ecosystems and biodiversity [19]. However, most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of between 200 and 500 EJ/year [2]. In other energy scenarios, bioenergy use is projected to be in the order of 150–400 EJ in the year 2100 [20].

Large-scale bioenergy production and associated additional demand for irrigation may further intensify existing pressures on water resources [21]. In tropical and sub-tropical developing countries deforestation happens due to land clearing for new crop- and pasture land but also due to the use of biomass for traditional heat and energy production. Forests are a major storage of carbon [22], so there is an adverse impact when forest carbon is released for the purpose of bioenergy production [23]. But deforestation not only removes a carbon sink, it is also regarded as the greatest threat to terrestrial biodiversity as forests are the most