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Current and future economic performance of first and second generation biofuels in developing countries

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HIGHLIGHTS

- First generation biofuels have a cost range of 5–45 \$/GJ for all settings considered in this study.
- Second generation biofuels have a cost range of 14–26 \$/GJ for all settings considered in this study.
- There is higher uncertainty in cost estimates for second than first generation biofuels.
- Key cost factors are labour costs, agricultural efficiency, biomass yields and conversion costs.
- Acquiring location specific data is essential for accurate cost estimation.

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ABSTRACT

Net Present Value (NPV) and total production cost calculations are made for first and second generation biofuels in 74 settings, covering 5 fuel output types, 8 feedstock types, 12 countries and 8 combinations of agricultural management systems between 2010 and 2030. Yields are assumed to increase due to better crop management and improved varieties. High NPVs (meaning profitable production) are calculated for cassava (up to 16,000 \$/ha) and palm production (up to almost 7000 \$/ha). But cassava can also have a negative NPV which indicates that the project investment is not without risk. The calculated NPVs for jatropha range from −900 to 2000 \$/ha, while for sugarcane and soy the NPV is always positive, (2500–5000 \$/ha and 200–3000 \$/ha respectively) and therefore profitable. Total production costs in 2010 are estimated to vary from 5 to 45 \$/GJ for 1st generation feedstocks in 2010, and from around 10–35 \$/GJ in 2020, compared to 20–30 \$/GJ for fossil fuels. Argentina and Malaysia are the regions with the lowest production costs for biofuel (soy and palm biodiesel for 11–15 \$/GJ and 8–23 \$/GJ respectively), although potential for cost reduction exists in other regions. Production costs of 2nd generation biofuels are estimated to be 17–26 \$/GJ in 2020 and 14–23 \$/GJ in 2030. Poplar based synfuel production in Ukraine has the lowest costs (14–17 \$/GJ) and rice straw based bioethanol the highest (23–26 \$/GJ) – for both the short and long term. The time between investment and benefits, as well as the size of investment and the alternative commodity markets, varies with the type of feedstock. The choice of feedstock therefore depends on the local agricultural system, and the preferences and means of the local farmers. Key to the competitive production of 2nd generation fuels is the optimisation of the conversion process, which dominates overall production costs (with 35–65% of total costs). Also important is the efficient organisation of supply chain logistics, especially for the low energy density feedstocks such as wheat straw – requires densification early in the chain. Key factors in the economic analysis are: labour costs and requirements, agricultural efficiency, conversion cost and biomass yields. Acquiring accurate location specific data is essential for detailed analyses.

1. Introduction

Climate change is at the top of the political agenda and negotiations are ongoing in order to set an international policy framework in a post-Kyoto era, where developing countries are expected to play an increasing role in global climate change mitigation. Biofuels offer a large potential to displace petroleum fuels in transport and some stationary applications, with the promise to decrease global greenhouse gas (GHG) emissions [1–3]. Furthermore, biofuels can provide other local and regional benefits such as energy security, rural development, positive impacts on (regional)

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gross domestic product (GDP), and mitigation of local pollutant emissions [4–8]. The main drivers for the deployment of biofuels include:

1. Contribution to energy security by diversifying energy supply sources, increasing the number of energy producing countries and a potential to supply 'homegrown' energy;
2. Potential to contribute to GHG emission reduction targets by replacing fossil fuels;
3. Potential to contribute to development, with special focus on rural development, revalorization of rural areas and improving access to modern energy services [1,9,10].

Moreover, increasing energy prices, particularly of oil, are also stimulating the market for alternative energy sources, and bioenergy appears to be increasingly competitive in developing countries, due to suitable climate conditions, comparatively large available/unutilised land areas and relatively low biomass production costs [4,11]. However, increasing concerns have been expressed with regard to the sustainability profile of biofuels [12]. Frequently cited issues of concern include potential negative environmental impacts due to biomass production and social conflicts that could result from potential food versus fuel competition, but critics also point to potential economic unsustainability of some biofuel pathways [1,13]. Various studies have analysed environmental impacts of biofuels production (e.g. GHG emissions by Hoefnagels et al. [14] and by Muench and Guenther [15]) and social effects in developing countries (e.g. [7,9]. These studies show that biofuel production impacts vary greatly from country to country and that some production and supply pathways, practices and technologies are more sustainable than others. The impacts of bioenergy projects in developing countries depend, among others, on the natural conditions (climate, soil), on the socio-economic setting (employment, poverty, governance) and especially on the feedstock production system that is used (crop type, agricultural management system) [8,16,17]. To effectively evaluate key biofuel production and supply impacts, detailed environmental and socio-economic datasets are required [18] . However, detailed data availability is problematic for developing countries. Also, studies that look at economic sustainability of biofuel value chains, typically focus on one specific region (e.g. Africa), or on one specific agricultural management system type (e.g. smallholders) [19–21], and usually this does not account for the large variety in sustainable biofuel production options. Therefore, the objectives of this study are to compile data sets for biofuel production in developing countries, and to analyse the corresponding economic performance of biofuel supply chains taking large variations between feedstocks and countries into account. Economic evaluation of biofuel production include a detailed analysis of the viability of feedstock production (in terms of Net Present Value (NPV) and the total production costs including conversion, transport and distribution.

Sustainability of biofuels production in terms of financial feasibility, depends (amongst others) on the specific local context, the type of business model that is used, and the type of feedstock [21]. For feedstock production, nearly all steps can be realised with different processes, intensity and efficiency, land use patterns, etc. and under very different social and economic circumstances. To assess the impacts of biofuel feedstock production, key variables considered include the biofuel type produced, feedstock used, soil characteristics and climate conditions where production occurs, the agricultural management system employed, socio-economic conditions (e.g. cost of labour, land and fuels, (un)employment rate, availability of land for energy crop production, ownership of land), among other factors. For the entire biofuel supply chain, there is a multitude of production pathways that include agricultural and forestry production and harvesting systems, downstream conversion routes as well as fuel and material inputs and associated many intermediate logistic operations.

The feedstocks that are selected include the most commonly used in developing countries (e.g. sugarcane and palm oil) for "first generation" biofuel production and some of the most promising ones (e.g. switchgrass, organic residues) for "second generation" biofuels production [22,23]. Currently, more than 99% of all currently produced biofuels are classified as "first generation" (i.e. fuels produced primarily from cereals, grains, sugar crops and oil seeds) [24,25]. "Second generation" or "next generation" biofuels, on the other hand, are produced from lignocellulosic feedstocks such as agricultural and forest residues, as well as purpose-grown energy crops such as vegetative grasses and short rotation forests (SRFs) [1,22]. Further definition of the scope of the study is given under description of the setting in the methodology section.

This paper is structured as follows: Section 2 explains the methodology and the 'setting' approach, while in Section 3 the results of the economic analysis is provided. In Section 4 the results are discussed and Section 5 finalises with the conclusion and recommendations. Detailed input data and key assumptions are provided in the Appendix.

2. Approach and methodology

2.1. Settings

To take into account the broad variety of biofuel production and supply pathways, a so-called setting approach was developed whereby several variables are combined into 74 different settings. A "Setting" is a combination of biofuel production and supply chains ("life-cycles") with similar typical socioeconomic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) characteristics. The variables that are considered in this study include biofuel produced, feedstock input, geographical scope (region), crop management system and time frame as discussed below.

Fuel output – All liquid fuels that have reasonably large market shares are considered (i.e.):

- VO (Straight Vegetable Oil).
- Biodiesel, 1st generation FAME (Fatty-acid methyl ester).
- Biodiesel, 2nd generation BTL (Biomass-to-Liquid).
- Ethanol, 1st generation (EtOH).
- Ethanol, 2nd generation (enzyme-enhanced lignocellulose conversion) (next EtOH).

Other fuels such as bio-butanol, bio-methane and bio-electricity are not considered in this analysis, because of their limited current market share and experience.

Time frame: Three timeframes are included; for 1st generation biofuels we evaluate the sustainability performance in 2010 and 2020, and for 2nd generation biofuels the assessment was for 2020 and 2030 (since commercialisation of 2nd generation technologies is expected in the next decade [8]. For analysis to 2020 and 2030, the projections take into account yield and cost developments as discussed in Sections 2.2 and 2.3.

Feedstock input: The selection of feedstocks that are analysed reflects a balance between including a representative list of common and promising feedstocks suitable for the different developing geographical regions, and maintaining a manageable number of settings. The following feedstocks (with reference – between parentheses – to the liquid fuels they are converted to) were selected:

- Sugarcane (1st and 2nd generation EtOH).
- Cassava (EtOH).
- Oil palm (FAME, SVO).