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Modelling production cost scenarios for biofuels and fossil fuels in Europe

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ABSTRACT

Competitive production costs compared to conventional fuels are imperative for biofuels to gain market shares, as current tax advantages for biofuels are only temporary. Comparing production costs of different biofuels with fossil fuels is a challenge due to the complexity of influencing factors. The objective of this research paper is threefold: 1) to project future bio-fuel feedstock prices based on the crude oil price development, the price index for agricultural products, growth in world population, growth in wealth per capita income, and change in energy consumption per capita, 2) to simulate production costs under consideration of likely economies of scale from scaling-up production size and technological learning and 3) to compare different biofuels and fossil fuels by scenario analysis. A calculation model for biofuel production is used to analyse projected production costs for different types of biofuels in Europe for 2015 and 2020. Unlike engineering oriented bottom–up approaches that are often used in other biofuel studies, the macro-economic top–down approach applied in this study enables an economic comparison and discussion of various fuel types based on reference scenarios of crude oil prices of €50, €100, €150 and €200 per barrel. Depending on the specific raw material prices as well as the conversion costs, the analysis delivered a differentiated view on the production costs and thus on the competitiveness of each individual type of fuel. The results show that 2nd generation biofuels are most likely to achieve competitive production costs mid- to long-term when taking into account the effects from technological learning and production scale size as well as crude oil price scenarios between €50 and €200 per barrel for both reference years. In all crude oil price scenarios, bioethanol from lignocellulosic raw materials as well as biodiesel from waste oil are associated with high cost saving potentials which enable them to outperform fossil fuels and 1st generation biofuels.

1. Introduction

A large portion of worldwide energy sources and tangible products are made from fossil resources. Crude oil is the single most important source of energy accounting for approximately 35% of worldwide primary energy consumption in 2005 and is expected to slightly decrease to 32% by 2030 (IEA, 2007). Although crude oil, natural gas and coal will still remain the most important sources of energy until at least 2030 (U.S. EIA, 2011; Birol, 2010), depleting oil reserves have been recognised as a main challenge to energy supply in the next decades.

Owing to the rising crude oil price and stricter emission standards, the demand for alternative fuels is growing. Alternative fuels able to mitigate climate change and reduce the consumption of fossil resources are increasingly being promoted by governments (Gustavsson, 1997; Mizsey and Racz, 2010; Fargione et al., 2008; Balat, 2011). Among these alternative fuels, biofuels are particularly important to bridge the gap until fuel cell or electrically driven vehicles are available on a large scale. The replacement of oil with biomass as raw material for fuel and chemical production is an interesting option and a driving force for the development of so-

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called biorefineries, where almost all types of biomass feedstocks can be converted to different products (Cherubini, 2010).

Renewable resources can lead to a higher security of supply and a better environmental performance due to lower greenhouse gas (GHG) emissions (Parry et al., 1999), and may also increase income in rural regions (Leistritz and Hodur, 2008). Some authors even expect the development of a bio-based economy (Tyner and Taheripour, 2008). Of special interest is the production of biofuels, such as bioethanol, biodiesel or biomass-to-liquids (BTL) fuel using various raw materials and production processes (Naik et al., 2010). In contrast to biofuels of the 1st generation (bioethanol from sugar or starch containing plants or biodiesel from rape seed or palm oil), 2nd generation biofuels are made from raw materials which are not used for the production of food products. These raw materials mainly include lignocellulosic materials (or lignocellulosic waste), such as straw and wood as well as various agricultural and wood processing waste products, such as organic waste. Ajanovic (2011) concludes that besides the advantage related to the absence of competition for raw materials with food production, 2nd generation biofuels are associated with higher energy yields, modest use of agro-chemicals and higher reduction potential of greenhouse gas emissions compared to 1st generation biofuels. The use of biofuels has increased considerably in the European Union (EU) (Bomb et al., 2007; Dautzenberg and Hantl, 2008), although, so far, only first generation biofuels are being produced in larger scales.

The main objective of this paper is to calculate biofuel production costs for different biofuels in Europe for the two years 2015 and 2002 and compare them with production costs for fossil fuels. For this purpose, a calculation model consisting of four steps was developed: 1) definition of biofuel production scenarios in 2015 and 2020, 2) estimation of future raw material prices based on assumptions on crude oil price development and the observed relation between crude oil price and prices for biofuel raw materials in the past, 3) modelling of scale and time dependant conversion and capital costs and 4) calculation of the total production costs as sum of raw material costs, capital costs and conversion costs. The input data for the production cost model are taken from publicly available production cost data for production processes as well as single production steps which were collected during the past five years based on literature research and expert interviews (Festel, 2008, 2007). The production costs are calculated in Euro Cent per litre (€Cent/l). The accuracy of the results was enhanced by plausibility checks based on current data as well as consistency of the results across production technologies. Simultaneously, data comparability was assessed in this course and, if necessary, corresponding adjustments were performed.

Both changes in raw material costs and conversion costs as well as capital costs based on different scenarios of price development for raw materials and crude oil were considered. Raw material costs are driven by the development of the markets for biomass and fossil raw materials, like crude oil due to substitution effects. Conversion costs are driven by scale effects as well as time dependent learning effects. Demand side restrictions in the availability of biofuels due to a strongly increasing demand and rapidly raising biofuel prices are assumed as negligible for this projection period. Despite the peak oil issue, biofuels are not expected to exceed a market share of 15% on the global fuel market within the next five to ten years (Gnansounou et al., 2009; Bagheri, 2011). The EU has set a target market share of 10% in terms of all petrol and diesel transport fuels in the EU by 2020 (EU-Commission, 2003). Consequently, prices on the fuel market will still be driven by fossil fuels.

Today, biofuels can compete with fossil fuels only due to governments' regulation and subsidies. The hypothesis of this study is that medium and long term biofuel demand will become decreasingly based on governmental regulations and more and more on cost competitiveness compared to fossil fuels. If biofuels can be produced cheaper than fossil fuels, demand will be high enough during the next years to absorb all the produced biofuel quantities. Therefore, biofuel production costs will be responsible for the market share of biofuels.

In this model it was assumed that biofuel demand in Europe will be met by biofuel production in Europe and the option of biofuel production at other locations and import of biofuels was neglected. European production sites may benefit from a more developed production infrastructure, economies of scope to other production activities and greater proximity to end users. The production cost input data are focused on the situation in Europe but the model could easily be applied to other regions if the input data are changed accordingly.

2. Related literature

2.1. Calculation models for energy production costs

Various calculation models have been developed to give a better insight into the complexities of energy production systems under a range of policy objectives. Many authors describe the entire energy system either through the use of a technical bottom–up approach or a macro-economic top–down approach (Junginger et al., 2006). There are also a number of studies evaluating whole supply chains for biobased products (Stephen et al., 2010; Kim et al., 2011), biorefinery concepts (Fernando et al., 2006; Clark, 2007; Francesco, 2010) or the potential of biofuels for individual countries (Martinsen et al., 2010). For example, Kim et al. (2011) use a mixed integer linear programming model that enables the selection of fuel conversion technologies, capacities, biomass locations, and the logistics of transportation from the raw material locations to the conversion sites and then to the final markets.

Furthermore, there are numerous specific evaluations of biofuels, like biodiesel (Zhang et al., 2003; van Kasteren and Nisworo, 2007; Araujo et al., 2010) and simulations of biofuel processes with specialised software, like Aspen HYSYS (West et al., 2008). Despite the fact that production costs of biofuels compared to fossil fuels are an important driver for biofuel demand, there are only a few approaches to compare different biofuel production processes with each other and with the established production of fossil fuels considering scale and learning curve effects in the production process. Whereas some studies focus on individual process steps, like production costs for enzymes (Tufvesson et al., 2011; Klein-Marcuschamer et al., 2012), other studies compare different biofuels based on a production cost analysis (Bridgewater and Double, 1994; Giampietro and Ulgiati, 2005; de Wit et al., 2010; NREL, 2011). The analysis by de Wit et al. (2010), for example, shows that biodiesel is the most cost competitive fuel, dominating the early market of 1st generation biofuels. The better cost performance of biodiesel compared to 1st generation bioethanol can be explained by lower feedstock costs for oil crops compared to sugar or starch crops together with lower capital and operational expenses for transesterification of oil to biodiesel compared to the hydrolysis and fermentation of sugar or starch crops to bioethanol (de Wit et al., 2010).

Feedstock production costs can decrease over time, mainly by scale economies and by gaining technological experience with its production. Analyses performed for sugarcane in Brazil (van den Wall Bake et al., 2009), for corn in the US (Hettinga et al., 2009) and for rapeseed in Germany (Berghout, 2008) demonstrated that indeed cost reductions of (food) crops do follow an experience (or learning) curve pattern. In addition, other research papers investigated the economic dependency of fossil fuels and the potential replacement of crude oil by biomass (Dixon et al., 2007). The