The interdependencies between food and biofuel production in European agriculture – an application of *EUFASOM*

Working Paper FNU-165

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Abstract

In the continuous quest to reduce anthropogenic emissions of carbon dioxide, the production and use of organically grown fuels in Europe has increased in importance in the recent past. However, the production of so-called biofuels is a direct competitor of agricultural food production for land, labor, water resources etc. with both land use options influencing each other depending on the respective boundary conditions defined by political regulations and economic considerations. In this study we will explore the economic and technical potentials of biofuels in Europe as well as the interdependencies between these two land use options for different economic incentives for biofuels using the European Forest and Agriculture Sector Optimization Model (*EUFASOM*). Key data on biodiesel and ethanol production have been gathered and are used for calibration of the model. The simulations extend until the year 2030, for which results are presented. Results indicate that moderate production targets of biofuels lead to an expansion of mainly the biodiesel production while more ambitious targets call for a focus on bioethanol. This has to do with the different levels of production efficiency depending on the production output. Growth of bioethanol feedstock is spread over entire Europe while the production of biodiesel feedstock occurs mainly in Central Europe.

Keywords

biodiesel, bioethanol, Europe, EUFASOM, modeling

1 Introduction

The current European energy supply depends to a large extent on imported fossil fuels. This dependence, which is supposed to increase carries possible geopolitical risks in the future, also there are many possible environmental and health related hazards associated with the combustion of these fuels and the emissions of their pollutants as well as greenhouse gases. The European Union has committed itself to achieve a reduction of greenhouse gas emissions of at least 20% in comparison to 1990 by the year 2020 [1].

Fuels derived from biomass are considered an alternative renewable energy source, which is claimed to have several advantages in comparison to fossil energy sources. It is a possible means to reduce greenhouse gas emissions [2, 3]. Also, biomass influences the humus content of the soil and reduces erosion, thus increased biomass production can improve soil quality of agricultural land [4]. However, it is unclear, how effective biofuels can be as a substitute for fossil fuels. Hoogwijk and others [4] have estimated guardrails for the global potential of biomass use in energy production. Depending on the demographic and economic development in the next few decades, the global biomass potential spans three orders of magnitude.

In this context, however, it is important not to disregard greenhouse gases other than carbon dioxide. Some of them have a much larger warming potential than CO_2 and appear in the production process of biofuels. Crutzen and others [5] show that emissions of nitrous oxide, which is a byproduct in the production of biofuels from oilseeds or corn, can completely wipe out the potential cooling brought about by the utilization of the biofuels instead of fuels from fossil sources. If biofuels are supposed to be used with the goal of reducing overall greenhouse gas emissions, any production incentives have to be directly related to the emission reduction potential. As CO_2 budgets can be much more readily obtained than the budgets of e.g. N_2O, the latter are often disregarded, causing an overestimation of the greenhouse gas emission reduction potential of biofuels.

Furthermore, there are leakage effects that should not be neglected. If Europe is considered separately from all other regions in the world, it is very well possible to use biofuels to drive down greenhouse gas emissions. On the other hand, an increased production of biofuel feedstock necessitates the import of other essential agricultural commodities from geographic regions outside the European Union. The rising exports lead to an intensified agricultural production that often coincides with increases in deforestation. This, in turn, leads to higher emissions in those regions that can partially or fully offset the emission reduction in Europe. Searchinger and others [6] show that a widespread use of agricultural land to produce biofuels in the United States actually causes increased greenhouse gas emissions in the long run due to such leakage effects. Therefore, it is important that such assessments do not exclusively focus on one geographic region while neglecting the rest of the world.

The conditions, under which biofuels can become a competitive alternative on the energy market, have been explored in recent studies. A partial equilibrium model is applied to assess substitution mechanisms between fossil and biofuels and their possible impacts on greenhouse gas emissions and agricultural land use [7]. Greenhouse gas emissions can be substantially reduced by a combination of a tax on fossil fuels and a subsidy of biofuels. However, the overall development of global, market-based welfare is generally negative. This is not just an empirical result of model simulations but an inherent characteristic.

McCarl et al. [8] focus on the agricultural sector using an early version of the *FASOM* (Forest and Agriculture Sector Optimization Model) model. The results indicate that the degree of competitiveness of biofuels is dependent on the success of improving the production efficiency of the necessary crops. For this, short-rotation woody crops appear to be the most suitable crops for energy production.

There are certain thresholds below which biofuels cannot be competitive in the energy sector. Johansson and Azar [9] analyze the connection between food and energy prices for two different U.S. climate policies using a non-linear dynamic optimization model. Based on their assessment, bioenergy production becomes competitive already at approximately $20 per ton of carbon, which is the same magnitude as the results obtained in Azar [10], Schneider and McCarl [11] and McCarl and Schneider [12]. Schneider and McCarl [11] find that carbon prices of approximately $40 per ton of carbon equivalent are necessary for biofuels to become competitive. Above this carbon price, biofuels can offset emissions from fossil fuels in US agricultural production. If prices increase even further, biofuels become the predominant means of emission mitigation at $70 per ton of carbon equivalent. These figures are substantially lower than the average abatement costs for bioethanol, which lie between $250 and $330 per ton of carbon [13]. A recent study focusing on Europe is less optimistic. The subsidies for biofuels necessary to reduce a unit of carbon emissions are found to be between more than € 200 for biodiesel and up to € 800 for bioethanol [14]. The emission reduction brought about by the same financial investment could be up to 20 times as high if instead funds were invested in emission offsets at the European Climate Exchange.

Due to the close interdependencies of the economics of food and non-food agriculture, any policy of further development of bioenergy production should always be considered in conjunction with agricultural food production. E.g. since the amount of land that can be used for bioenergy production is limited, there is a constant competition between agricultural food production and bioenergy production for this resource. A continued expansion of biofuels production will therefore have a lasting impact on agricultural land use patterns worldwide.

One important aspect to consider is the fact that the different biofuel feedstocks require different amounts of land for each unit of biofuel produced. All other factors being equal, the production of bioethanol requires less agricultural land than the production of biodiesel [15]. This is because the bioethanol yield in the EU-15 countries is generally much higher than the biodiesel yield. Therefore, a focus of biofuel production on bioethanol would drastically reduce the amount of land required for biofuel production in the next few years. E.g. only 7 to 9% of the arable farm land in the EU-15 countries would be required to fulfill the future EU target if the entire biofuel production focused on bioethanol.

Currently, bioethanol still has the greatest significance among all biofuels on a global scale [16]. In 2004, about 30 billion liters were produced worldwide. This amounts to roughly 2% of the total fuel use. However, biodiesel, which used to be produced exclusively in the EU, is now gaining importance in other parts of the world as well, thus increasing its relative importance in the bioenergy sector. At present, Germany, France and Italy are the main producers of biodiesel, leading the EU-25 production of close to 2 million tons in 2004. In contrast, biogas is only of regional significance, mainly in Scandinavia. An expansion of biofuel feedstock production to reach EU targets in the next years requires additional agricultural land to be set aside for bioenergy production [17]. Based on model simulations, about 40% of the additional land will need to be taken from land that was formerly set aside. Almost as much land will have to be shifted from production for exports to production for the domestic market. In conjunction, it is expected that market prices of agricultural goods increase. However, the intensity of agricultural production is expected to remain more or less unaffected, as there is little room for further intensification of agriculture in Europe.

The increased importance of biofuel production in Europe is the consequence of the EU policy on alternatives to fossil fuels, which attempts to decrease the reliance on fossil energy sources in the next decades. The first target of the EU strategy to increase the share of biofuels in the energy sector was at 2% in 2005 [15]. This target could be easily reached, as enough agricultural land is available in all EU countries to produce the necessary amount of biomass. The next target is set for 2010, when 5.75% of transport fuels are supposed to arise from biofuels production. This target will be much harder to reach, since it necessitates changes in agricultural production patterns throughout the EU to grow the required amounts of biomass as an area of 16-40% of the arable farm land in the EU-15 countries would be needed to grow biofuel feedstock. Assessments of the biofuel potentials in the European countries indicate that the maximum share of arable land that can be used for growing biofuels feedstock in the entire EU is approximately 14% [18, 19].

In the long run, the market share of biofuels is expected to increase even further. In this context, it is necessary for agricultural policy to internalize the external benefits of biofuels. Under current conditions, these benefits are not yet fully accounted for. In this assessment we will explore the economic and technical potentials of biofuels in Europe and their influence on agricultural food production. Using *EUFASOM*, the development of the agricultural sector is simulated until 2030 for various biofuel incentives and the resulting structures are compared to the current state of the bioenergy market. In the subsequent section, the model setup and the scenarios will be described. The results of the simulations are presented in section 3. These are discussed in section 4, where conclusions are drawn as well.

2 Methodology

So far, estimates of biofuel potentials in Europe are usually based on microeconomic assessments, where macroeconomic feedback is lacking. This study closes this gap by focusing on biofuel production in the context of the entire agriculture and forestry sector, paying attention to the close interdependencies between food and non-food agricultural production. This approach calls for the utilization of a model that endogenizes key processes of agricultural production in particular detail.

EUFASOM is a partial equilibrium model focusing on Europe that describes resource allocations for the agricultural and forestry sectors over a specified number of optimization periods. Land is allocated to maximize marginal profitability of all endogenous agricultural and forestry land uses [20]. The model output consists of equilibrium market prices of goods, yields and trade quantities of the goods covered in the model.

The European version of *FASOM* is based on an approach developed at Texas A&M University. The original version, which is suitable for the U.S. only, was particularly adapted to comply with the situation in Europe. This led to the development of *EUFASOM*. The main features and detailed descriptions of the main equations are given in Schneider et al. [20].

This study applies the *EUFASOM* model in a way that it incorporates and combines empirical data on European biofuel production and potentials [21]. Detailed data on current biofuel production, agricultural production, co-products of biodiesel and current biofuel capacities have been provided, as well as data on feedstock needs for bioethanol and production costs of biofuels. These data are integrated into the model for calibration purposes and for the assessment of the current situation. In all scenarios, deforestation was prohibited.

The development of the biofuel market in Europe is simulated for the time period from 2000 to 2030. Calculations are performed in time steps of five years. It is assumed that a production target of 10 million hl of biofuels is reached by the end of the simulation period. During the simulations prices of commodities and market developments are endogenously determined. Simulations are conducted for various levels of economic incentives to produce biofuels in Europe. These scenarios will differ in the degree to which the production of biodiesel and ethanol is subsidized and whether the subsidies are applied directly to biofuel production or indirectly via the general costs of carbon emissions.

3 Results

Simulations with *EUFASOM* are conducted for a large range of biofuel incentives from no incentive to € 1000 per hl for illustrative purposes. It is rather unlikely that such high incentives for biofuel production are realized; however, such high price scenarios provide additional insights about the general model behavior and can be obtained at little additional cost. Economic and technical potentials are assessed, as well as the interdependency between agricultural biofuel and food production.

To explore the technical potential of biofuel production in Europe, the output from biofuel production is determined if biofuel production is maximized irrespective of the production costs and all suitable agricultural area is utilized for this purpose. For comparison, in 2003, fuel consumption for transportation in the 27 EU countries amounted to almost 1850 million hl of diesel and close to 1520 million hl of gasoline [22].

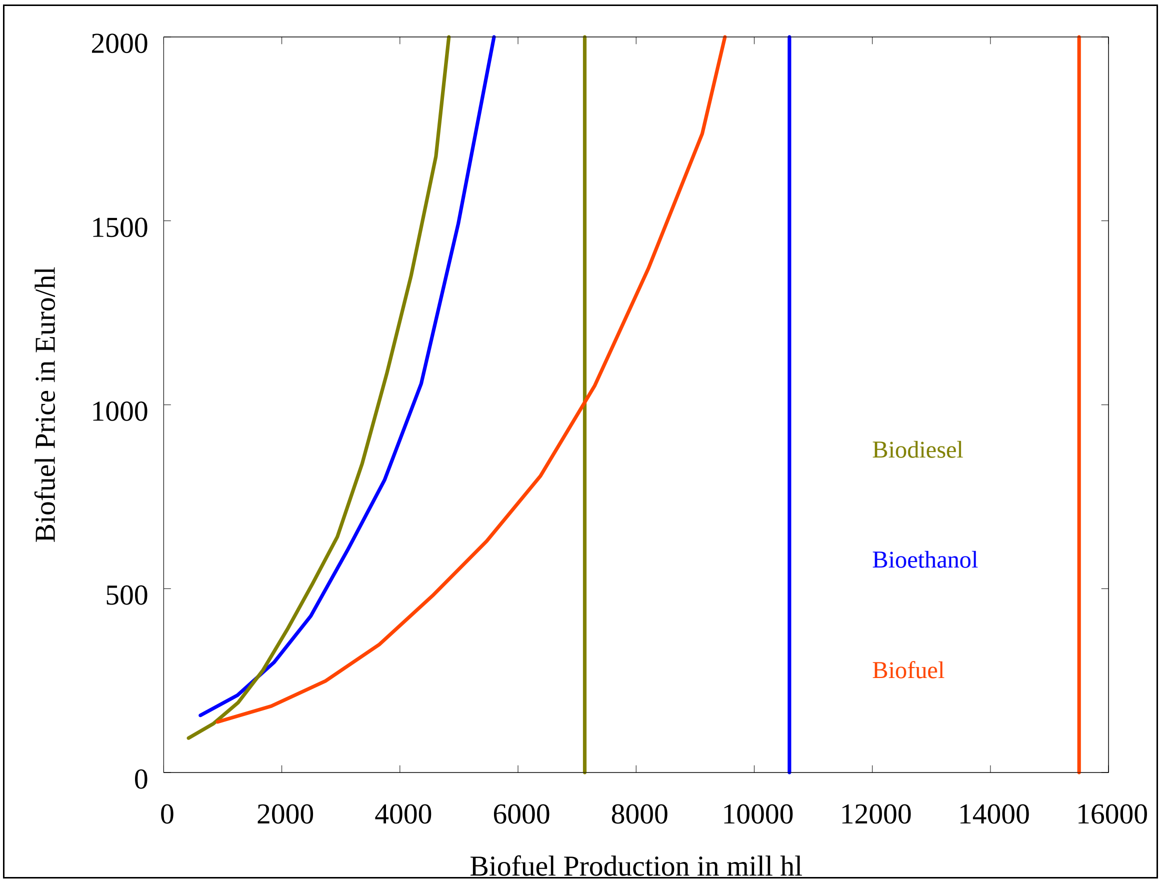

Figure 1. Economic versus technical potential of biofuel production in EU 25

The technical potential of biodiesel production in Europe is slightly greater than 7000 million hl, while more than 10000 million hl could be produced if all of the agricultural land available in the EU would be used for this purpose (Fig. 1). The combined technical biofuel production potential is close to 16000 million hl. In this case each country has the choice, which biofuel is going to be produced. Consequently, the biofuel with the higher production efficiency is always selected.

In contrast to the technical potential, the economic potential considers production costs and opportunity costs of biofuel production (Fig. 1) and shows how resource scarcity limits the amount of biofuels that is feasible to be produced. For low combined production costs, there is a substantial expansion in biofuel production as biofuel prices can be maintained at reasonable levels. Considerable amounts of biofuels can be produced at prices below € 4 / l (Fig. 2). Initially, biodiesel production is the more efficient choice as a limited amount of biodiesel can be produced at lower cost than bioethanol. Eventually, bioethanol production becomes more cost efficient than biodiesel production so that for large production targets bioethanol is relatively cheaper than biodiesel. However, it has to be noted that high production levels are possible only due to the concurrent subsidization by imports. The continued expansion of biofuel production leads to substantially higher prices, which puts a limit on the amount of biofuels produced in Europe. This limit is closer to the technical potential for biodiesel than for bioethanol.

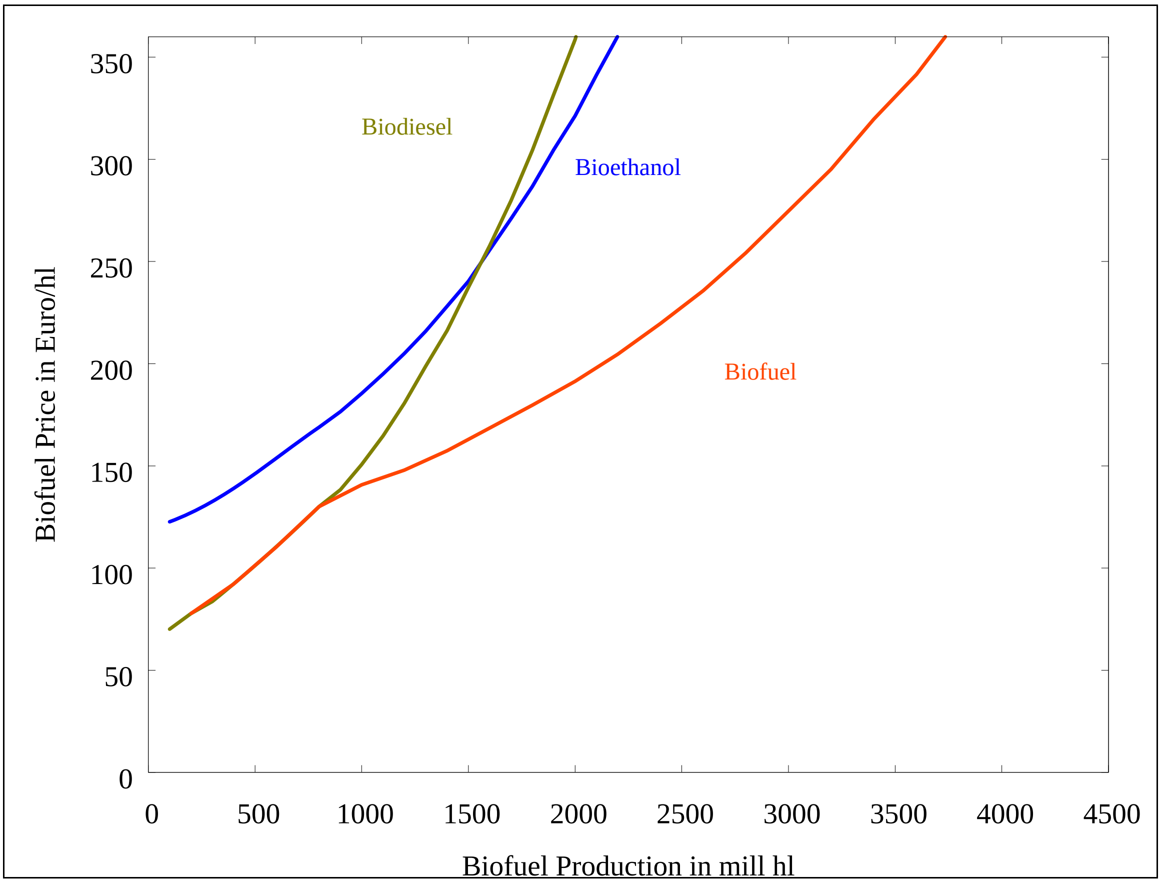

Figure 2. Supply function for bioethanol, biodiesel, or biofuels

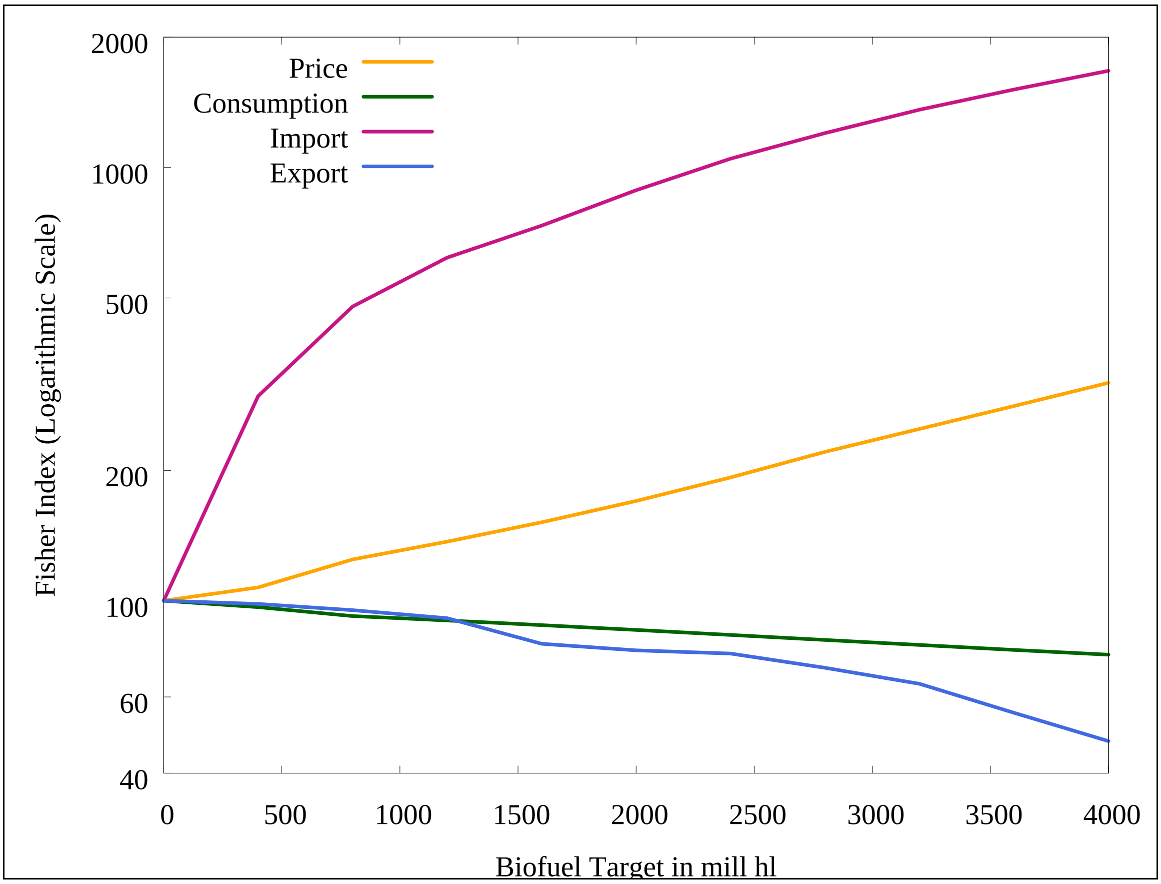

Figure 3. Impact of the biofuel target (bioethanol or biodiesel) on production, trade, and prices for agricultural commodities in EU 25.

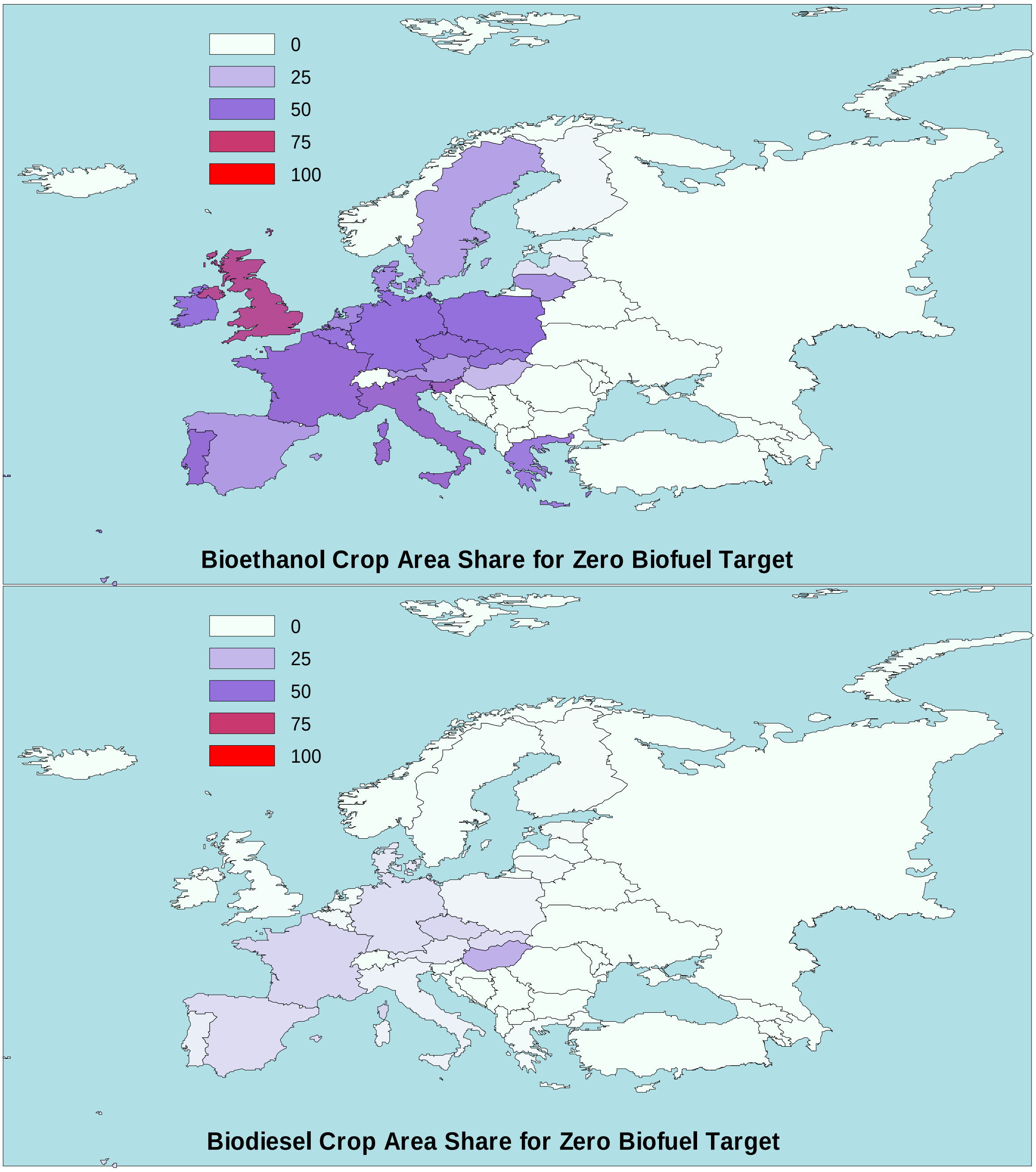

Figure 4. Shares of agricultural land area (in %) used for energy crop production for no biofuel production target.

Of course, higher levels of biofuel production have an influence on the amount and value of food crops grown in Europe. Figure 3 shows the indices of food crop prices, production, imports and exports in the EU25 countries as a function of the amount of biofuels produced. As biofuel production increases, less agricultural area can be allocated to the production of food crops. Consequently, agricultural food production decreases and has to be substituted by imports from other regions in the world. There is no saturation, as imports continue to rise with growing biofuel production targets. Overall consumption of agricultural commodities remains remarkably stable regardless of the biofuel production target and changes only very little. Of course, exports of agricultural commodities suffer considerably with increasing biofuel production since an increasing share of the goods produced is consumed or used industrially within Europe.

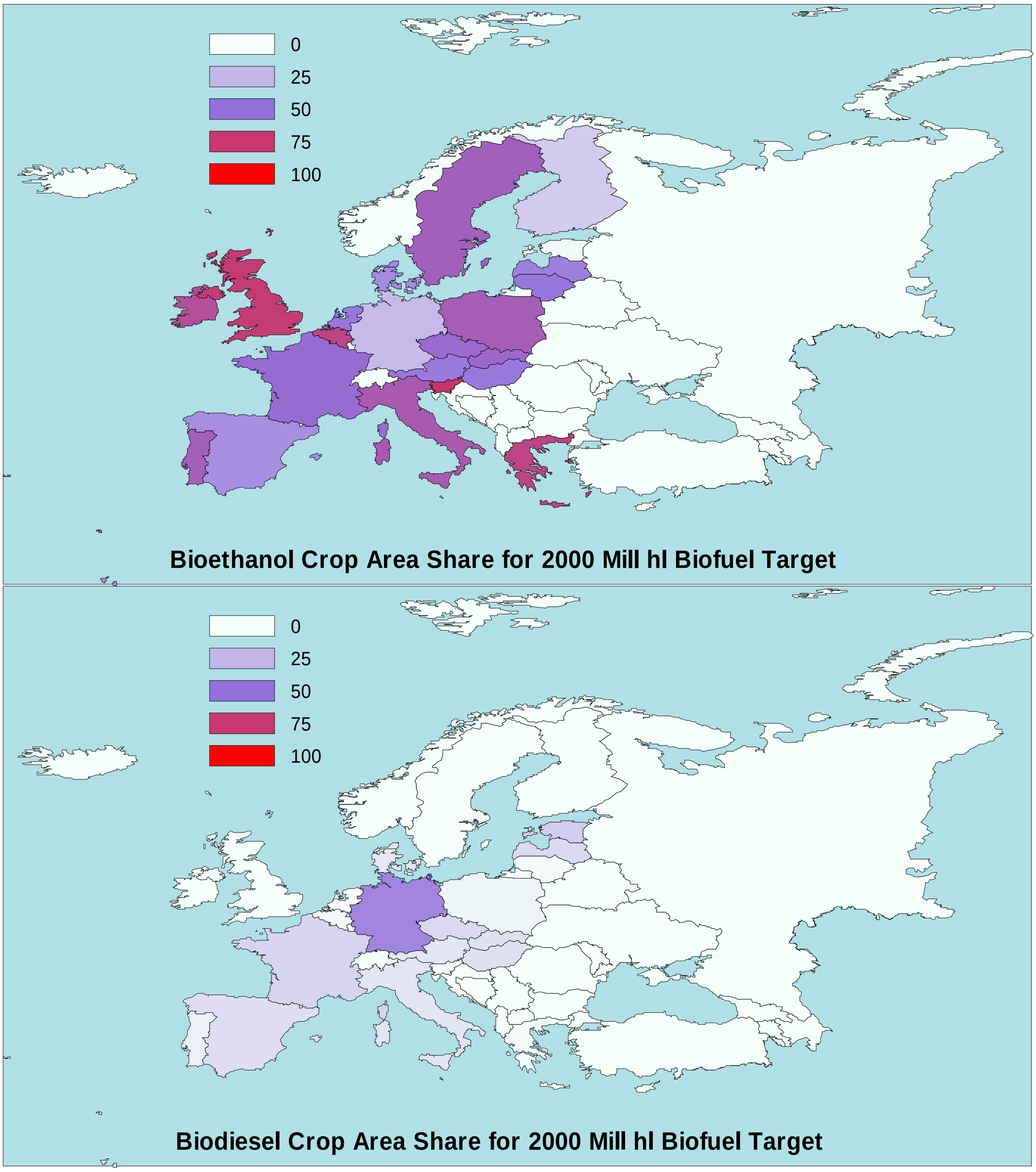

Figure 5. Shares of agricultural land area (in %) used for energy crop production for a biofuel production target of 2000 million hl.

As the total agriculturally utilized area in Europe is unlikely to change significantly during the next few decades, it can be expected that the food crop production area develops complementarily to the area used for biofuel crop production. An assessment of the bioenergy production areas shows that the biofuel production target applied has a profound influence on the amount and distribution of agricultural land used for this purpose.

If no production target for biofuels is set in Europe, the amount of agricultural land used for growing crops that can be used for bioethanol production generally exceeds the area allocated for biodiesel crop production (Fig. 4). The largest share of agricultural land, on which crops for bioethanol production are grown, is found in the United Kingdom, where more than half of the area is used that way. The share of land used for this purpose in

Central Europe is somewhat lower but still amounts to around 50%. The area of agricultural land used to grow crops for biodiesel production is much lower. Only in Hungary this share exceeds 25%. Other countries with fairly high amounts of land allotted to this purpose include Germany, France, Spain and the Czech Republic.

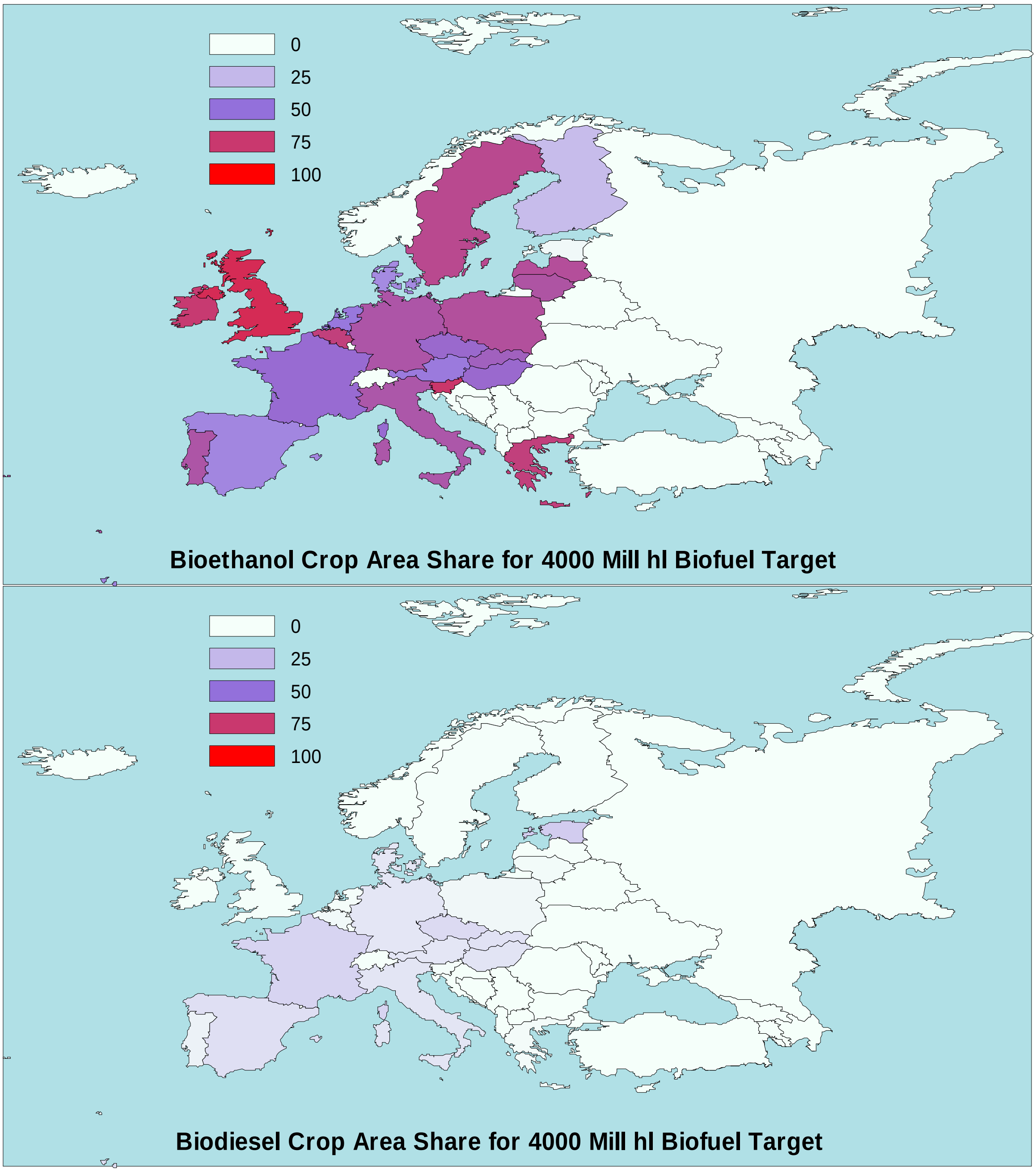

Figure 6. Shares of agricultural land area (in %) used for energy crop production for a biofuel production target of 4000 million hl.

The picture changes distinctly if a production target of biofuels in introduced in Europe. For a target of 2000 million hl of biofuels the amount of land allocated to grow crops for bioethanol production expands greatly and shares of 50% are exceeded in practically all parts of Europe (Fig. 5). In addition to the United Kingdom, where this land allocation was already high to start with, more than 75% of the agricultural land is used for bioethanol feedstock crops in Belgium, Slovenia and Greece. Biodiesel production plays a lesser important role in Europe.

This fuel is mainly produced in Germany, which has a high production efficiency of biodiesel and large areas, on which the rapeseed necessary can be grown.

If the biofuel production target is increased even further, the dominance of bioethanol over biodiesel becomes even more evident. All European countries except Finland allocate more than half of their agricultural area to the growth of crops that are used to produce bioethanol. In most countries the share exceeds 75%, in the United Kingdom it is almost 90% (Fig. 6). On the other hand, biodiesel production is even less important than with a production target half as large. In no European country more than a quarter of the agricultural land is used to grow biodiesel feedstock crops. This has to do with the fact that the relative production output of bioethanol per unit area is larger than that of biodiesel. And the larger the overall production target becomes, the more agricultural land has to be set aside to grow fuel crops. Consequently, it is necessary to maximize the amount of biofuel produced on the limited land area available. This results in an almost exclusive focus on the production of bioethanol from wheat and sugar beet at the expense of rapeseed and other oilseeds, which are mainly used in biodiesel production.

	wheat	sugar beet	rapeseed
no target	22.71	16.83	3.38
400	22.65	17.03	7.81
800	22.55	16.46	15.49
1200	21.69	21.54	13.71
1600	20.46	26.36	12.96
2000	20.69	33.17	8.13
2400	22.01	38.94	3.50
2800	21.23	43.00	3.54
3200	21.30	46.54	3.57
3600	21.50	49.71	3.57
4000	21.72	53.02	3.57

Table 1. Area used to grow biofuel crops (in million ha) for different production targets

There is a distinct pattern of biofuel production in Europe depending on the production target that is set. Overall, the total area of agricultural land allocated to wheat production remains more or less constant at slightly above 20 million ha, regardless of the biofuel production target specified (Tab. 1). Any policy changes regarding the production targets have a much more profound influence on the other two key biofuel crops. For small biofuel production targets of up to little more than 1000 million hl, the main expansion in production area occurs for rapeseed, thus increasing the output of biodiesel. For any larger biofuel production targets it is better to focus on the production of bioethanol. In order to achieve the desired production goals it is therefore necessary to grow much larger amounts of the ingredients of this particular biofuel. Since the limiting factor in this case is sugar beet, it is mainly that crop whose production is especially intensified. For large production targets the area on which sugar beet is grown exceeds the area of wheat by more than a factor of two. It is optimal to focus on the production of this crop since any wheat missing for the production of biofuels can be more readily imported from other regions of the world.

4 Discussion and Conclusion

In this assessment, the partial equilibrium model *EUFASOM* is applied to investigate the potentials of biofuel production in Europe in the near future and to explore the influence of an expanded biofuel production on agricultural food production. This is done by determining the extent of bioenergy production for various production targets either of biodiesel, bioethanol or both biofuels together.

The simulations reveal that there is a shift in the general agricultural production depending on the production target of biofuels. For moderate production targets it is more efficient to produce biodiesel and therefore grow large amounts of rapeseed and other oilseeds such as sunflowers. This leads to an initial expansion of areas of rapeseed growth, particularly in Central Europe, e.g. in Germany. If, however, it is desired to produce very large amounts of biofuels, it is necessary to focus more on the production of bioethanol. Therefore, a massive expansion in the production of wheat and sugar beet, the main ingredients of bioethanol, can be observed. This expansion in growth of the bioethanol feedstock can be observed in all regions of Europe, led by the United Kingdom. A closer look at the distribution of the individual crops shows that it is particularly sugar beet production that is enhanced in Europe as it is much easier to import additional wheat from other regions of the world as necessary. In conjunction with an increase in biofuel production, the production of agricultural food commodities in Europe decreases, causing consumption to decrease as well in the long run. Interestingly, there is not such a sharp signal in the price index of food crops. This has to do with the fact that food crop availability remains at stable levels via larger imports from other regions of the world.

The assessment of the technical potential of biofuels indicates that the scarcity of the resources used in the production process puts an economic cap on the amount of biofuels that can produced at a level that is still far away from the technically possible amount. Then the marginal costs of biofuel production would increase by such a large extent that it would make no sense to continue approaching the technical potential by all means. But even if the amounts of biofuels produced in Europe remained even below the economic potential, already a considerable share of the diesel and gasoline from fossil sources used for transportation could be replaced by fuels from agricultural production.

It should be noted that the results obtained in these simulations are dependent on the boundary conditions to which they are calibrated. They can therefore point to interesting effects occurring as a consequence of increases in biofuel production targets in Europe. However, this also means that the findings are only valid in the context of the settings that govern the simulations. All empirically obtained input data are subject to inherent uncertainty, which is transferred into the model. Possible changes in European energy policy or technical progress concerning biofuel production can have a profound influence on the efficiency of incentives to produce biofuels. The exploration of such developments is beyond the scope of this paper and would have to be conducted in a separate study.

Acknowledgements

This study was conducted as part of the research projects TranSust.Scan, which is funded by the European Union (contract no. 022773) and CIRCE (contract no. 036961). Modeling efforts were also conducted in the research projects ENFA (contract no. SSPE-CT-2005-006581) and GEO-BENE (contract no. 037063). The authors would like to thank O. Henniges for providing key data on European biofuel production parameters.

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