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CHP or biofuel production in Europe?

Sylvain Leduc[a,]*, Elisabeth Wetterlund[a,b], Erik Dotzauer[c], Georg Kindermann[a]

[a] *International Institute for Applied System Analysis (IIASA), A-2361 Laxenburg, Austria*
[b] *Linköping University, SE-581 83 Linköping, Sweden*
[c] *Mälardalen University, SE-721 23 Västerås, Sweden*

Abstract

In this study, the opportunity to invest in combined heat and power (CHP) plants and second-generation biofuel production plants in Europe is investigated. To determine the number and type of production plants, a mixed integer linear model is used, based on minimization of the total cost of the whole supply chain. Different policy scenarios are studied with varying values of carbon cost and biofuel support. The study focuses on the type of technology to invest in and the CO_2 emission substitution potential, at constant energy prices. The CHP plants and the biofuel production plants are competing for the same feedstock (forest biomass), which is available in limited quantities. The results show that CHP plants are preferred over biofuel production plants at high carbon costs (over 50 EUR/t_{CO2}) and low biofuel support (below 10 EUR/GJ), whereas more biofuel production plants would be set up at high biofuel support (over 15 EUR/GJ), irrespective of the carbon cost. Regarding the CO_2 emission substitution potential, the highest potential can be reached at a high carbon cost and low biofuel support. It is concluded that there is a potential conflict of interest between policies promoting increased use of biofuels, and policies aiming at decreased CO_2 emissions.

Keywords: second-generation biofuel; CHP; Europe; carbon cost; biofuel support.

1. Introduction

The EU energy and climate change policy defines targets of 20% greenhouse gas reduction, 20% reduced energy use through increased energy efficiency and a 20% share of renewable energy by 2020 [1]. Bioenergy is promoted as a key to reaching the targets [2], as biomass can replace fossil fuels in

* Corresponding author. Tel.: +43-2236-807267; fax: +43-2236-807599.
E-mail address: leduc@iiasa.ac.at.

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stationary applications, such as heating utilities or electricity production, as well as in the transport sector. If the objective is to maximize the mitigation of CO_2 emissions, biomass is currently used more cost-efficiently for substitution of fossil fuels in the heat and electricity sectors than in the transport sector, as discussed by e.g. Azar et al. [3] and Schmidt et al. [4]. However, if the objective is also to maximize the substitution of fossil oil, biomass may play an important role in the transport sector, as discussed by e.g. Gustavsson et al. [5]. That renewable energy in the transport sector is important on the political agenda is evidenced by the mandatory target of 10% renewable energy in the EU transport sector by the year 2020 [6], which supplements the overall 20% renewable energy target.

Biofuels currently constitute the major option regarding renewable energy in transport. However, increased use of biofuels is not without complications, for example due to uncertainties regarding CO_2 mitigation potential and issues related to competition with food production. Second-generation biofuels have lower land use requirements than the biofuels on the market today, and use non-food feedstocks, such as forest residues. Even though second-generation biofuels are not yet commercially viable, they are stated as a prerequisite to reach the 10% target for the year 2020 [6], and would need to constitute around 3% of the total EU transport fuel consumption in order to reach the target without substantial interference with other objectives [7].

To reach high process efficiencies and acceptable production costs, second-generation biofuels will have to be produced on a large scale (see e.g. [8]). Large plants require a larger feedstock supply area and put significant demands on the supply chain. In order to minimize the biofuel supply costs, it is essential to choose the location of biofuel production plants optimally.

BeWhere is a spatially explicit optimization model that is used to determine the location and size of biomass conversion plants, taking into consideration the demand as well as supply side. The model has previously mainly been applied at the national level, e.g. for Austria [4, 9], Sweden [10] and Finland [11]. On a European level BeWhere has previously been used to assess the potential for second-generation biofuel production [12, 13]. This article presents the latest development in the BeWhere model at the European level, with the inclusion of combined heat and power (CHP) plants in addition to biofuel production plants.

The aim of this article is to study the use of forest residues for biofuel or CHP production on a European level. Special focus is put on the impact of economic policy instruments in the form of carbon cost or biofuel policy support on biomass use, and on the potential conflict between targets for biofuels and for CO_2 emission reduction.

2. Methodology and input data

2.1. Model description

BeWhere is based on mixed integer linear programming, and is written in the commercial software GAMS, using CPLEX as a solver. The objective of the model is to minimize the cost of the entire supply chain, including biomass harvest, biomass transportation, conversion processes, and transportation and delivery of products. The model takes into account locations and quantities of both feedstock supply and demand for various energy carriers. Fossil CO_2 emissions are considered by including a cost for emitting fossil CO_2. This cost could for example be in the form of a tax or tradable emission permits. The model will choose the least costly pathways from one set of feedstock supply points to a specific production plant and further to a set of energy demand points. The output from the model includes the location of a set of plants, the flows of feedstock and biofuel between different regions, and the costs and CO_2 emissions of the supply chain. For a detailed model description, see [13, 14].

The study is limited to the European Union (EU), which has been divided into eight naturally defined regions (Fig 1). Each region is divided into grid cells with a half-degree spatial resolution. Feedstock and biofuels can be transported by truck, train or ship. Interchange between the regions can only take place at defined trade points, situated at major harbor locations or strategically located border points.

Fig 1. Region definition and location of the trade points. The hatched areas are non-EU countries and not included in the study.

2.2. Biomass supply

A number of different lignocellulosic feedstocks could be used for the production of second-generation biofuels or in CHP plants, for example various woody materials and waste feedstocks. This study only considers forest residues. The potential supply of forest biomass is assumed to be dependent on the total annual increment of forest biomass, which depends on the net primary production and the forest share of each grid cell. Model input data of the biomass increment is obtained from the G4M model [15]. It is assumed that 10% of the total annual forest biomass increment, representing residues such as branches and tops from final felling, is available for biofuel or CHP plants.

The forest biomass costs include costs of logging and forwarding to the forest road, which depend on topology, land costs, forest cover and population density. The costs range from below 1 to over 20 EUR/GJ, with an average cost of 4.7 EUR/GJ.

2.3. Biomass conversion technologies

This study includes two biofuel production technologies (methanol via biomass gasification and ethanol via hydrolysis and fermentation) and one CHP technology (biomass integrated gasification combined cycle, BIGCC). The biofuel processes include co-production of electricity and/or heat suitable for district heating. All plants can be scaled within the range 25-100 $t_{biomass}$/h, which corresponds to approximately 110-450 $MW_{biomass}$. Key parameters are given in Table 1.

Table 1. Key input data for the considered biomass conversion technologies.

	Methanol [16, 17]	Ethanol [18]	CHP [9]
Base plant capacity (MW)	357	105	100
Base investment cost (MEUR)	505	143	78
O&M cost (EUR/$GJ_{biomass}$)	1.2	2.5	3.7
Biofuel efficiency ($GJ_{biofuel}/GJ_{biomass}$)	0.55	0.30	0
Electrical efficiency ($GJ_{electricity}/GJ_{biomass}$)	0	0.11	0.42
Heat efficiency ($GJ_{heat}/GJ_{biomass}$)	0.11	0.40	0.43

2.4. Energy demand and prices

The computations are based on projected data for transport fuel demand and population for the year 2020 [19]. For the transport sector this means a total fuel demand in the EU of about 15 EJ. The national demand is downscaled based on grid point population [20], with the demand per capita assumed equal in all grid points of each country. Data on district heating in the EU has been obtained from Werner [21] and Egeskog et al. [22], with the total national district heating demand downscaled under the assumption that the district heating demand is proportional to the population of each grid point. It is assumed that all existing fossil heat can be replaced with heat from the new biomass conversion facilities.

For transport fuel, country-specific average petrol and diesel pump prices are used [23]. District heating prices are estimated from consumer price averages [21], under the assumption that it is possible to sell heat at 50% of the consumer buying price. Electricity prices are average end-user prices [24]. The energy selling prices used are shown in Table 2. For details, see [13].

2.5. CO_2 emissions

The cost of emitting fossil CO_2 is internalized in the model by including the possibility to apply a CO_2 cost to the supply chain emissions. The cost could for example represent a CO_2 tax or tradable emission permits. Emissions from transportation of feedstock and biofuels, as well as emissions from displaced fossil energy carriers, are considered. CO_2 emissions from the combustion of biomass are not considered, as it is assumed that the CO_2 released when combusting the biomass is balanced by CO_2 uptake in re-growing trees.

Produced biofuel is assumed to replace fossil transportation fuels on a 1:1 energy ratio. Thus each GJ of produced biofuel displaces 78.3 kg of CO_2 [25]. Potential country-specific differences in CO_2 emissions from transport fuels are not considered. Concerning heat, all fossil district heating, as well as the share of the fossil fuel-based heat that could be replaced by district heating, is included, with CO_2 emission factors ranging from 70.6-118 kg_{CO2}/GJ [13]. Co-produced electricity is assumed to replace marginal coal power-based electricity production, with a CO_2 emission factor of 201 kg_{CO2}/GJ (e.g. [26]).

2.6. Scenarios

This study focuses on the policy aspect, by studying the impact of the cost of emitting fossil carbon, and the policy support for biofuels. Those parameters are varied stepwise. A set of 49 scenarios are computed, with the carbon cost and biofuel support varied. All combinations of carbon cost and biofuel support are considered. Table 3 presents an overview of the different values used for the scenarios.

For comparison, the value of CO_2 within the EU ETS (EU Emission Trading System) is around 15 EUR/t_{CO2} [27]. The current average support for biofuels in the EU is just over 7 EUR/GJ for biodiesel, and 13 EUR/GJ for ethanol [28].

Table 2. Country-specific energy prices (selling prices) used (EUR/GJ), and region classification (see also Fig 1).

Country	Region classification	Transportation fuel prices [23]	District heating prices [21]	Electricity prices [24]
Austria	8	11.9	8.50	21.1
Belgium	5	12.6	6.56	20.8
Bulgaria	7	11.4	3.47	13.0
Czech Republic	8	12.9	5.72	24.5
Denmark	5	13.5	9.92	19.2
Estonia	6	11.9	3.47	11.1
Finland	6	13.5	4.72	14.1
France	3	12.0	6.75	13.6
Germany	5	12.3	7.89	21.1
Greece	7	13.9	5.14	16.7
Hungary	8	12.9	5.33	25.2
Ireland	4	12.4	3.78	22.8
Italy	2	13.9	9.50	22.5
Latvia	6	12.5	4.94	20.0
Lithuania	6	12.6	5.25	18.9
Luxembourg	5	12.8	6.56	18.2
Netherlands	5	12.8	6.56	24.0
Poland	8	12.2	4.39	19.1
Portugal	1	13.5	3.78	16.0
Romania	7	12.7	3.33	16.2
Slovakia	8	12.6	4.97	27.1
Slovenia	7	11.9	5.14	20.0
Spain	1	13.3	3.78	19.0
Sweden	6	11.8	7.75	13.7
UK	4	11.3	3.78	24.9

Table 3. Overview of the values of the parameters studied.

	Carbon cost (EUR/t_{CO2})	Biofuel support (EUR/GJ)
Min	0	0
Max	150	30
Step	25	5

3. Results

3.1. Production

Fig 2 shows the resulting production of the three included energy carriers (biofuel, electricity and heat) over the studied scenarios. With a carbon cost applied, electricity and heat production is favored, due to higher CO_2 emission reduction potential of replaced fossil heat and electricity, compared to replaced fossil transport fuels. When instead a biofuel support is applied, biofuel production is naturally favored. The figure also shows that the heat and electricity production reach a ceiling value at a carbon cost of around 50 EUR/t_{CO2}, which is where all available biomass is utilized. When a biofuel support is applied, this ceiling is reached at 25 EUR/GJ.

The figure indicates that CHP plants would also be beneficial in places where the heat sink is not sufficiently large to accommodate all produced heat, which is shown as waste heat in the diagram. In reality the CHP plants would of course be dimensioned to fit the available heat loads, but in this study individual district heating systems were not considered.

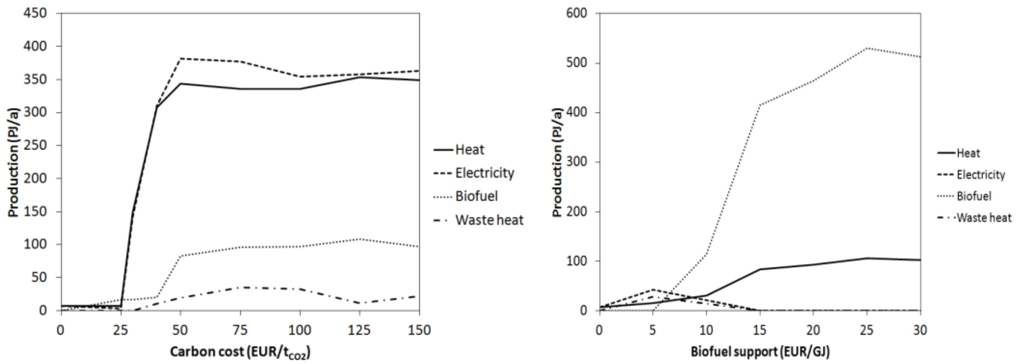

Fig 2. Resulting production of heat, electricity and biofuel, for varying levels of carbon cost (left) and biofuel support (right).

3.2. Biomass use

Fig 3 shows the amount of biomass used for CHP and biofuel plants in each region, for all carbon cost scenarios. Correspondingly, Fig 4 shows the amount of biomass used for the biofuel support scenarios. Regions 6 and 8 (see Table 2 for details on which country belongs to which region) dominate for both types of plants over all scenarios. The relative importance of region 6 in particular is higher for biofuel production plants with biofuel support than for CHP plants with carbon cost. The reason is that when biofuel plants are dominant (with biofuel support) it is more cost efficient to export biofuels, since they have higher energy density. When CHP plants are dominant no such option exists, for which reason more biomass is traded instead.

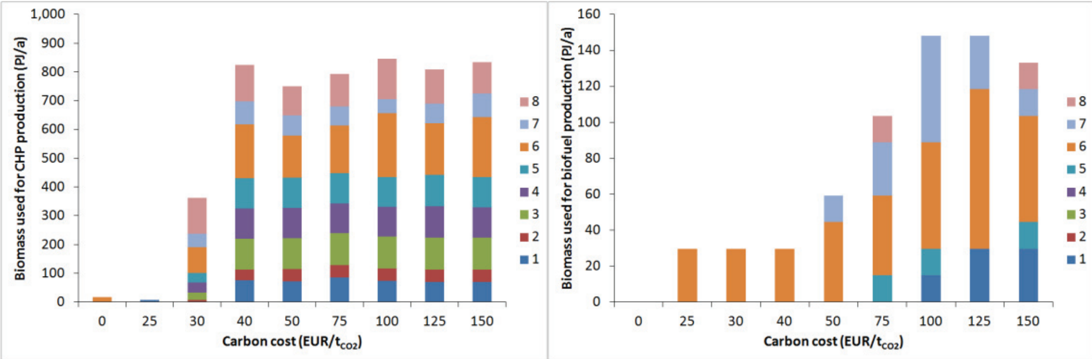

Fig 3. Biomass use for CHP plants (left) and biofuel plants (right), for varying levels of carbon cost.

Fig 4 shows that CHP plants are preferred over biofuel plants for low biofuel support levels (0-10 EUR/GJ) in regions 6 and 8. The price of the fossil fuel sets the transition between the implementation of CHP versus biofuel: at a higher fossil fuel price this transition would decrease to a lower biofuel support level.

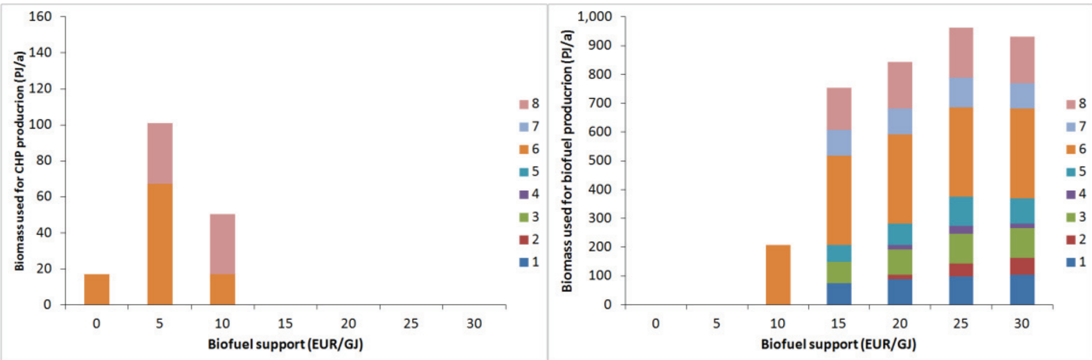

Fig 4. Biomass use for CHP plants (left) and biofuel plants (right), for varying levels of biofuel policy support.

The previous figures presented the resulting biomass use at a regional level, with either a carbon cost or a biofuel support applied independently. Fig 5 shows the amount of biomass used for CHP plants and biofuel production, respectively, when a biofuel support and a carbon cost are applied simultaneously. It can be seen that CHP plants are preferred for higher carbon costs (over 50 EUR/t_{CO2}) and low biofuel support (lower than 10 EUR/GJ). Conversely, biofuel production plants are preferred for higher biofuel support (over 15 EUR/GJ), independently of the carbon cost.

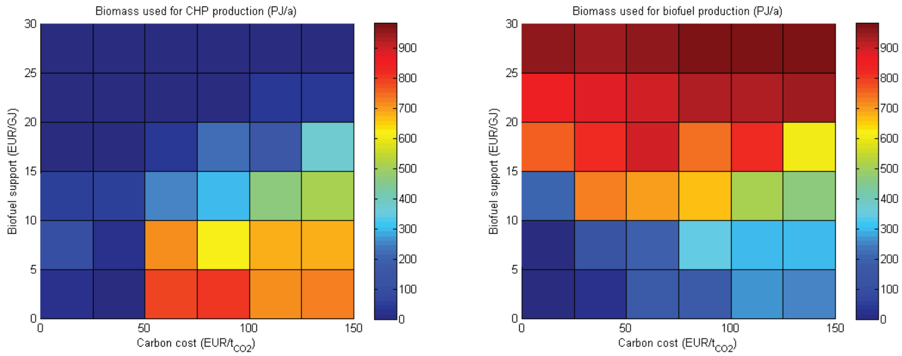

Fig 5. Biomass used (PJ/a) for CHP (left) and biofuel (right) plants for different combinations of biofuel support and carbon cost.

3.3. Substituted CO_2 emissions

Fig 6 shows the amount of substituted CO_2 emissions, for different combinations of applied carbon cost and biofuel support. The highest amount of emission substitution is reached at a high carbon cost (150 EUR/t_{CO2}), with a low biofuel support. When a biofuel support is combined with a carbon cost, biofuel production is stimulated, which decreases the emission substitution potential. For example, with a carbon cost of 150 EUR/t_{CO2}, the emission substitution decreases from 107 Mt_{CO2} when no biofuel support is applied, to 52 Mt_{CO2} with a biofuel support of 30 EUR/GJ. As discussed above, this is due to the higher CO_2 reduction potential of replaced heat and electricity, compared to replaced transport fuels.

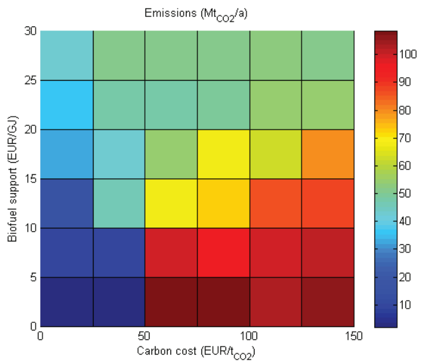

Fig 6. Emissions substituted (Mt_{CO2}/a) for different combinations of biofuel support and carbon cost.

4. Concluding discussion

This study has investigated the opportunity to invest in CHP plants or biofuel production plants under different policy scenarios for the EU, utilizing available forest residues. Different levels of carbon cost and biofuel support have been applied to the system at constant energy prices, and the number and locations of CHP and biofuel production plants have been determined by minimizing the cost of the complete supply chain.

The results show that CHP plants are preferred over biofuel production plants for high carbon cost (over 50 EUR/t_{CO2}) and low biofuel support (below 10 EUR/GJ), whereas more biofuel production plants would be set up at high biofuel support (over 15 EUR/GJ) irrespective of the carbon cost. At a regional level, region 6 (countries around the Baltic Sea) and region 8 (Austria, Czech Republic, Hungary, Poland and Slovakia), with high biomass potentials, stand out as important regions with high potential for biofuel production as well as for CHP plants.

The results also show that the highest CO_2 emission substitution potential is reached when a high carbon cost and a low biofuel support are applied. It can thus be concluded that if substantial CO_2 emission substitution is the primary objective, a carbon cost must be applied. This would lead to allocation of a major part of the available forest biomass to the heat and power sector, with significantly less biomass available for the transport sector. If, however, the main objective is to reach high shares of renewable energy for transportation, a targeted biofuel support is required, which would result in a higher share of forest biomass allocated to the transport sector.

This study shows that there is a potential conflict of interest between different parts of the overall EU targets of both increased use of biofuels and decreased CO_2 emissions. Since biomass is a limited resource, policies aiming at promoting its use must for this reason be very carefully designed, in order to reduce the likelihood of a possible conflict between different policies and different targets.

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