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BIOMASS FOR HEAT OR AS TRANSPORTATION FUEL? A COMPARISON BETWEEN TWO MODEL BASED STUDIES

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ABSTRACT: In two different energy economy models of the global energy system, the cost-effective use of biomass under a stringent carbon constraint has been analyzed. Gielen *et al.* conclude that it is cost-effective to use biofuels for transportation, whereas Azar *et al*. find that it is more cost-effective to use most of the biomass to generate heat and process heat, despite the fact that assumptions about the cost of biofuels production is rather similar in the models. In this study, we compare the two models with the purpose to find an explanation for these different results. It is found that both models suggest that biomass is most cost-effectively used for heat production for low carbon taxes (below 50-100 USD/tC, depending on the year in question). But for higher carbon taxes the cost effective choice reverses in the BEAP model, but not in the GET model. The reason for that is that GET includes hydrogen from carbon free energy sources as a technology option, whereas that option is not allowed in the BEAP model. In all other sectors, both models include carbon free options above biomass. Thus with higher carbon taxes, biomass will eventually become the cost-effective choice in the transportation sector in BEAP, regardless of its technology cost parameters.
Keywords: CO_2 emission reduction, bio-energy competitiveness, bio-energy strategy, global energy system model

1 INTRODUCTION

Due to the expected increase in global energy demand, the supply of CO_2-neutral energy may have to grow to levels similar to or even larger than the present global total fossil fuel use, if we are to avoid venturing into a future with a doubled, tripled or even quadrupled pre-industrial atmospheric CO_2 level. Among several candidates capable of supplying large amounts of CO_2-neutral energy, biomass ranks as one of the few options already competitive on some markets.

There are large uncertainties about the potential for biomass, but it is nevertheless clear that the potential supply is low compared to the future required levels of climate neutral energy, see, e.g. [1] and [2]. Biomass will thus not be available for all possible energy applications and it is therefore important to discuss where to use the scarce biomass resources for climate change mitigation.

In two different energy economy models of the global energy system, the cost-effective use of biomass under a stringent carbon constraint has been analyzed. Azar *et al.* [3] find that it is more cost-effective to substitute biomass for fossil fuels in power and heat production, whereas Gielen *et al*. [4-5] conclude that, most of the biomass is cost-effectively used as biofuels for transport, despite the fact that assumptions are rather similar in the models.

The aim of this study is to compare the two models with the purpose to find an explanation for the differing results.

2 THE TWO MODELS RESULT ON BIOMASS USE

In this section, we present the published results on biomass use from the two models. Both studies base their results on models developed especially for these studies. Gielen *et al*. have developed the BEAP (Biomass Environmental Assessment Program) model and Azar *et al*. the GET 1.0 (Global Energy Transition) model. Both models are run under ambitious constraints on carbon dioxide emissions corresponding roughly to an atmospheric carbon dioxide concentration target of 400 ppm by the year 2100. Such a target might be required if we are to be relatively certain that we meet the EU target that the global temperature increase should remain below 2°C [6].

In both models there is a steady increase in total biomass use, but the biomass distribution between energy sectors differs between the two models, see Figures 1a and 1b.

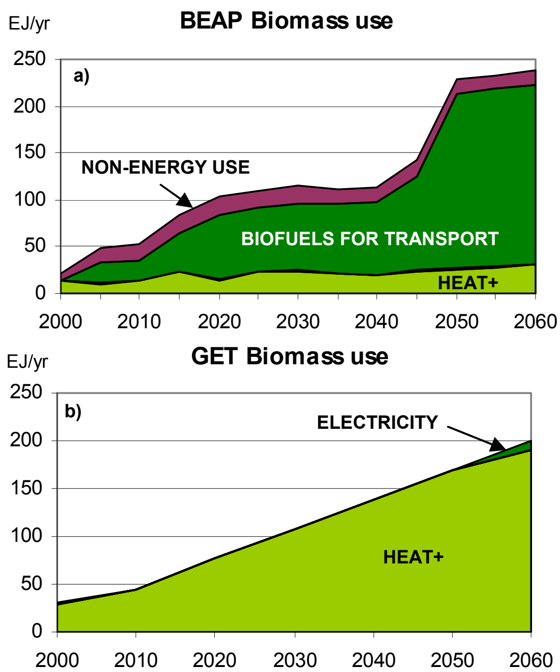


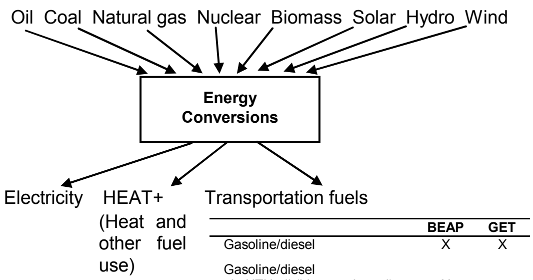
Figure 1: Biomass use as presented in a) the BEAP paper and in b) the GET paper. In the BEAP model the largest share of biomass is used for the production of fuels for transport but in the GET model the largest share of the biomass is used for HEAT+ production (stationary energy use that neither aims at generating electricity nor transportation fuels but mainly heat production).

Since the biomass use differs, the two models also present differing results for the transportation sector. Gielen *et al*. find that biofuels dominate in the transportation sector, whereas Azar *et al*. find that oil based fuels remain in the transportation sector for the next four to five decades and thereafter solar hydrogen or hydrogen produced from fossil fuels with carbon capture and storage enters.

3 MODEL DESCRIPTIONS

Both models are global energy systems optimization models. The BEAP model is a mixed integer programming (MIP) model and simulates an ideal market based on an algorithm that maximizes the sum of the consumers' and producers' surplus. The GET model is a linear programming model that is set up to meet exogenously given energy demand levels at the lowest energy system cost. Both models exhibit so-called 'perfect foresight' which means that all features of the model (future costs of technologies, future emission constraints, availability of fuels etc) about the future are known at all times.

In the GET model, there is only one aggregate heat and process heat sector that includes all stationary use of energy that neither aims at generating electricity nor at producing transportation fuels. We refer to this as HEAT+. The BEAP model has a more careful treatment of the heat sector in that it distinguishes between industrial heat, urban heat and rural heat. In order to facilitate comparisons between the models, we aggregate energy demand into three main sectors: Electricity, Transportation fuels and HEAT+. The primary energy supply options, the three energy demand sectors and fuel choices in the transportation sector are roughly outlined in Figure 2.



	BEAP	GET
Gasoline/diesel	X	X
Gasoline/diesel via HTU-oil (biomass based)	X	-
Methanol	X	X
Ethanol	X	-
Fischer-Tropsch diesel	X	-
Hydrogen (fossil fuel based)	X	X
Hydrogen (CO2-neutral)	-	X
Natural gas	-	X

Figure 2: The basic flow chart of supply and fuel choices in both energy system models.

The BEAP model database, including the model output files, is available on the Internet [7]. Details of the BEAP and GET models are available in Gielen *et al*., [4-5] and Azar *et al*. [1, 3, 8], respectively.

3.1 Energy demand

In the GET model, electricity and HEAT+ demand levels are exogenous and taken from the ecologically driven scenario C1 in IIASA/WEC [9]. The transportation scenario is developed separately, assuming that increase in the amount of person-kilometers traveled is proportional to the GDP growth (in PPP terms). Details of the demand scenarios are available in Azar *et al*. [8].

The BEAP model covers the global energy, food and materials system. The demand for food and materials are based on statistics from the Food and Agricultural Organization [10-11] and United Nations [12]. The energy demand is based on the BP review of world energy use [13]. Future demand in the base case is an extrapolation of historical trends and forecast as a function of regional GDP growth and income elasticities. Details on demand projections in the BEAP model are available in Gielen et al., [5] and on the Internet [7].

In the BEAP study, price elasticities in the range of −0.1 to −1 have been used for all demand categories. In the GET model energy efficiencies are assumed in the given heat and electricity demand scenario and it is also assumed that there is an exogenous improvement in energy efficiency in the transportation sector by 0.7% per year.

3.2 Constraints

Constraints have been added to both models so as to avoid solutions that are obviously unrealistic. In the GET model, there are constraints on the maximum expansion rates of new technologies (in general set so that it takes 50 years to change the entire energy system). There is also a constraint, which limits the contribution of intermittent electricity sources to a maximum of 30% of the electricity use. To simulate the actual situation in developing countries at least 20% of the heat demand needs to be produced from biomass the first decades.

In the BEAP model investments in some of the heat processes are constrained, e.g., no investments can take place in gas and biomass fuelled industrial heat boilers before the year 2020. Also urban heat produced from biomass is limited to very low levels (or even zero) for all industrialized regions.

4 RESULTS OF THE COMPARISON

Due to the ambitious CO_2 target, also the transportation sector has to be almost CO_2-free towards the end of this century. The two models present different development paths for the transportation sector, where biofuels enter the BEAP model but solar based hydrogen replaces gasoline and diesel in the GET model. The reason for the different results is that GET allows for CO_2-neutral hydrogen in the transportation sector, whereas BEAP does not. The implication is that biofuels are the only available option in the BEAP model for reaching zero emission levels.

However, it may be noted that hydrogen derived from natural gas can be used in the transportation sector also in BEAP. If the costs of hydrogen vehicles drop, then hydrogen from natural gas enters the transportation sector in BEAP, and biomass will be used to a larger extent for heat production.

5 EXPLAINING THE RESULTS

We attempt to shed light on technology options in the BEAP model by running it with a fixed CO_2 tax over the period 2005-2100. We made 13 runs with the tax set in the range 0-300 USD per ton C in steps of 25 USD/tC. The result for the year 2020 is presented in Figure 3.

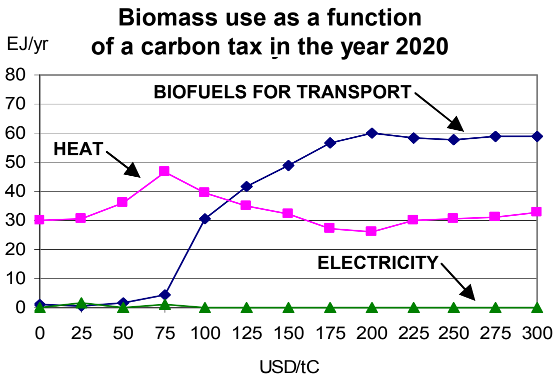


Figure 3: The biomass use (primary energy) in the BEAP model for various CO_2 taxes. The taxes have been fixed during each run and the figure includes 13 runs.

In Figure 3, it is shown that no biofuels are produced but 30 EJ of biomass is used for heat production by the year 2020 when no CO_2 tax is applied. When increasing the CO_2 tax, the use of biomass for heat production increases more rapidly than in the two other sectors, but only for taxes below 75 USD/tC. For higher taxes, biofuels increase rapidly at the expense of biomass for heat. Since the yearly biomass supply potential is limited[1], the biomass for heat production decreases when the use of biofuels increase.

In the BEAP reference scenario the CO_2 tax has reached 300 USD/tC by the year 2020 and at that tax, as shown in Figure 3, most of the biomass is used for the production of biofuels. Since Gielen *et al*. ran their model with very high taxes right from the beginning this concealed the fact that biomass is more cost-effectively used for heat production also in the BEAP model for low taxes. For that reason, BEAP and GET agree.

Thus, we can conclude that biomass is most cost-effectively used for heat when the carbon tax is low (in the year 2020 below 75 USD/tC).

For higher taxes, there is a difference between GET and BEAP. Biomass is most cost-effectively used for biofuels production in the BEAP model but in the GET model biomass remain most cost-effectively used for heat production. A reason for that is that GET allows for hydrogen from carbon free sources in the transportation sector, whereas BEAP has no other carbon free option than biomass. Both GET and BEAP has carbon free options in the two other sectors.

[1] The total biomass supply in any given year depends on the tax. The higher the tax the larger total supply, but the supply never becomes so large that it can cover the total demand in all sectors. For that reason, the question about in which sector it is most cost-effective to use remains important to address

6 DISCUSSION AND CONCLUSIONS

Our purpose has been to find an explanation for the differing results on the cost-effective use of biomass, and we came to the following conclusions:

1) Biomass is most cost-effectively used for heat productions at low CO_2 taxes, up to about 75 USD/tC in both models. This was not evident in previous runs of the BEAP model since these runs focused on higher carbon taxes.

2) The sector in which biomass is most cost-effectively used at higher CO_2 taxes depends on assumed possible energy carriers and technologies. In GET, hydrogen derived from carbon free energy sources are available in the transportation sector at a cost that makes this option more cost-effective than biofuels when very low carbon emissions are to be obtained. In BEAP, this option is not available and for that reason biofuels become the only option if low or zero carbon emissions are to be achieved.

6.1 Discussion and conclusions for modelers

Attempts to model optimal fuel choices in the transportation sector or optimal biomass use are fraught with difficulties. There are several factors that are important for the result that can be expected to depend primarily on non-economic factors, such as comfortability. Clearly, oil or natural gas is more comfortable for residential heating than solid biomass, industries might prefer natural gas to biomass for reasons related to requirements on temperature variability/ stability, or if the fuel is used as a feed stock (steel, ammonia etc). Further it is difficult to model willingness of buying electric cars, which is an energy-efficient technology but not really comparable to current standard cars. (Neither BEAP or GET consider electric cars as an option.) These factors are difficult to include in an optimization model: adding a price premium for different fuels and technologies could help but it will also add uncertainties.

Finally, the result in this case does not primarily depend on choices for parameter values but on the carbon tax scenario and whether CO_2-neutral hydrogen or electricity is available or not in the transportation sector.

Thus the assumptions about the availability of CO_2-neutral hydrogen and/or electricity as a fuel option in the transportation sector will determine whether biomass will be used for transportation or not in the long run. If hydrogen is assumed to make it as an energy carrier in the transportation sector, then cost assumptions on fuel cells, storage options, infrastructure and supply will determine in which sector the biomass will be used. Clearly, these cost numbers are very uncertain, so the long run future is still in the open.

6.2 Discussion and conclusions for policy makers

A separate question is related to which policy conclusions that should be drawn from models like this. Before drawing such conclusions, all the problems and difficulties with the models should be made clear to the policy makers. It should also be made clear that these models not are prescriptive. For instance, the fact that low carbon taxes do not generate sufficiently strong incentives to introduce biofuels does not mean that biomass should not be used in the transportation sector, since cost-effectiveness in dealing with climate change can not be the only criterion for policy makers. Rather, the implication is that if governments would want to see biofuels take off, then they would also need to introduce complementary policies (e.g., mandatory blending). Similarly, the models are not predictive in the sense that they purport to say what will happen. If it turns out that a lot of biomass are used in the transportation sector, that does not necessarily mean that the GET results were wrong, but it could equally well have been a result of a government decision to force the introduction of biofuels.

Further, even if both models would find that biomass is cost-effectively used in the transportation sector, this does not necessarily mean that governments should introduce policies that make biofuels mandatory. The reason for this is that if biofuels enter in the model with a carbon constraint as the only policy, and the model is a reasonably correct representation of reality, then biofuels should also enter the transportation sector in the absence of a biofuels obligation. If, on the other hand, biofuels are not used in the real world, despite being cost efficient in the model, there would be reasons to analyze possible barriers in the market that prevent the use of a cost-effective option (e.g., information barriers, monopolistic situation, hen and the egg problem with the expansion of infrastructure etc). If such barriers are shown to exist and play a decisive role in preventing the introduction of biofuels, then this would be a reason for governments to introduce policies to make sure that the markets function more properly, e.g., a law mandating biofuels.

The models should be used to generate insights about the cost-effectiveness of different technology options under different policy scenarios.

The first insight generated in this paper is that both models suggest that biomass is most cost-effectively used for heat generation for low carbon taxes. This is also in line with the Swedish experience where biomass is expanding rapidly in the heat sector, but not in the transportation sector, despite extensive additional subsidies (worth several hundred dollars per ton carbon).

The second insight generated in this paper is that assumptions about the possibility to use CO_2-neutral hydrogen/electricity at reasonable costs and performance are the determining factor of the long run fuel choice, in the transportation sector. If these options do not become available, then biomass will have to enter in order to bring down overall energy and transport related emissions to low levels. Since this is still an open question, policies at present should primarily aim at trying to bring down costs for both the biofuels option and the hydrogen option, rather than trying to force a large-scale introduction of biofuels since that may lock us into a suboptimal technology choice for a long time to come, see Sandén & Azar [14].

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