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Physical Resource Theory is a multidisciplinary research department doing research within a number of areas connected to sustainable development (sustainable industrial metabolism) and complex systems. Within the field of energy and the environment, most research focus on the Kyoto protocol, energy efficiency in buildings and the transportation sector, fuel choices in the transportation sector and issues related to biomass, e.g., potentials for energy, food fuel competition and the global food system, and industrial ecology (recycling).

The department is very active in its interactions with the rest of the society. Our results are presented in newspaper articles, through interviews in press, radio and television and in lectures to the general public, government committees, the parliament, the EU and companies.

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COST-EFFECTIVE BIOENERGY USE FOR CLIMATE CHANGE MITIGATION – A MODEL BASED ANALYSIS FOR EUROPE

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ABSTRACT: This paper presents results from a study of future bioenergy use in Europe, within the specific context of an enlarged EU, including agricultural reforms suggesting opportunities for large scale production of biomass for energy in Central and Eastern European countries, and given different climate change related policies. The analysis is made using a cost-minimization country-level energy and transport system model for Europe. The domestic biomass potential seems sufficient to meet the proposed demand for biofuels for transport in Europe to 2030. But competition for available bioenergy resources is likely to arise. Under a stringent carbon cap regime, biomass demand in stationary applications is the major driver behind the bioenergy expansion. Transport biofuel policies may redirect biomass flows from stationary uses to the production of transport fuels. Thus, ambitious biofuel targets in EU-s transport sector can reduce the efficiency of biomass use for CO_2 emission reductions. However, it may still be justifiable to use biomass for transport today, e.g., if a lack of technological progress for other carbon neutral transport fuels, e.g., hydrogen, lead to that biofuels will be required for reaching ambitious long term CO_2 targets for the transport sector.
Keywords: bio-energy competitiveness, CO_2 emission reduction, biomass trade, energy system model

1 INTRODUCTION

In addition to European goals stressing the use of biomass and other renewable energy sources (RES) in general [See e.g., 1, 2] the importance of using biofuels for transport has also been stressed in strategy and action plans of the European Union (EU) [3, 1]. There is also an EU Directive on the promotion of biofuels and other renewable fuels for transport, that obliges the member states to sell a certain amount of biofuels on their national markets for transport fuels in the period 2005 – 2010 (in this study denoted the Biofuels directive) [4].

At present there is a modest use of bioenergy in EU25, about 6 % of the primary energy supply is biomass based [5]. In order to meet EU goals, bioenergy use need to increase substantially. Studies indicate that Central and Eastern European countries (CEEC) have a substantial biomass production potential, and production costs that are much lower than in Western European countries [6]. If this potential becomes realized, CEEC could contribute to EU targets on bioenergy and RES. The opportunities for energy crop production are also acknowledged in the Common Agricultural Policy of the EU. Conversion of excess cropland to profitable energy crop production is regarded one option for addressing several key challenges for the agricultural sector arising from the enlargement of the EU such as abandonment of cropland, increased unemployment and depopulation in rural areas.

There are large uncertainties about the regional and global potential for biomass. But it is nevertheless clear that the potential long term supply is low compared to the future required levels of climate neutral energy [7, 8]. Thus, it is important to discuss where to use the scarce biomass resources for climate change mitigation.

The question of the relative cost-efficiency of different biomass uses for energy has been addressed by several research groups, with diverging findings. Some indicates that the use of transportation biofuels is a cost-effective strategy [9]; while others suggest that biomass should initially be used for heat generation, and/or co-generation, rather than in the transportation sector [10].

2 SCOPE AND AIM OF THIS STUDY

This paper reports results from a study of future bioenergy use in the European energy and transport sectors, given different climate change related policies. The CEEC biomass supply and cost potentials are here given special attention, within a regional focus on EU15 and CEEC. Below, we discuss three specific questions:

- What is the relative importance of biomass as an energy source in the transport, power and heat sectors respectively?
- In which sector is biomass most cost-effectively used?
- What is the relative importance of domestic bioenergy demand versus export opportunities to EU15 for an expanded biomass production for energy in CEEC?

Two kinds of policy instruments are taken into consideration; carbon dioxide (CO_2) emission reduction targets and transport fuel policy schemes promoting the use of biofuels and other alternative fuels (i.e., besides biofuels natural gas based fuels and hydrogen) in the transport sector.

3 METHODOLOGY

The analysis is made primarily using a regionalized energy and transport system model, the PEEP (Perspectives on European Energy Pathways) model that was developed as part of the EC supported project VIEWLS (then denoted the ChamersVIEWLS model).

The model is linear programmed and implemented in GAMS (General Algebraic Modeling System). It uses the Cplex solver and operates with an optimization algorithm. The algorithm decides which primary energy sources, energy conversion technologies and energy carriers that should be used to meet the energy demand for the studied time periods at the lowest energy system cost (net present value costs over the modeling period), while meeting specific targets. The energy system cost

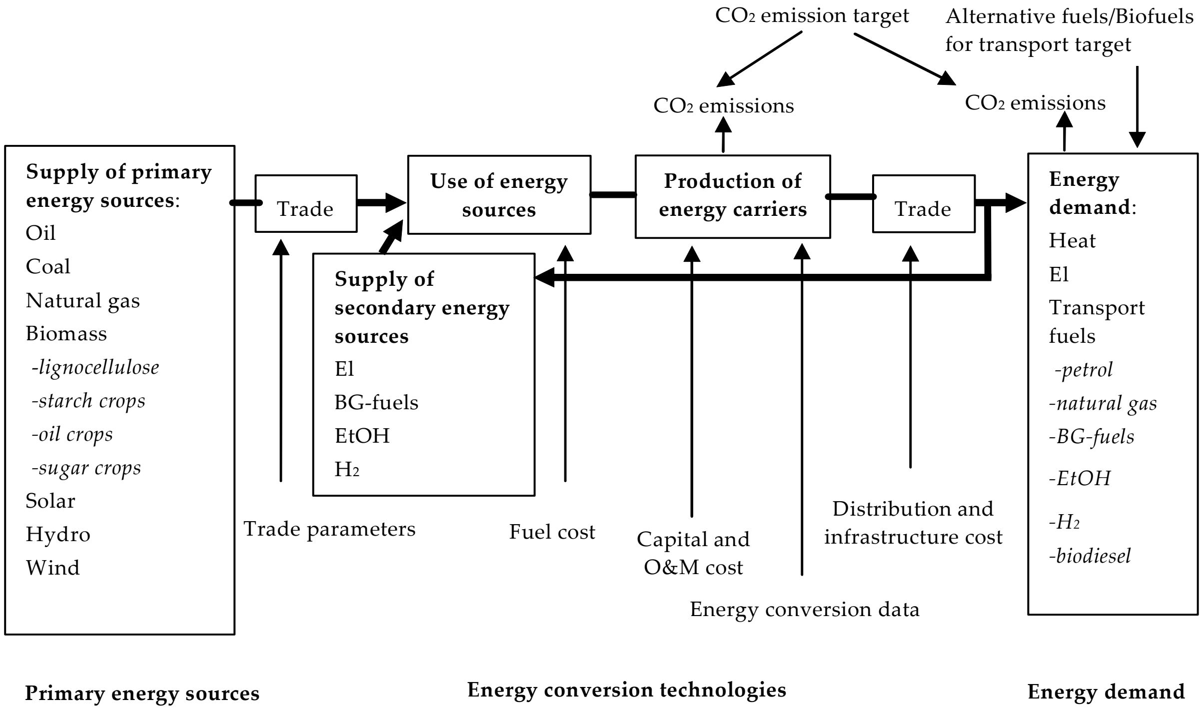

Figure 1: Graphic presentation of the model. The thick arrows represent energy flows within the model and the thin arrows represent exogenously given parameters. Also the energy demand (where heat represents heat and other energy use) and the supply of primary energy sources are given exogenously. Ligno-cellulose includes residues and energy crops from both forestry and agriculture. BGfuels denotes biofuels based on biomass gasification with subsequent synthesis (e.g., methanol, FT diesel). Petrol includes both diesel and gasoline.

includes costs for fuel, capital, operation and maintenance, distribution and infrastructure. The timeframe considered is 2000-2030, and the model provides output for every decade. The optimization algorithm represents the market mechanisms in an ideal market where all actors always have access to perfect information and act rationally. A graphic description of the model is presented in Figure 1.

The model has 24 regions (i.e., countries: EU25, excluding Malta and Cyprus, but including Romania) and three end-use sectors: (i) electricity; (ii) transportation; and (iii) heat and other fuel use (here denoted heat). Energy demand scenarios are exogenously defined on a country level and for each of the three sectors, based on [5]. In addition to energy demand, the set of exogenously defined parameters include primary energy supply potentials and costs, energy conversion characteristics, the initial energy system capital stock, trade parameters and CO_2 emissions for the included primary energy sources and related conversion/end use technologies. Also the policy targets are exogenously defined.

The domestic potential for the different biomass types is defined using country and biomass type specific estimates of residue availability and estimates of yields and land availability for energy crops. Besides the domestic resources each country can import biomass and biofuels from other European countries. Unlike fossil fuels biomass use is assumed to give no net contribution of CO_2 emission to the atmosphere.

The model is run with three different scenarios:

- CO_2 and transport fuel policy scenario (CTP)
- CO_2 policy scenario (CP)
- No policy scenario (NP)

CTP includes an exogenously defined CO_2 emission limit for the enlarged EU and country-level targets for the introduction of biofuels and other alternative fuels in the transportation sector. The CO_2 emission target places an upper limit on the total accumulated emission from fossil fuel use during the studied time period. The limit is estimated assuming a reduction of CO_2 emission by 35% in 2020 and 40% in 2030 compared to the baseline projection in [5]. In the transport sector 8%, 20% and 30% of the petrol and diesel use has to be replaced with alternative fuels in 2010, 2020 and 2030 respectively. Also, 5.75%, 11.5% and 17.25% of the total transport energy use has to be replaced with biofuels or other renewable fuels for transport (initially following the indicative targets of the Biofuel directive). CP includes the CO_2 emission target only and NP includes no policies. There are two mechanisms for CO_2 emissions abatement in the model; CO_2 emissions can be reduced by switching fuel or by switching to an energy conversion technology with a higher efficiency.

4 RESULTS

There are clear differences in the total primary energy supply in CTP and CP, compared to NP. The use of coal is much lower and there is an increased use of natural gas and biomass. In CTP and CP the use of oil for transport decreases and the contribution of natural gas –and for CTP also biofuels– gradually increase. In both these scenarios biomass is used to the maximum of its assessed potential. Energy crops are high in demand since the potential waste and residue supplies fall short of demand.

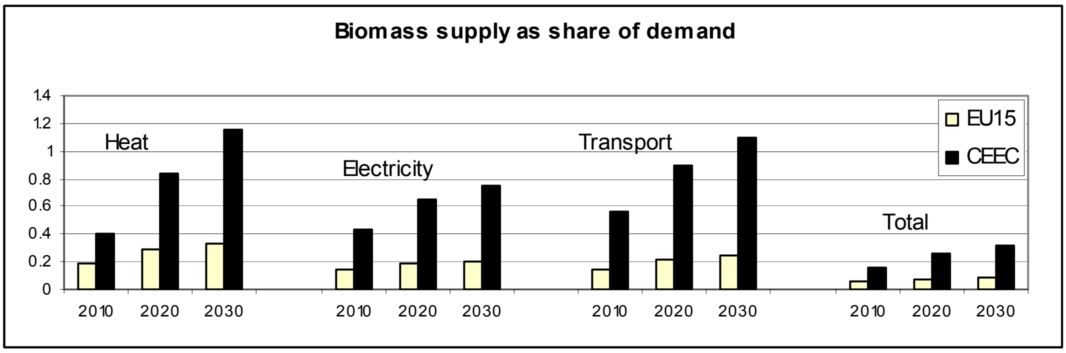

Figure 2: Relative importance of biomass supply for total and sector energy demand (expressed in biomass equivalents) in EU15 and CEEC, respectively.

4.1 Relative importance of biomass as an energy source

The relative importance of biomass as an energy source in EU15 and CEEC, is indicated in Figure 2, where the domestic biomass supply potential is compared to the total and sectoral energy demand (converted to biomass equivalents) in the regions. Here, the domestic biomass supply potential is estimated by adding the energy content of all available lignocellulosic residues and waste to the energy crop output given a crop distribution leading to maximum output from the total area that is available for energy crop production in each region. The default values for land availability are set based on the V3 Scenario in [6] and supplemental VIEWLS data, with additional restrictions related to expansion rates: the available area increases every decade during 2000-2030 at a rate leading to a maximum area corresponding to 5, 10, 30 and 40 percent of the present arable land + land under permanent crops.

The regional potentials correspond to about 5-10% and 15-30% of the total energy demand in EU15 and CEEC, respectively, during the studied time period. Thus, domestic biomass resources can make a substantial contribution in each of the sectors in CEEC. In 2030, the biomass supply is in fact larger than the respective demand in the heat and transport sectors. Thus, a large share (exceeding the present targets) of the transport fuel demand in CEEC can be meet with biofuels produced within the region. However, this requires that the biomass is not directed to stationary energy uses or exported abroad. Both these alternative uses could arise.

The attractiveness of using biomass for climate change mitigation in a given sector depends on the relative competitiveness of biomass compared to other carbon-neutral options in the same sector.

Furthermore, not all EU15 countries have sufficient domestic bioenergy resources for meeting the biofuel targets based on own biomass. In order to reach targets, biofuel import or burden sharing mechanisms will be required. Thus, it may be that the biomass produced in CEEC will become exported to EU15 instead of used within CEEC. These issues are further discussed below.

4.2 Cost-effective biomass use from a sector perspective

Biomass demand in stationary applications (primarily heat) is the major cause behind early expansion of bioenergy in CTP, but biomass is also required in the transport sector to meet the transport policy targets (Figure 3). As can be seen in Figure 4, there is a substantial and increasing contribution of bioenergy in the heat sectors, especially in CEEC. However, quantitatively, biomass use for heat production in EU15 dominates the total bioenergy use. Lignocellulosic biomass dominates the supply in all sectors.

In CP, that lacks policies directing biomass to the transport sector, biomass is mainly used in stationary applications (primarily for heat). This since it is more cost-effective to substitute biomass for fossils fuels in the power and heat sector than for transport fuels production. On the other hand, in NP where there are no restrictions on CO_2 emissions, less biomass is used to replace fossil fuels in stationary applications. Instead coal dominates as a fuel both for electricity generation and heat production. Though, some biomass is still used for heat, especially in CEEC where the biomass production costs are low. In addition, a small amount of biofuels are also introduced in the transport sector as they become competitive in 2020. Thus, biofuels can become competitive in the transport sector, despite the lack of biofuel obligations, as long as there is no competing demand for biomass in stationary applications.

4.3 Cost-effective biomass use from a regional perspective

The major part of the domestically produced biomass is used to meet the domestic demand in CEEC in CTP (Figure 5). However, a large share is also exported to meet the demand in EU15. The total export of biomass and biofuels for transport from CEEC increases over time in CTP (Figure 6). Less biomass is exported in 2030 compared to 2020, but the export of biofuels increases substantially during the whole time period. In fact the major part of the biofuels produced in CEEC is exported in CTP.

In CP, the major part of the domestic biomass is also used domestically in CEEC. On the other hand, in NP, the major part of the biomass is exported in 2020 and 2030. This, since there is a lower total biomass demand and since the cheaper biomass from CEEC is used first.

4.4 Model evaluation

The optimization depends on uncertain assumptions about future costs and technological performance. Therefore, the result has been exposed to a careful sensitivity analysis. The model results reported here have been found robust for parameter variations over a wide range.

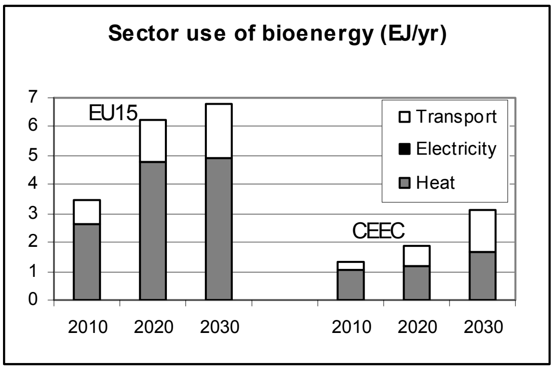

Figure 3: Sector use of bioenergy in the CTP scenario
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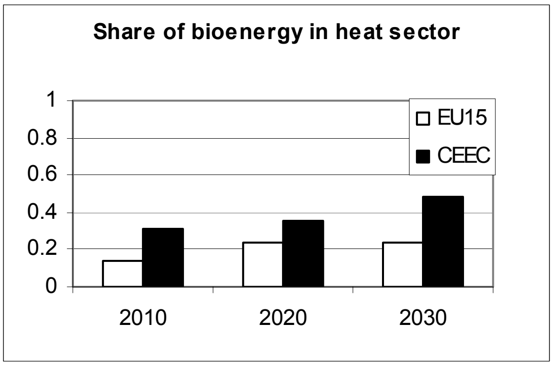

Figure 4: Share of bioenergy in the fuel mix in the heat and transport sectors in the CTP scenario.

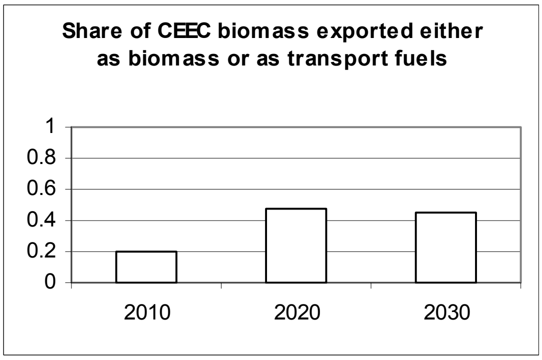

Figure 5: Share of domestically produced biomass in CEEC that is exported either as biomass or as biofuels for transport in the CTP scenario.

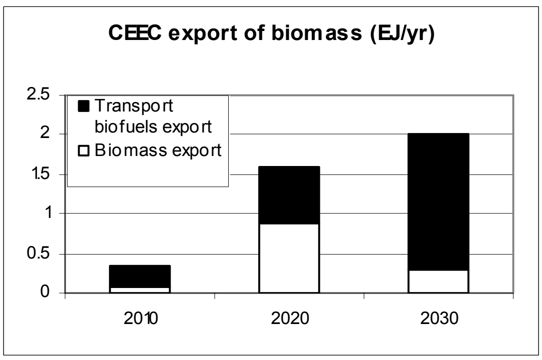

Figure 6: Export of domestically produced biomass and biofuels in CEEC, the latter expressed in biomass equivalents, in the CTP scenario.

5 CONCLUSIONS

The total domestic biomass potential is estimated to be sufficient to meet the proposed demand for biofuels for transport in CEEC and EU15 to 2030. But under a stringent climate policy scenario there will be a competition for the available bioenergy resources.

Without climate policies biomass is used to some extent for heat and also for some limited transport fuels production (2020-2030). Under a stringent carbon cap regime, biomass demand in stationary applications (primarily heat) is the major driver behind the large expansion of bioenergy and no biomass is used for transport. The introduction of a transport policy induces a redirection of biomass flows from stationary uses to the production of transport fuels, leading to a reduced average CO_2 emission reduction per unit of biomass use for energy. Thus, ambitious targets for the introduction of biofuels for transport in the EU can be considered to reduce the efficiency of using domestic biomass to reduce CO_2 emissions. Import from other regions would increase the biomass potential, but the demand for bioenergy can be expected to increase also in other regions.

However, the result does not mean that biomass should never bee used for transport fuels production. There might be several aspects limiting the possible use of biomass for power and heat production, directing biomass to the transport sector. Also, in a long-term perspective, a lack of technological progress for other carbon neutral transport fuel alternatives e.g., hydrogen, might influence the biomass use. This since an early introduction for biofuels might then be required to meet a large need for biofuels at a later stage.

Assuming inter-European biomass trade only, the use of bioenergy in EU 15, in particular biofuels for transport, clearly stimulates biomass production in CEEC. However, it is the domestic use of biomass in stationary applications (mainly heat) and also for transport fuel production in CEEC that is the major driver behind increased biomass production for energy in CEEC. Such domestic biomass use requires ambitious climate policies.

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FUTURE BIOENERGY PRODUCTION AND TRADE FLOWS IN EUROPE – AN ENERGY-ECONOMY MODEL BASED ASSESSMENT

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ABSTRACT: This paper presents results from a study of future bioenergy use in Europe, within the specific context of an enlarged EU, including CO_2 caps and biofuel for transport policies. The analysis is made using a cost-minimization country-level energy and transport system model. The main issue addressed concerns the opportunities for bioenergy production and trade within Europe. In the presence of ambitious climate policies and assuming inter-European biomass trade only, the use of bioenergy in EU 15, in particular biofuels for transport, stimulates biomass production in CEEC. However, the domestic biomass use in CEEC is the major driver behind increased biomass production for energy in CEEC. The capacity in EU15 ports seems sufficient to accommodate a substantial biomass import flow from CEEC. However, the capacity of CEEC ports may constrain the future biomass export from CEEC to EU15. A closer examination of the logistic capacity by ship and other transport modes is required before any firm conclusion regarding the prospects for large scale bioenergy trade flows from CEEC to EU15 can be made.
Keywords: biomass production, biomass trade, CO_2 emission reduction, energy system model

1 INTRODUCTION

Bioenergy has the possibility to play an important role in European climate change mitigation. In addition to European goals stressing the use of biomass and other renewable energy sources (RES) in general [See e.g., 1, 2] the importance of using biofuels for transport has also been addressed. There is e.g., an European Union (EU) Directive on the promotion of biofuels and other renewable fuels for transport, that obliges the member states to sell a certain amount of biofuels on their national markets for transport fuels in the period 2005 – 2010 (in this study denoted the Biofuels directive) [3].

At present there is a modest use of bioenergy in EU25, about 6 % of the primary energy supply is biomass based [4]. In order to meet EU goals, bioenergy use needs to increase substantially.

Traditionally, biofuels have been used mainly in the region where they are produced. However, international trade with bioenergy has been envisaged as a feature of the future global energy system [5]. Studies indicate that Central and Eastern European countries (CEEC) have a substantial biomass production potential, and production costs that are much lower than in Western European countries [6]. The opportunities for energy crop production are also acknowledged in the Common Agricultural Policy of the EU. Conversion of excess cropland to profitable energy crop production is regarded one option for addressing several key challenges for the agricultural sector arising from the enlargement of the EU such as abandonment of cropland, increased unemployment and depopulation in rural areas.

Given that the CEEC biomass potential becomes realized, through an increased domestic demand or export demand from EU15, CEEC could contribute to EU targets on bioenergy and RES.

2 SCOPE AND AIM

This paper reports results from a study of future bioenergy use in the European energy and transport sectors, given different climate change mitigation related policies. The main issue addressed concerns the opportunities for bioenergy production and trade within Europe and the implications of various bioenergy uses. There is a regional focus on EU15 and CEEC and biomass supply and cost potentials in CEEC are given special attention.

The aim is to gain insight into the following issues:

- Cost-effective bioenergy production, trade and use in Europe under different policy regimes.
- The relative importance of domestic bioenergy demand versus import demand in EU15 for an expanded biomass production for energy in CEEC.
- The prospective size of biomass transport flows from CEEC to EU15, compared to logistic capacities.
- The implications of bioenergy production and trade for employment generation in agriculture.

Two kinds of policy instruments are taken into consideration; carbon dioxide (CO_2) emission reduction targets and transport fuel policy schemes promoting the use of biofuels and other alternative fuels (i.e., besides biofuels natural gas based fuels and hydrogen) in the transport sector.

3 METHODOLOGY

The analysis is made primarily using a regionalized energy and transport system model, the PEEP (Perspectives on European Energy Pathways) model that was developed as part of the EC supported VIEWLS project (then denoted the ChamersVIEWLS model).

The model is linear programmed and implemented in GAMS (General Algebraic Modeling System). It uses the Cplex solver and operates with an optimization algorithm. The algorithm decides which primary energy sources, energy conversion technologies and energy carriers that should be used to meet the energy demand for the studied time periods at the lowest energy system cost (net present value costs over the modeling period), while meeting specific targets.

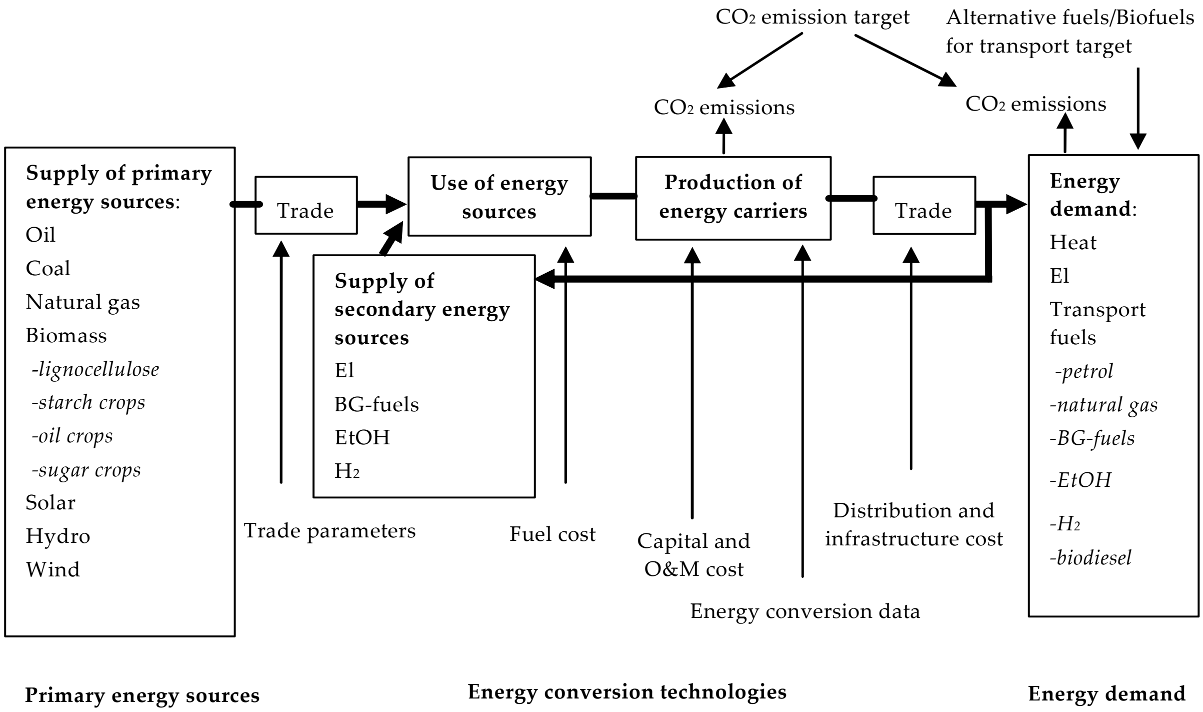

Figure 1: Graphic presentation of the model. The thick arrows represent energy flows within the model and the thin arrows represent exogenously given parameters. Also the energy demand (where heat represents heat and other energy use) and the supply of primary energy sources are given exogenously. Lignocellulose includes residues and energy crops from both forestry and agriculture. BGfuels denotes biofuels based on biomass gasification with subsequent synthesis (e.g., methanol, FT diesel). Petrol includes both diesel and gasoline.

The energy system cost includes costs for fuel, capital, operation and maintenance, distribution and infrastructure. The timeframe considered is 2000-2030, and the model provides output for every decade. The optimization algorithm represents the market mechanisms in an ideal market where all actors always have access to perfect information and act rationally. A graphic description of the model is presented in Figure 1. The model has 24 regions (i.e., countries: EU25, excluding Malta and Cyprus, but including Romania) and three end-use sectors: (i) electricity; (ii) transportation; and (iii) heat and other energy use (here denoted heat).

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The domestic potential for the different biomass types is defined using country and biomass type specific estimates of residue availability and estimates of yields and land availability for energy crops. Besides the domestic resources each country can import biomass and biofuels from other European countries. Unlike fossil fuels biomass use is assumed to give no net contribution of CO_2 emission to the atmosphere.

The model is run with three different scenarios:

- CO_2 and transport fuel policy scenario (CTP)
- CO_2 policy scenario (CP)
- No policy scenario (NP)

CTP includes an exogenously defined CO_2 emission limit for the enlarged EU and country-level targets for the introduction of biofuels and other alternative fuels in the transportation sector. The CO_2 emission target places an upper limit on the total accumulated emission from fossil fuel use during the studied time period. The limit is estimated assuming a reduction of CO_2 emission by 35% in 2020 and 40% in 2030 compared to the baseline projection in [4]. In the transport sector 8%, 20% and 30% of the petrol and diesel use has to be replaced with alternative fuels in 2010, 2020 and 2030 respectively. Also, 5.75%, 11.5% and 17.25% of the total transport energy use has to be replaced with biofuels or other renewable fuels for transport (initially following the indicative targets of the Biofuel directive). CP includes the CO_2 emission target only and NP includes no policies. There are two mechanisms for CO_2 emissions abatement in the model; CO_2 emissions can be reduced by switching fuel or by switching to an energy conversion technology with a higher efficiency.

4 RESULTS

The total domestic European biomass potential is estimated to be sufficient to meet the proposed demand for biofuels for transport to 2030. But in a stringent CO_2 emission reduction scenario, there will be a competition for the available bioenergy resources from stationary energy uses (especially heat and other fuel use).

There are clear differences in the total primary energy supply in CTP and CP, compared to NP. The use of coal is much lower and there is an increased use of natural gas and biomass. In CTP and CP the use of oil for transport decreases and the contribution of natural gas – and for CTP also biofuels– in the transport sector gradually increases. In both these scenarios biomass is used to the maximum of its assessed potential. Energy crops are high in demand since the potential waste and residue supplies fall short of demand.

4.1 Biomass production, use and trade in Europe

In Figure 3, the production and use of total biomass for energy and, explicitly, transport fuels in CEEC and EU15 in the CTP scenario is given. For the same scenario, Figure 4 presents the trade flows of biomass and biofuels between the two regions. The major part of the biomass produced in CEEC is used to meet the domestic demand. However, a substantial share is also exported to meet the demand in EU15. The biomass export consists of both solid fuels that are used in the heat sector in EU15 and liquid biofuels that are used to meet the biofuel for transport targets. In fact, most of the biofuels produced in CEEC is exported to EU15, which can be explained by the larger demand in EU15. Though, the major part of the biofuels for transport demand in EU15 is met domestically (Figure 3). The total export of biomass and biofuels for transport from CEEC increases over time (Figure 4). As a result of the increased demand for biofuels for transport, the biomass export decreases between 2020 and 2030.

In CP, the major part of the domestic biomass is also used domestically in CEEC. On the other hand, in NP, the major part of the biomass is exported in 2020 and 2030. This is due to the fact that the total biomass demand is lower and that cheap biomass from CEEC becomes an attractive option in EU15.

4.2 Bioenergy trade flows versus logistic capacity

In Table I, a comparison is made between biomass flows in the CTP scenario and selected indicators of transport flows and logistic capacities in Europe today.

The comparison indicates that future biomass exports from CEEC to EU15 could potentially make up a substantial part of the future dry bulk management in CEEC. It has not been further investigated here whether a biomass export of the size indicated in Table I would require extensive investments in order to increase the logistic capacity in CEEC. This is subject to further research.

Considering liquid biofuels, the situation is different: they fit well within the present liquid fuel transport infrastructure and could therefore co-opt freight and port capacity that becomes available due to the substitution of diesel and petrol. In addition, it may also be possible to use freight capacity that has been phased out due to stricter rules for seaborne transport of oil products. Thus, it can be expected that liquid biofuels transport can be managed within the present global freight system.

When considering biomass import flows to EU15 ports, it seems possible to handle the volumes indicated in Table I. Compared to the present dry bulk flows in EU15 ports, and also the rate of increase in these flows, biomass import flows from CEEC appear relatively small (but not insignificant).

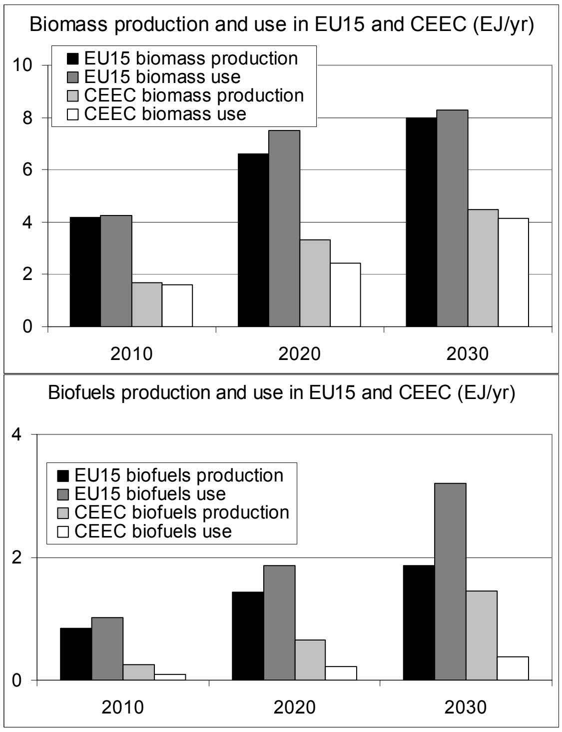

Figure 3: Production and use of biomass and biofuels for transport in CEEC and EU15 in the CTP scenario.

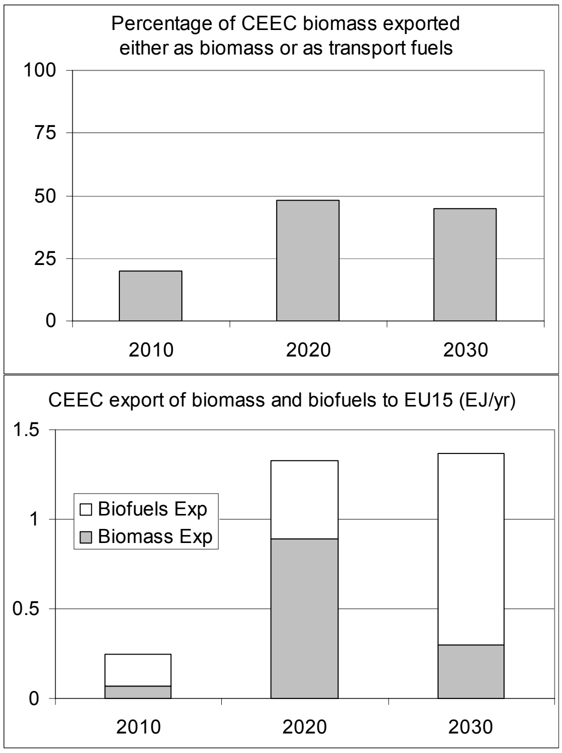

Figure 4: Export of biomass and biofuels for transport from CEEC to EU15 in the CTP scenario.

Table I: Bioenergy trade flows in the CTP scenario compared to selected indicators of transport flows and logistic capacity in Europe.

	2010	2020	2030
Biomass flows (million ton per year)			
From CEEC to EU15			
Biomass	3.5	45	15
Biofuels	8	20	51
Comparison			
CEEC* outward dry bulk flow, all ports 2001-2003 average[1]		73	
Dry bulk flows in EU15 ports, 1998-2001 average		850	
Average annual increase in dry bulk flow in EU15 ports, 1998-2001		22	

[1]CEEC*=Estonia, Latvia, Lithuania, Poland, Slovenia, Romania. Data from [7]. It is assumed that dry bulk amounts to 44% of total outward trade flow. This is based on a comparison of dry bulk and total throughput in 2001 in Latvia, Lithuania and Poland, reported in [8].

4.3 Bioenergy and employment

Domestic energy crop production to supply an increased biomass demand would generate employment opportunities in agriculture in both EU15 and CEEC (See Table 2). The employment generation in Table 2 is calculated assuming that lignocellulosic crops are produced on the total area available for energy crop production (the default values for land availability are set based on the V3 Scenario in [6] and supplemental VIEWLS data, with additional restrictions related to expansion rates: the available area increases every decade during 2000-2030 at a rate leading to a maximum area corresponding to 5, 10, 30 and 40 percent of the present arable land + land under permanent crops).

Lignocellulosic crops are considered to have a high climate benefit compared to traditional agricultural crops e.g., oil seed and wheat. This, in combination with cost differences, makes the former an attractive option for CO_2 emission reductions in the model. On the other hand, the latter are somewhat more labor intensive. Thus, there is a potential conflict between the maximization of climate benefits and the maximization of employment generation. This issue is not covered in these analyses.

In addition to the employment generation estimated in Table 2, there are opportunities for job creation linked to the use of agricultural residues and to the increased wood extraction for energy purposes within the forest industry.

Table II: Employment in agriculture generated by the bioenergy production in 2010, 2020 and 2030.

	2010	2020	2030
		Labor input (1000 AWU)[1]	
EU15	47	68	73
CEEC	105	100	81
		Labor input (% of AWU loss 1995-2000)[2]	
EU15	4	6	7
CEEC			

[1] AWU = annual work unit. Calculated based on country-specific yield levels and an average work input at 7, 6 and 5 hours/ha/yr for 2010, 2020 and 2030, respectively.
[2] Source: [9].

5 CONCLUSIONS AND DISCUSSION

In the presence of ambitious climate policies, the domestic use of biomass in stationary applications (mainly heat and other fuel use) but also for transport fuel production in CEEC is the major driver behind increased biomass production for energy in CEEC. However, the demand for biofuels in the heat sector and the transport sector in EU15 is also important. In particular, a large future demand for biofuels for transport in EU15, as a response to ambitious targets for alternative fuels, could induce a substantial biomass production in CEEC, with conversion to liquid biofuels for export.

Though, a prerequisite for such a scenario is that this option is less costly than both import of biofuels for transport from regions outside Europe and domestic biofuel for transport production in EU15, based on domestic biomass resources or imported biomass. At present, several EU countries i.e., Sweden, UK and Germany imports substantial amounts of ethanol from Brazil [10]. However, in the future the price of Brazilian ethanol could increase due to increased competition, making biofuel for transport from CEEC competitive.

The capacity in EU15 ports seems sufficient to accommodate a substantial biomass import flow from CEEC. However, the capacity of CEEC ports may constrain the future biomass export from CEEC to EU15. A closer examination of the logistic capacity by ship and other transport modes is required before any firm conclusion regarding the prospects for large scale bioenergy trade flows from CEEC to EU15 can be made.

6 ACKNOWLEDGEMENTS

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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.

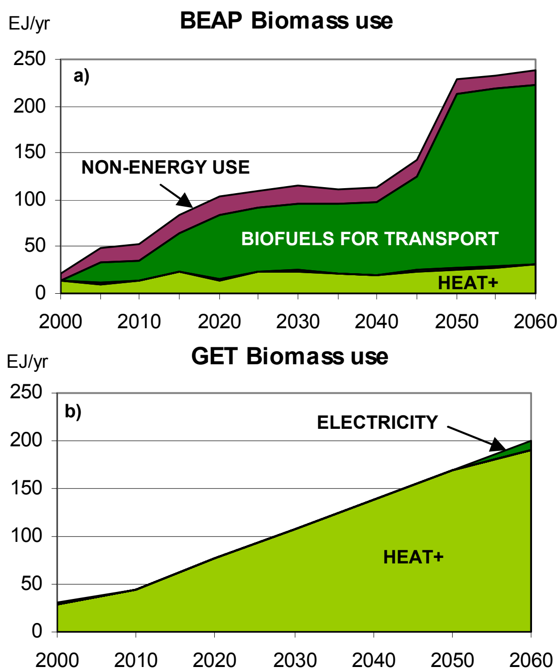


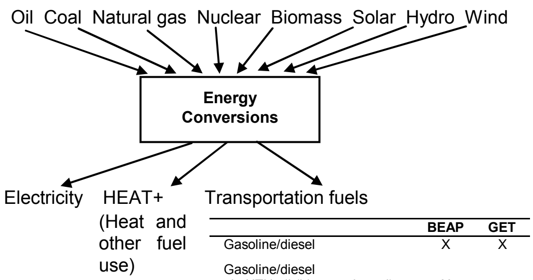
Figure 1: Biomass use as presented in a) the BEAP paper and in b) the GET paper. In the BEAP model the largest share of biomass is used for the production of fuels for transport but in the GET model the largest share of the biomass is used for HEAT+ production (stationary energy use that neither aims 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.

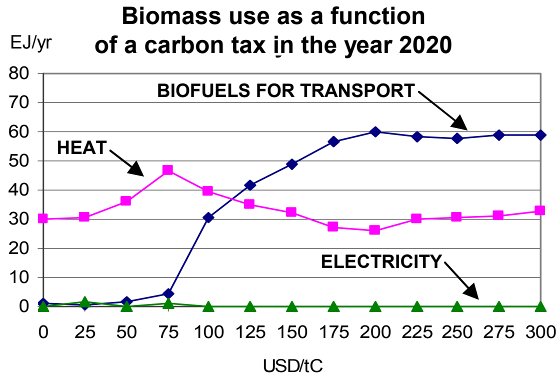


Figure 3: The biomass use (primary energy) in the BEAP model for various CO_2 taxes. The taxes have been fixed during each run and the figure includes 13 runs.

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].

ACKNOWLEDGEMENT

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CARBON SEQUESTRATION VERSUS BIOENERGY: A CASE STUDY FROM SOUTH INDIA EXPLORING THE RELATIVE LAND USE EFFICIENCY OF TWO OPTIONS FOR CLIMATE CHANGE MITIGATION

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ABSTRACT: In this study the benefits of using land for biomass production for the substitution of fossil fuels are compared with the benefits of using the same land for C sequestration, via afforestation. The study is site specific, comparing two different options for a future expansion of the bioenergy system in Hosahalli village, Karnataka, India. The demand for electricity is increasing in the village and it is estimated that meeting the demand by using biomass, requires that about 16 ha of short rotation (6 yrs) forest is planted (increasing the total plantation area to 20 ha). This option is compared with a scenario where the same 20 ha is used for plantation of short (6 yrs) or long (30 yrs) rotation forests, delivering wood for non-energy purposes, and delivering climate benefits via C sequestration. The internal ranking of the different options varies depending on the system boundaries. Results indicate that in the short term (30 yrs) perspective, the mitigation potential of the long rotation plantation is largest, followed by the short rotation plantation delivering wood for energy. The short rotation forest delivering wood for non-energy purposes has the smallest mitigation potential. In the longer perspective, the mitigation potential of the biomass for bioenergy option will exceed that of the long rotation plantation.
Keywords: gasification, land use, rural electrification.

1 INTRODUCTION

The forestry sector in the developing countries provides low cost mitigation opportunities [1]. Land Use, Land Use Change and Forestry (LUCUCF) activities lead to both emissions and removal of carbon. One example is biomass production for bioenergy. If produced in a sustainable manner, and replacing fossil fuels, biomass use for energy reduces the rate of build-up of atmospheric CO_2. Apart from the carbon benefit it is possible to conserve soil, rainwater, and biodiversity. LULUCF projects can also lead to local employment generation, capacity development, self-reliance, local control and community participation [2]. Biomass has been suggested a major source of energy in the future and the large-scale expansion of biomass plantations has been envisioned a possible strategy for climate change mitigation [3].

There are other land management strategies that can lead to CO_2 emission reductions, such as slowing deforestation (slowing the C loss from plants and soils), or afforestation/reforestation (sequestering atmospheric C in plants and soils by establishment of so-called C sinks). The forestry sector mitigation projects are, however, more complex than most other CDM (Clean Development Mechanism) projects. Factors like long gestation periods, non-linear rates of C accumulation, varying rates of extraction of different woody biomass products and C emission from decomposition, is associated with a lot of uncertainties [4].

In the village of Hosahalli, Tumkur district, Karnataka state in southern India, a biomass driven energy system has been under operation since 1988 [5]. The system is based on a standard diesel engine generator system. The fuel is provided using a biomass gasifier. The biomass is produced on a 4 ha plantation with fast growing tree species, about 1 km from the village. This system has the potential of reducing the consumption of fossil fuels by a long-term average of 75 percent. The system generates electricity for lighting, irrigation, drinking water and services such as the milling of grains. In order to improve the economic viability of the system there are plans to increase the plant load factor and consequently the demand for biomass would increase.

2 STUDY AREA

The village of Hosahalli is located in Tumkur district, Karnataka state in southern India (13° 26’ 50 N: 77° 26’ 41 E). The village consists of 35 households with a population of 218. Before the biomass power project was initiated in 1988 the villagers had no access to electricity and limited access to clean drinking water. The farmers relied primarily on rainfall for crop production and there was no flour mill in the village. The project was a result of an initiative from the Center for Sustainable Technology, Indian Institute of Science and the local community was involved in the project at an early stage. The biomass gasifier supplies the village with electricity for several services. All the households in Hosahalli are electrified and connected to the bioenergy system. The households are also provided with water through private taps. Since 1994 the village has its own flourmill with a capacity of 7.5 hp and four irrigation water pumps have been installed and connected to the bioenergy system. Hosahalli is located in a semi-arid region with a mean annual rainfall of 700 mm and most of the rainfall is concentrated in the rainy season (July – September). The demand for irrigation therefore exceeds the supply.

The bioenergy-based power generation system is fed with producer gas from a biomass gasifier. The woody biomass is dried, chopped and sized and finally combusted under controlled air supply inside the gasifier. The producer gas is then used to replace diesel in a standard diesel engine in a dual fuel mode. The system operates on dual fuel mode most of the time (355 days in 2003). If producer gas can not be supplied for some reason, the system operates on diesel only. The diesel substitution rate under dual fuel mode is high, reaching an average of almost 86 % in 2003.

The 20 kW biomass gasifier system provides the village with electricity for lighting, drinking water supply, flour mill and irrigation pumps. The total end use demand is higher than the system can provide (30.7 kW). Therefore, the different load activities has to be run on separate hours during the day. In 2003, the total amount of electricity generated almost reached 22 MWh, the highest so far.

The plantation providing the needed biomass was established during two phases: 2.5 ha in 1988 and an additional 1.5 ha in 1991-92. It contains a mix of species, including: *Eucalyptus* (58%), *Cassia siamea* (22%), *Acacia auriculiformis* (13%) and *Dalbergia sisso* (7%).

3 OBJECTIVES

The aim of the study is to compare the relative attractiveness of two different land-use strategies for climate change mitigation within the context of the village bio-electricity project in Hosahalli, Tumkur district, Karnataka state. To meet the villagers demand for irrigation and to improve the cost effectiveness of the project, the load factor of the system has to be increased. This estimated rise in power demand would lead to new challenges for the fuel supply chain. Two options for meeting these challenges will be evaluated:

- using land for biomass production for the substitution of fossil fuels (bioenergy option), or
- using land for C sequestration, via reforestation or afforestation, and meet the increasing power demand by using more fossil fuels in the system (C sink option).

4 METHOD

The study is based on data obtained from the biomass gasification project in Hosahalli. This project has been carried out by Center for Sustainable Technology (CST) at the Indian Institute of Science (IISc) in Bangalore and at Physical Resource Theory, Department of Energy and Environment, Chalmers University of Technology in Gothenburg.

First three land-use strategies are defined, characterized and parameterized:

- In the bioenergy case; characterization of the biomass power system, capacity and loads for different services and the carbon replacement efficiency of the biomass system.
- On the forestry side; rotation periods, above ground woody biomass accumulation rates (t C/ha/yr) and soil carbon accumulation rates (t C/ha/yr).
- The financial inputs; investment costs, opportunity costs of land and annual maintenance, monitoring and management costs, benefit flows and discount rates.

Using the PRO-COMAP model (Project based Comprehensive Mitigation Analysis Process model) the mitigation potential and the cost effectiveness of the different options was evaluated. PRO-COMAP is a tool developed for comprehensive assessment of different forestry mitigation strategies. The process includes identification and specification of baseline and mitigation scenarios [6]. Outputs of the PRO-COMAP model include mitigation potential and cost-effectiveness parameters. Two different strategies for C sequestration were evaluated, short rotation plantation (Eucalyptus, Acacia mix) and long rotation plantation (Timber species mix).

5 RESULTS

5.1 Energy demand

Based on an assessment of the present and planned activities, the annual electricity demand is projected to rise to approximately by 78 MWh to meet the irrigation demand from the villagers. With a Plant Load Factor (PLF) of 60 %, the bioenergy system can meet both the domestic- and the agricultural electricity demand. At this load, the irrigation pumps can provide 16 hectares of land with water during the dry season. Expanded utilization of the system would also increase the cost effectiveness. The unit cost of electricity declines both for the producer gas system and the diesel system as the number of working hours increase. An increase in the number of average daily working hours to over 5 hours would make the bioenergy system favorable in comparison to an identical-capacity diesel alone system [7].

5.2 Land requirement for biomass production for energy

In order to meet the projected rise in power demand based on an increased biomass supply, the biomass plantation has to be expanded. Approximately 120 ton of wood per year has to be supplied if the system is to generate 78 MWh per year. An additional 16.2 ha degraded land bordering the existing plantation would be needed for this expansion.

5.3 Carbon Mitigation potential

Given the amount of land needed for the production of biomass for the biomass gasifier in the future demand scenario (20 ha), the mitigation potential of the different land-use strategies –biomass for bioenergy or C sequestation via afforestation or reforestation (A/R)– are calculated (see Table I).

Table I: The carbon mitigation potential of the different land use strategies (t C per ha).

	2034	2100
Bioenergy	43	104
Short Rotation	24	24
Long Rotation	53	45

5.4 Baseline scenario

In the baseline scenario no additional plantations are established. The degraded land is used as grazing land with no carbon accumulation. The amount of soil organic carbon has been estimated to be 40.22 t C/ha on the degraded land and no additional C will be sequestered during the period. The opportunity cost of this barren land is assumed to be very low, 5 Rs/ha/yr.

5.5 Bioenergy scenario

The bioenergy plantation is continuously harvested to supply biomass to the gasification system. The biomass and soil carbon pool will stabilize at about 15 t C per ha above the level of the baseline scenario. The C emission reduction benefits from the fossil fuel substitution will keep accumulating. The total mitigation potential of the bioenergy scenario will be 43 t C per ha in 2034 and 104 t C per ha in year 2100.

5.6 Short rotation plantation scenario

The short rotation plantation is harvested with 6 years rotation. The wood product stock, 80% of the AGB harvested, consist of poles with a lifetime of 6 years used largely in construction industry. As a result, all of the poles from the previous harvest will be phased out before the next harvest. The mitigation potential of the project will depend on when in the harvest cycle the project is due to end. The maximum amount of C sequestered per ha will be 23.9 t C both in year 2034 and year 2100.

5.7 Long rotation plantation scenario

The long rotation plantation is harvested with 30 years rotation. The wood product stock, 75% of the AGB harvested, consist of sawn wood with a lifetime of 30 years. The carbon in the sawn wood from one harvest will therefore be lost before the next harvest. Just as in the short rotation scenario the mitigation potential of the project will depend on when the rotation cycle the project is due to end. In this scenario the maximum amount of C sequestered per ha will be 52.7 t C per ha in year 2034 and 45 t per ha year 2100.

6 SOCIAL AND ENVIRONMENTAL BENEFITS

6.1 Social benefits

The social benefits of the project are difficult to monetize. The bioenergy project in Hosahalli has proven to affect the local community in a positive way [8]. The operation, maintenance and monitoring of the system has created employment. Access to clean drinking water has improved the health situation and the irrigation has increased the yields. Electricity for lightning has improved the domestic situation and made it easier for the school children to study.

The project as a whole, involving the local community in the planning, implementation and management of the bioenergy system, have strengthened the society. Disagreements have occurred during the 15 years of operation concerning issues like the sharing of water, forest protection and recovery of fee-for-service. These conflicts have however been resolved by local institutions helping to improve the self-reliance and local control.

If the expansion of the system is carried out in the same manner, positive social side effects are likely to occur, both direct and indirect.

6.2 Environmental benefits

Forest plantations on the degraded land will not only sequester carbon in the soil and standing trees. If managed in a sustainable manner, it will also help improve the local soil and water quality and prevent soil erosion. By reducing pressure on natural forests the plantations indirectly contribute to biodiversity conservation [9]. Mixed species plantations can if planted in appropriate density have direct positive impact on the biodiversity on degraded land.

7 CONCLUSION

This study aimed at comparing the relative attractiveness of two different land-use strategies for climate change mitigation in India. The effectiveness of using land for bioenergy plantation for the substitution of fossil fuels was compared with using land for C sequestration in short or long rotation plantations.

The results indicates that the attractiveness of the different strategies depend to a large extent on the system boundaries. The time horizon of the projects is one such restriction that will affect the comparison. In the 30 yr perspective the unit abatement cost in terms of lifecycle costs will be relatively high for all of the studied options; 918 or 1001 Rs/t C (19 respectively 21 US$/t C) for the biomass for bioenergy option depending or which fuel is being replaced, 1507 Rs/ t C (31 US$/t C) for the long rotation plantation, and 2080 Rs/ t C (43 US$/ t C) for the short rotation plantation. In an earlier study of the cost-effectiveness of forestry activities in India, the unit abatement cost of short- and long rotation forestry has been estimated to 15.0 and 9.9 US$/t C respectively [10]. The small scale of the Hosahalli project makes the expenditures relatively high compared to the potential benefits from C trading. Initiatives like the CDM can, however, provide the incentive needed to make LUCF projects more attractive by providing revenues in the beginning of the project.

In the longer perspective (100 years and onwards), the relative attractiveness of the bioenergy option will increase, and the mitigation potential will exceed that of the long rotation plantation. Climate benefits can be obtained perpetually from a given unit of land, as long as the biomass replaces fossil fuels. Under both short- and long rotations the increase of C in soils and standing biomass ceases as a new equilibrium is reached. Thus, as found also by others (see, e.g., [11]), in the long term using biomass for fossil fuel substitution would be far more effective than sequestering carbon in trees when it comes to stabilizing atmospheric C t [11].

Considering the high level of uncertainty linked to the C sequestration strategies, the relative attractiveness of the bioenergy option is likely to improve. Avoided net C emissions from fossil fuel substitution are permanent, while strategies for C sequestration can lose their benefits through leakage or unintentional re-release through a forest fire or disease.

The level of certainty with which one can report the actual amount of CERs in any project of this kind will depend on the monitoring efforts. The monitoring efforts will on the other hand depend on the homogeneity of the plantation. Less effort is required to reach a given level of certainty in a homogenous plantation compared to a heterogeneous plantation. This leads to a trade off, because a homogenous plantation with one or two species is likely to gain more CERs than a mixed species plantation, while the mixed species plantation is likely to lead to more benefits in the form of soil improvements and biodiversity.

All of the LUCF strategies assessed in this study represent potential CDM activities and would if introduced in a sustainable manner have beneficial environmental, social and economical impacts. The climate benefits of one small-sized project like this are of course negligible on the global level. But considering the facts that there are tens of thousands of villages around India that depend on unreliable power from the centralized electricity grid, –and that a further 15 % of the Indian villages are still not electrified– the potential for bioenergy projects can be considerable. Hosahalli, with its 218 inhabitants, could serve as a representative for the 587000 villages in India with a population of less than 500 [12]. Previous studies have shown that small biomass gasifier-based decentralized power generation systems can meet all of the electricity needs in rural India [13].

Around 60 million ha of the total amount of geographical land in India is classified as degraded land or wasteland, which urgently require revegetation to prevent further degradation. Energy forests and C sequestration could all play an important role in the reclamation of these lands.

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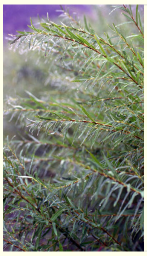
CONTEXT: Studies indicate that Central and Eastern European countries (CEEC) have a substantial biomass production potential and production costs that are much lower than in Western European countries. If this potential becomes realized, CEEC could contribute to EU targets promoting the use of bioenergy and renewable energy sources. The total European domestic biomass potential seems sufficient to meet the proposed demand for biofuels for transport in Europe to 2030. But a competition for the available bioenergy resources is likely to arise. Thus, it is important to discuss where to use the scarce biomass resources for climate change mitigation.



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Cost-effective bioenergy use for climate change mitigation — a model based analysis for Europe

AIM: The purpose of this study –carried out within the EC-funded VIEWLS project– was to analyze the future bioenergy use in the European energy and transport sectors, given different climate change related policies: CO_2 emission reduction targets and transport fuel policies promoting the use of biofuels and other alternative fuels. For the study, a regionalized energy and transport system model was developed. The model is a linearly programmed cost-minimization model, set up to meet exogenously given energy demands while meeting the policy targets at the lowest energy system cost. The main results and insights gained from the analysis is presented below.

In which sector is biomass most cost-effectively used?

In the absence of carbon emission reduction targets and biofuels for transport obligations biofuels can become competitive in the transport sector, as long as there is no competing demand for biomass in stationary applications (i.e., feedstock prices in CEEC stay low: at levels slightly above production costs).

Under a stringent carbon cap regime, biomass demand in stationary applications (primarily heat and other energy use) is the major driver behind the large expansion of bioenergy and no biomass is used for transport.

The introduction of a transport policy induces a redirection of biomass flows from stationary uses to the production of transport fuels (Figure 1), leading to a reduced average carbon dioxide emission reduction per unit of biomass use for energy.

Thus, given ambitious carbon emission reduction targets and a limited biomass supply potential it is more cost-effective to use biomass for power and heat production than using the biomass as feedstock in the production of transport fuels. However, the introduction of biofuels in the transport sector might be interesting under other conditions and for other reasons.

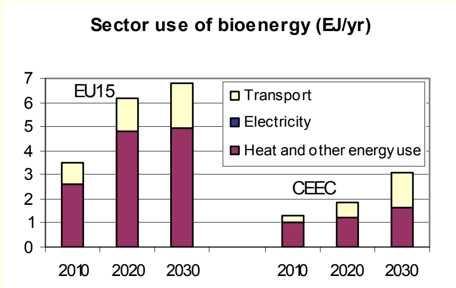

Figure 1: Sector use of bioenergy in CEEC and EU15 in a scenario with stringent carbon abatement targets and policies promoting the use of biofuels and other alternative fuels for transport.

Note that, the biomass use for transport is a response to biofuels for transport obligations.

What is the relative importance of domestic bioenergy demand versus import demand from EU15 for an expanded biomass production for energy in CEEC?

Assuming inter-European biomass trade only, the use of bioenergy in EU15, in particular biofuels for transport, clearly stimulates biomass production in CEEC. However, in scenarios where there are stringent caps on carbon dioxide emissions, it is the domestic use of biomass in stationary applications (mainly heat), and also for the production of transport fuels, that is the major driver behind increased biomass production for energy in CEEC (Figure 2).

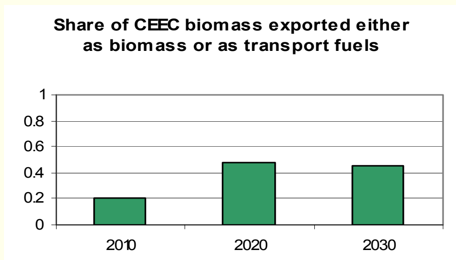

Figure 2: Share of domestically produced biomass in CEEC that is exported, either as biomass or as biofuels for transport, in a scenario with stringent carbon abatement targets and policies promoting the use of biofuels and other alternative fuels for transport.

More information: www.viewls.org

Lennart Edvardsson, Grästorp, Sweden. Farmer growing Salix for energy purpose. Should this biomass be used for heat production or as biofuels for transport? Photo: Maria Grahn, 2002.

INTRODUCTION: 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. However, biomass will 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 stringent carbon constraints has been analyzed. Azar *et al.* find that it is more cost-effective to substitute biomass for fossil fuels in power and heat production, whereas Gielen *et al.* 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.

Salix plantation in Grästorp, Sweden. Should this biomass be used for heat production or as biofuels for transport? Photo: Maria Grahn, 2002.

Biomass for heat or as transportation fuel? A comparison between two model based studies

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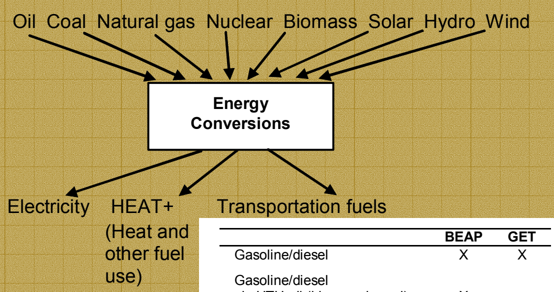
The basic flow chart of supply and fuel choices in both energy system models.



	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

BIOMASS USE IN THE TWO MODELS

Both studies base their results on models developed especially for the given studies. Gielen *et al.* have develop-ed the BEAP model and Azar *et al.* the GET model. Both models are run under ambitious CO_2 constraints, roughly corresponding to an atmospheric carbon dioxide concentration target at 400 ppm by the year 2100.

In both models there is a steady increase in total biomass use, but the use of the biomass differs between the two models, see Figure 1.

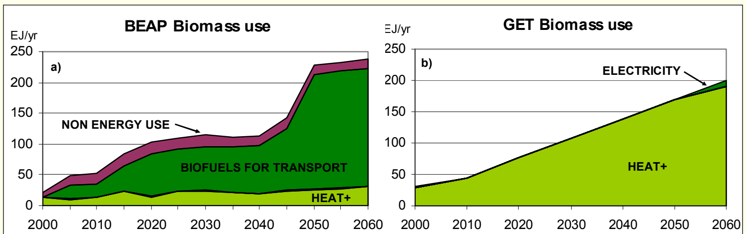


Figure 1: Biomass use as presented in a) the BEAP paper and in b) the GET paper. In the BEAP model the largest share of biomass is used for the production of fuels for transport but in the GET model the largest share of the biomass is used for HEAT+ production (stationary energy use that neither aims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

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.

EXPLAINING THE RESULTS

We run the BEAP model with fixed CO_2 taxes in the range 0-300 USD/tC in steps of 25 USD/tC. For year 2020 it is shown that no biofuels are produced but 30 EJ of biomass is used for heat production 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, see Figure 2.

For higher taxes, biofuels increase rapidly at the expense of biomass for heat. Since the yearly biomass supply potential is limited, biomass based heat production decreases when the use of biofuels increase. In the BEAP reference scenario, the carbon tax has reached 300 USD/tC by the year 2020 and at that tax, most of the biomass is used for the production of biofuels.

Since Gielen *et al.* ran their model with high carbon 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.

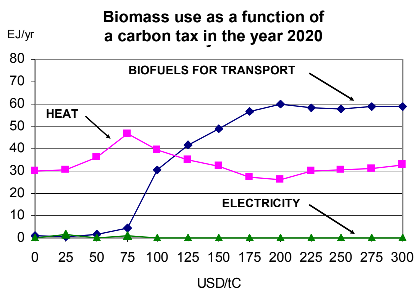


Figure 2: The biomass use (primary energy) in the BEAP model for various CO_2 taxes. The taxes have been fixed during each run and the figure includes 13 runs.

CONCLUSION:

Biomass is most cost-effectively used for heat production when the carbon tax is low (below 75 USD/tC for year 2020).

Since it still is an open question if CO_2-neutral hydrogen/electricity will be available in the transportation sector, at reasonable costs, it is too early to state the most cost-effective use of biomass for higher carbon taxes.

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Carbon sequestration versus bioenergy: A case study from South India exploring the relative land use efficiency of two options for climate change mitigation

The aim of the study has been to compare the relative attractiveness of two different land-use strategies for climate change mitigation within the context of a village bio-electricity project in Hosahalli in South India. The options being:

- using land for biomass production for the substitution of fossil fuels (bioenergy option), or
- using land for C sequestration, via reforestation or afforestation, and meet the increasing power demand by using more fossil fuels in the system (C sink option).

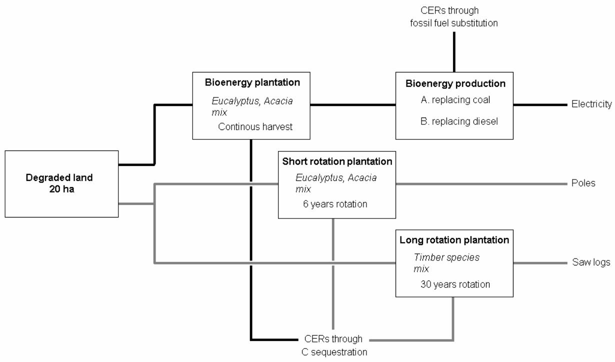


Illustration of the different land use strategies; Bioenergy plantation for bioenergy production and short and long rotation plantation for C sequestration

In the village of Hosahalli, Tumkur district, Karnataka state in southern India, a biomass driven energy system has been under operation since 1988 . The system is based on a standard diesel engine generator system. The fuel is, however, provided through a biomass gasifier. A plot of 4 ha, about 1 km from the village, planted with fast growing tree species provides the biomass needed. This system has the potential of reducing the consumption of fossil fuels by a long-term average of 75 percent. The system generates electricity for lighting, irrigation, drinking water and services such as the milling of grains.

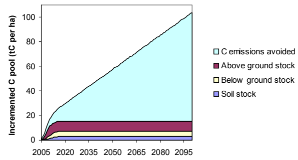
Several aspects were taken into account. The system need to fulfill the demands for climate change mitigation and simultaneously meet the needs of the villagers:

- reliable electricity supply,
- reduction of GHG emission,
- cost effectiveness
- and rural development in general.

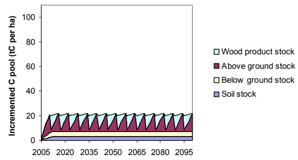
Our assessment show that all of the strategies have the potential to contribute to the development of the local society, socially as well as economically.

the competitive rank of the different strategies depend, to a large extent, on the system boundaries. The time horizon of the projects is one such restriction that will affect the comparison.

Incremented C pool in the bioenergy scenario (t C / ha). The C pools in the bioenergy plantation will stabilize while the fossil fuel substitution will lead to continuous C emission reduction.



Incremented C pool in the short rotation scenario (t C / ha). The total C pool vary over the rotation cycle due to variation in the above ground biomass stock.



Incremented C pool in the long rotation scenario (t C / ha). The total C pool vary over the rotation cycle due to variation in the above ground biomass stock.