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Prospects for alternative energy carriers based on biomass sources in EU-15 up to 2050

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ABSTRACT

In this paper we conduct the analysis of economic and ecological aspects of alternative energy carriers based on biomass sources. These sources encompass short rotation copies, forest wood residue, wood industry residues, waste wood as well as energy crops. In 2010 the energy output from all these biomass-based alternative energy carriers was about 4000 PJ in the EU-15. We show which energy output from these energy carriers can be expected by 2050 under the following conditions: (i) with and without a CO_2-based tax, (ii) with and without additional use of arable land. We also consider different priorities for hydrogen and biofuels.
Major conclusion is that even in the most promising scenario total energy quantity from biomass-based resources of about 10500 PJ can be produced by 2050, which equals to about 16% of the total final energy consumption in EU-15 in 2008 (about 65000 PJ).

Keywords: biomass, biofuels, alternative energy carriers, costs, scenarios, energy output

INTRODUCTION

The current energy supply is mainly relying on fossil fuels. Alternative energy carriers, based on renewable, CO_2-poor or -free energy sources, are of central importance for the future sustainability of our energy system. The most important alternative energy carriers used nowadays are electricity from renewable energy sources, wood products (fuel wood, pellets…) and 1st generation biofuels. The use of biofuels in transport sector is continuously increasing and forced by policy. In the EU the goal is to have 10% of biofuels in transport by 2020. Although, conventional biofuels are already mature, they are not able to solve the existing problems in transport, such as increasing energy import dependency or increasing GHG emissions. At the same time, using these biofuels some new problems have appeared. Currently, the most discussed problems are sustainability of biofuels and competition with food production. Some of these problems could be solved with the 2nd generation biofuels. These, advanced biofuels could be produced from wood residues from industry and other lignocellulose feedstocks (e.g. woody and herbaceous plants such as perennial grasses and fast growing tree species). Advanced biofuels have also higher energy yields and higher GHG reduction potential. The only problem is that these biofuels are still in the developing stage and may become commercially available only in the next 10 to 20 years [1].
In this paper we conduct the analysis of economic and ecological aspects of biomass-based alternative energy carriers (BBAEC). The sources for BBAEC encompass short rotation copies, forest wood residue, wood industry residues, waste wood, as well as energy crops. The core objective of this paper is to analyze whether and under which circumstances, to which extent and when BBAEC could be more economically important in EU-15 by 2050 (inclusive external costs). Of special interest are the energetic potentials of BBAEC in a

dynamic context. Furthermore, their costs and environmental aspects are analysed considering technical progress (mainly with respect to conversion efficiency) and technological learning. Special focus is put on BBACE which can be used in transport - 1st and 2nd generation biofuels, electricity and hydrogen from biomass.

METHOD OF APPROACH

For all considered BBAEC a dynamic ecological assessment is conducted up to 2050. The calculation of greenhouse gas (GHG) emissions and primary energy demand is based on the method of Life Cycle Assessment (LCA). The environmental impacts are calculated along the supply chain of a product or service: from extraction of raw materials for its production through its use to its disposal (from cradle to grave), for more detail see [2]. Our dynamic economic assessment is based on technological learning. We have considered different technologies regarding technological learning which is expected to be of relevance for future cost decreases of the analysed BBAEC. Detailed costs calculations are given below for biofuels, as well as our considerations regarding technological learning.

Biofuels costs are dependent on many factors, such as feedstock price, conversion costs, and different promotion policies, but the largest impact on the biofuels costs have feedstock costs, which are currently very volatile and they differ depending on the type of crop used, harvesting technologies, and agricultural subsidies for crops and regions. Besides feedstock costs the scale of the conversion factor (feedstock quantity used per ton biofuels) has a considerable impact on biofuels production costs. We consider three major cost components[1] to calculate total specific biofuels production costs (C_{BF}) for year t (see also [3]):

$$C_{BF} = C_{FS} + C_{CONV} + C_{DR} \qquad \text{[EUR/kWh BF]} \qquad (1)$$

C_{FS}....... .Net feedstock costs
C_{CONV}.....Gross conversion costs
C_{DR}....... Distribution and retail costs

Net feedstock costs C_{FS} are calculated for every year[2] as:

$$C_{FS} = \frac{(P_{FS} * Q_{FS} * f_{TC} - R_{FS\_by-product})}{LHV}) \qquad \text{[EUR/kWh FS]} \qquad (2)$$

P_{FS}.......................Feedstock market price [EUR/ton FS]
Q_{FS}.................... .Feedstock quantity used per ton biofuels [ton FS/ton BF]
$R_{FS\_by-product}$.........Revenues for feedstock-by-product (e.g. rapeseed-cake) [EUR/ton BF]
f_{TC} ....Factor for considering transaction costs
LHV.....................Lower heat value of feedstock [kWh FS/ ton FS]

The gross conversion costs C_{CONV} for converting feedstock into biofuels are calculated as:

$$C_{CONV} = CC + C_{LABOUR} + C_{INP} + C_{OM} - R_{BF\_by-product} \qquad \text{[EUR/kWh BF]} \qquad (3)$$

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[1] However, it has to be noted that taxation respectively tax exemption on (bio) fuels are not included in specific biofuel production costs.
[2] We considered feedstock price increases (2% per year), for detail see [2].

CC…………. Capital costs per year [EUR/year]
C_{LABOUR}……...Labour costs
C_{INP} ………....Input costs (chemicals, energy, water…)
C_{OM}…………Costs for maintenance and insurance
$R_{BF\_by\text{-}product}$….Revenues from biofuel production by-products (e.g. glycerine or DDGS)

Capital costs depend on specific investment costs IC and capital recovery factor (CRF). Specific investment costs are calculated as a sum of national (IC_{Nat}) and international (IC_{Int}) investments costs. It is assumed that 60% of the investment costs are same in all regions and 40% of investment costs are dependent on countries' or regions' specific circumstances.
Annual capital costs are calculated as:

$$CC = \frac{(IC_{Int} + IC_{Nat}) \cdot CRF}{P \cdot T} \qquad \text{[EUR/kWh BF]} \qquad (4)$$

IC……...Investment costs [€]
CRF…...Capital recovery factor
P………Capacity [kW]
T………Full load hours [h/yr]

Revenues from by-products (i.e. the sales value of rapeseed-cakes, electricity, glycerine, animal feeds etc.) of biofuels play a minor role regarding the overall biofuels costs. However, the way in which by-products are used has a significant impact on total greenhouse gas emissions. The role of by-products could be even lower in the future due to oversupply. For example, demand for glycerine is currently limited for a number of food, beverage, personal care and oral products, as well as pharmaceutical and other industrial uses. With the increasing biodiesel production it will be necessary to create additional markets for the glycerine.
Future biofuels production costs or at least capital costs could be reduced through technological learning. Technological learning is illustrated for many technologies by so-called experience or learning curves. The effects of technological learning play a major role for the dynamic of economics. For an in-depth analysis on technological learning see [2].
As usual, to express an experience curve for investment costs we used the following exponential regression:

$$IC_t(x) = a \cdot x_t^{-b} \qquad (5)$$

$IC_t(x)$……..Specific investment cost (€/kW)
x_t …………Cumulative capacity up to year t (kW)
b ………….Learning index
a ………….Specific investment cost of the first unit (€/kW)

Finally, in order to be able to evaluate the long-term perspectives of BBAEC three major influence parameters are considered in scenarios: (i) possible developments of the energy price level and the energy demand; (ii) global developments (particularly regarding learning effects); (iii) environment and energy policies at EU level.

ECOLOGICAL ASSESSMENT

In the following figures GHG emissions of different BBAEC are shown compared to fossil fuels. All analysed BBAEC reduce WTW - GHG emissions compared to fossil reference systems, but there are considerable differences between the BBAEC.

The alternative energy carriers based on biomass have mostly negative WTT-GHG emissions, due to the uptake of CO_2 during photosynthesis accounted as negative CO_2-emissions (called CO_2-fixation), see Fig. 1. Negative WTT-GHG emissions are also related to non-energy co-products of the BBAEC which substitute conventional products and thus avoid related GHG emissions. Another contribution to WTT-GHG emissions are processes providing auxiliary energy and materials in the biofuels production facilities.

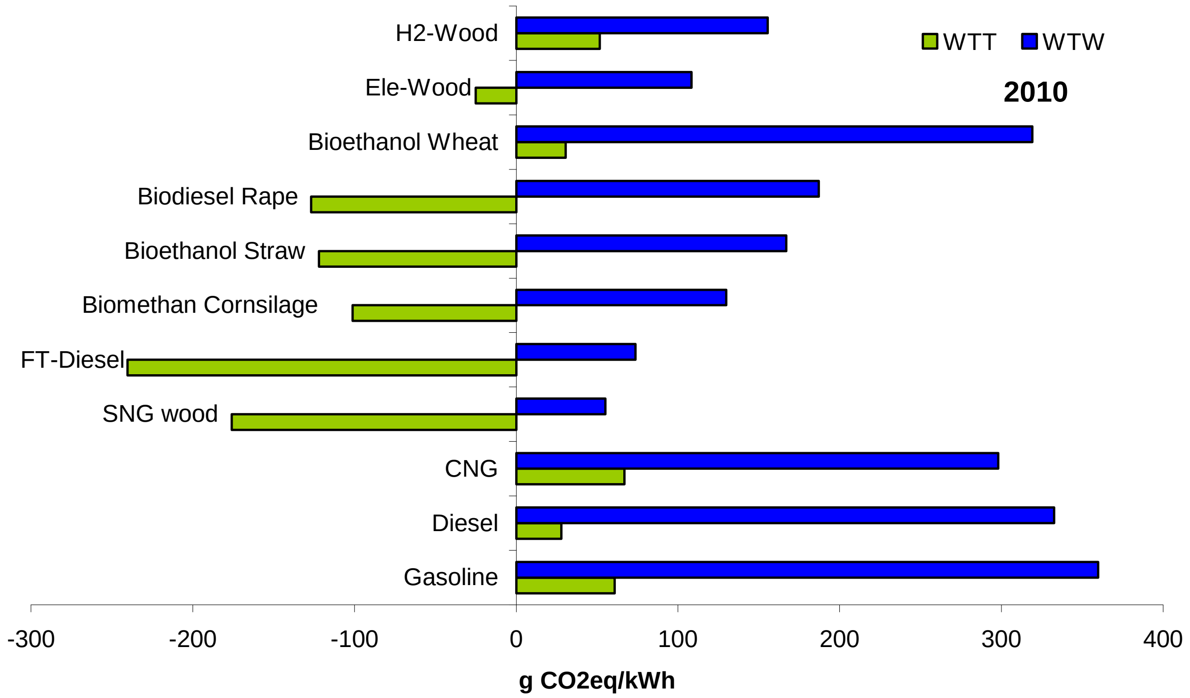

Figure 1. Life cycle WTT GHG emissions of BBAEC in comparison to fossil fuels vs. WTW emissions of transport service in 2010 [2]

Relatively high WTT-GHG emissions for BF-1 (bioethanol production from wheat) are mainly due to the electricity and process heat required in the ethanol plant and its distillation unit. TTW-GHG emissions include the emissions for production, operation and disposal of the passenger cars. Alternative fuels based on wood (FT-Diesel, SNG) have the lowest WTW-GHG emissions compared to the other biofuels. These systems require relatively low energy and material input for collection of the wood as well as for the biofuel production plants and its gasification units [2].

WTW-GHG emissions for 2050 are lower than for 2010 for all BBAEC-systems, see Fig. 2. Biomass and biofuel production processes, as well as the passenger cars, are assumed to be more efficient by 2050.

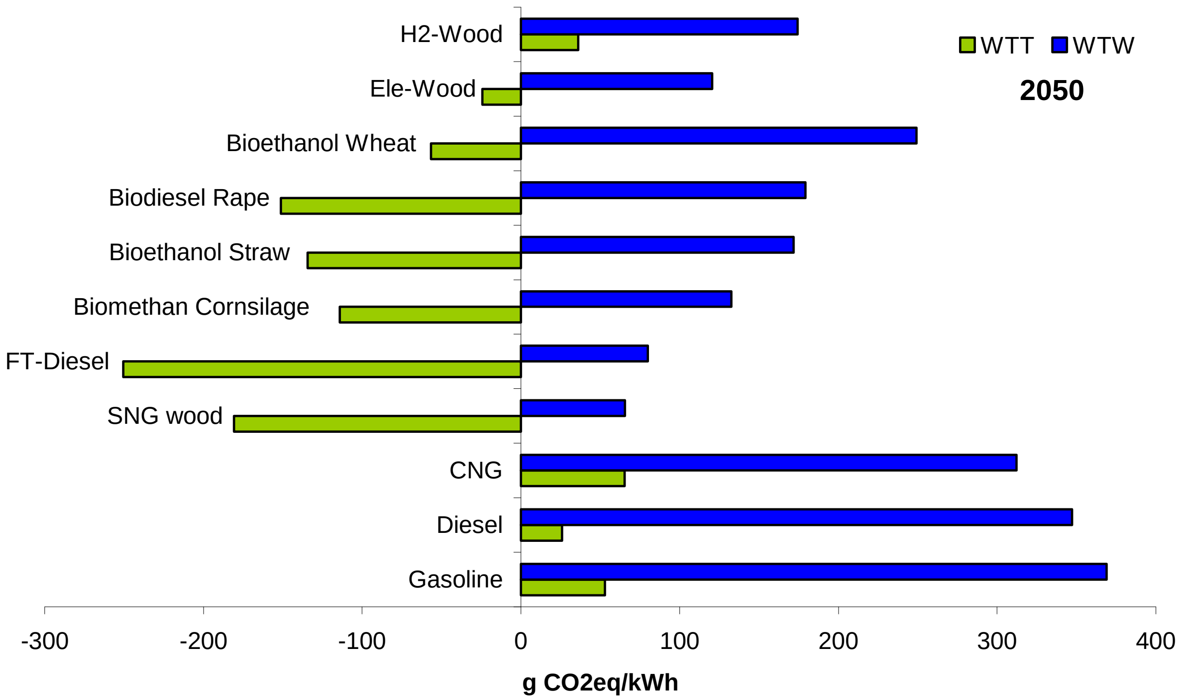

Figure 2. Life cycle WTT GHG emissions of BBAEC in comparison to fossil fuels vs. WTW emissions of transport service in 2050 [2]

ECONOMIC ASSESSMENT

To what extent the available biomass resources will be used for BBAEC depends mainly on their economic performance and on policy interferences. This may also affect the aspect which BBAEC will be produced. In the following a comparative dynamic analysis of the economic performance of BBAEC in comparison with fossil fuels is provided. This comparison is based on the assumptions for the future price development of fossil fuels done by IEA [4, 5].

Future competitiveness of BBAEC on the market is very dependent on implemented policy measures. Currently some BBAEC could be competitive with conventional fossil fuels (incl. excise tax) only due to tax reduction or exemptions. However, a justified tax system based on WTW CO_2 emissions of BBAEC could enable earlier market entrance for BBAEC with better CO_2 balanced such as e.g. electricity and hydrogen from biomass or 2nd generation biofuels.

An introduction of CO_2 based tax an all energy carriers is considered in this paper. The suggested tax system is as follows: The highest excise tax in 2010 – which was on gasoline – is converted in a CO_2 tax of the same magnitude. For all other fuels including diesel and CNG this tax is set relative to their WTW- CO_2 emissions compared to gasoline. The implementation of this tax starts in 2013 and is increasing by 0.015 EUR per kg CO_2 per year up to 2050. In this way BBAEC with lower CO_2 balances will have lower tax levels in the future.

The development of costs of various BBAEC in comparison to conventional fuels including all taxes up to 2050 is depicted in Fig. 3. As it can be seen, the fuels with the lowest WTW CO_2 emissions - electricity and hydrogen from biomass, biodiesel (BD-2) and SNG – are the cheapest ones by 2050. With CO_2 tax BBAEC could become competitive with fossil fuels starting from 2020. With no switch to a CO_2 based tax system BBAEC would become competitive with conventional fuels about ten years latter than in Fig.3.

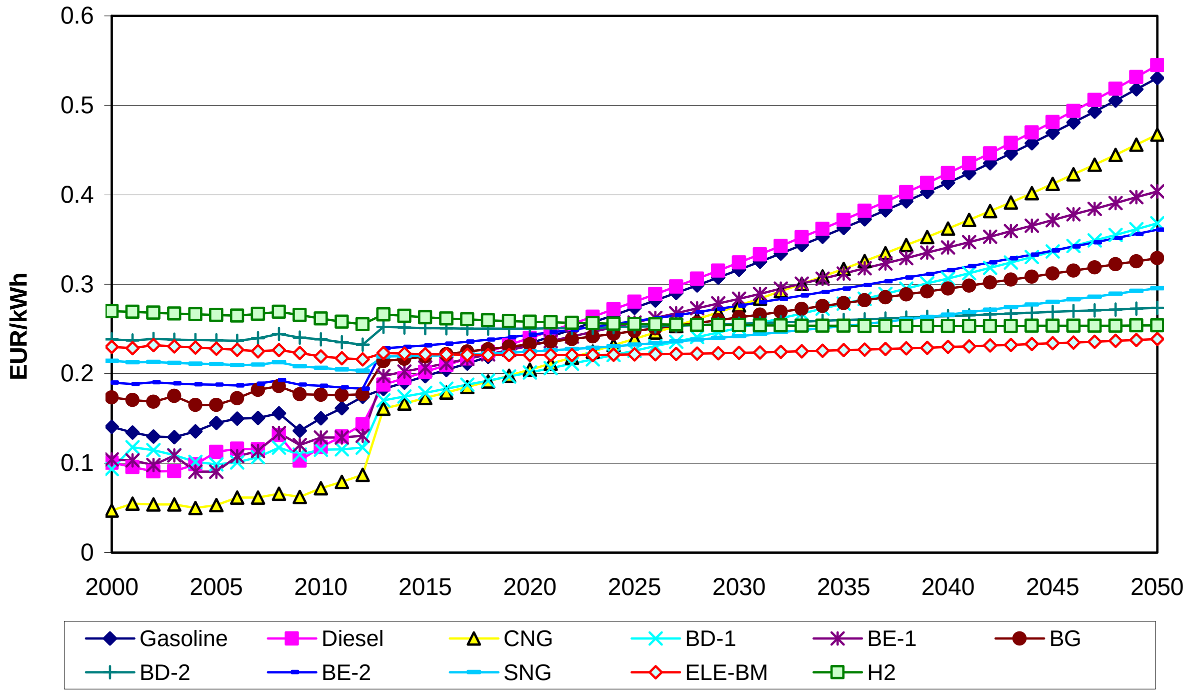

Figure 3. Development of costs of various BBAEC in comparison to conventional fuels including taxes up to 2050

Fig. 4 depicts the costs of BBAEC versus fossil fuels (inclusive and exclusive taxes) in 2010 and 2050. We can see that due to the introduction of a CO_2 based tax – as described above – the economic attractiveness of all biofuels fractions increases.

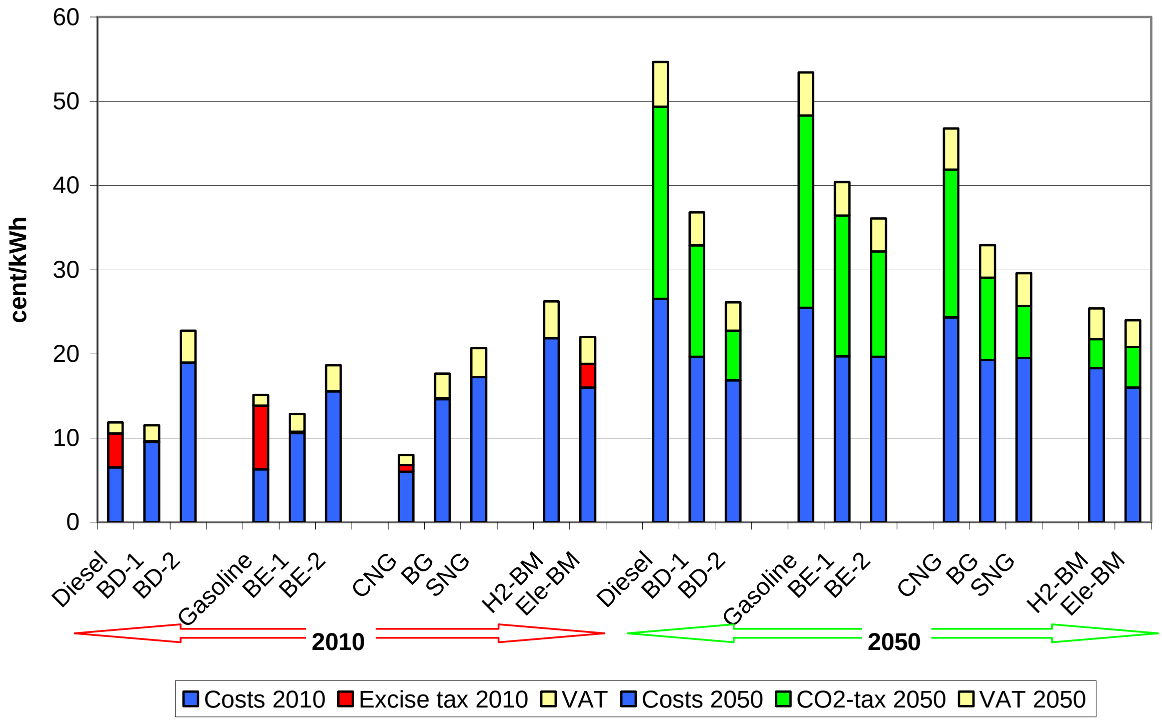

Figure 4. Cost of BBAEC vs. fossil fuels incl. and excl. taxes in 2010 and 2050

SCENARIOS FOR BBAEC

In order to provide a sound assessment of the future prospects of BBAEC based on biomass sources, we derived scenarios up to 2050 to show under which circumstances, to which extent and when specific BBAEC could become economically competitive. As shown in Fig. 3 after 2020 BBAEC start to become increasingly competitive. Most important is to identify which BBAEC can achieve a critical mass and relevant potential. Our major scenario is a "Policy Lead Scenario" (PLS) which corresponds to the assumptions of international deployments of biofuels and hydrogen according to IEA [4, 6, 7]. In this scenario priority is given to the production of liquid biofuels over electricity.
Based on the PLS further scenarios are derived: with and without a CO_2-based tax; with and without additional arable land (max: 30% use of arable land). We also consider different priorities for biofuels and hydrogen. From these analyses it is derived which market diffusion of the BBAEC is to be expected in a dynamic context and which BBAEC have a special relevance in EU-15 in the long-term. We present the results of the corresponding quantities of BBAEC that can be possibly produced in EU-15 till 2050. A major focus is put on BBAEC which can be used in transport sector. However, an increasing use of biomass in the future could raise two issues: (i) the use of biomass requires large amounts of land which otherwise could be used for other purposes (e.g. food production); (ii) increasing biomass production might be in contradiction with sustainability issues.

In the following the major results of these scenarios are depicted. Fig. 5 depicts the energy production in PLS scenario. Major characteristics of this scenario are additional use of arable land for BBAEC (with max. 30% arable land in 2010), CO_2 based tax starting from 2013 and priority for biofuels production. As it can be seen in this scenario by 2050 about 6000 PJ of BBAEC will be produced. This is about six times more than in 2010. After 2023, due to technology maturity, a significant share of the 2nd generation bioethanol can be noticed. The share of 2nd generation biodiesel is increasing starting from 2030. In this scenario with biofuels priority SNG provide significant contribution to energy production starting from 2017. Yet, this takes place only if BTL-, FT-Diesel-, SNG- technologies become mature and if significant learning effects are achieved. Due to better energetic and economic performance of BD-2 it also substitutes BE-2 production after 2040. However, it must be noticed that energetic as well as economic developments of the different categories of BF-2 are not known in detail today. Due to these uncertainties other fractions of BF-2 could also "win". What can be stated today is that – given that the economic performance of any BF-2 leads to cost-effectiveness under the suggested CO_2-tax policy – there is a significant potential for BF-2 after 2030 regardless which one will succeed. Due to the priority for biofuels in this scenario electricity will be produced only from those feedstocks which are not usable for biofuels production such as waste wood.

The major reasons why in Fig. 5 BD-2 and SNG reach so high amounts are:

- they have highest energy efficiency and hence lowest feedstock costs;
- they have lowest CO_2-emissions and hence lowest CO_2-taxes.

In Fig. 5 energy output of BBAEC which can be used in transport sector is shown. Additionally, Fig. 6 shows total energy output of alternative energy carriers from biomass in EU-15 including also wood products such as pellets, fuel wood and wood chips. In 2050 these energy carriers could contribute to about 45% of the total energy from BBAEC.

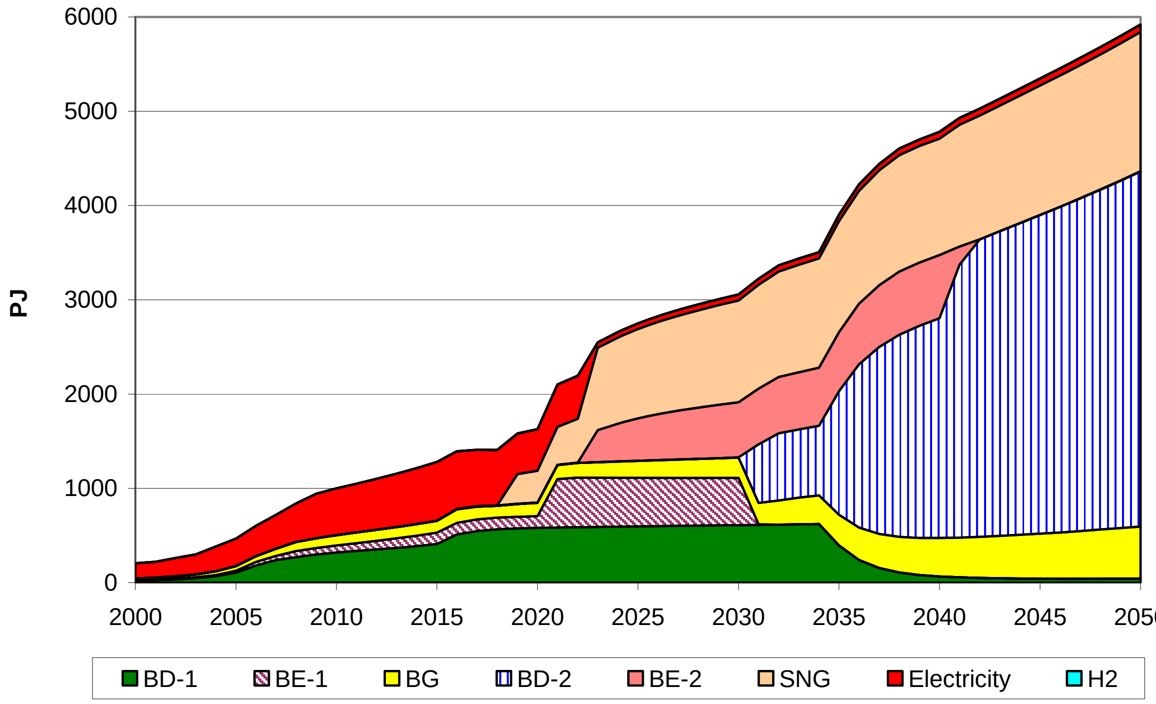

Figure 5. Energy production (final energy) in the Policy Lead Scenario (with max. 30% arable land in 2010, with CO_2 tax, and with priority for biofuels)

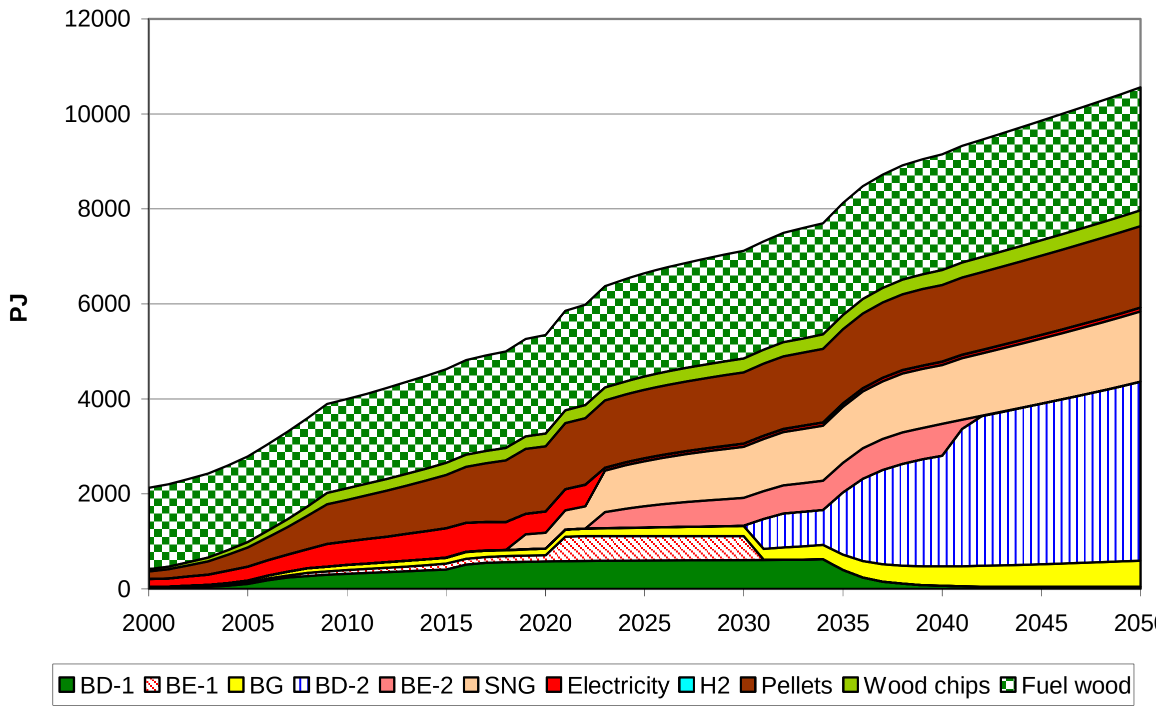

Figure 6. Total energy from alternative energy carriers from biomass only in PLS

Fig. 7 depicts energy from alternative energy carriers from all biomass resources by type of feedstock. In this figure most impressing is that the share of corn stover for 2nd generation biofuels increases considerably after 2035.

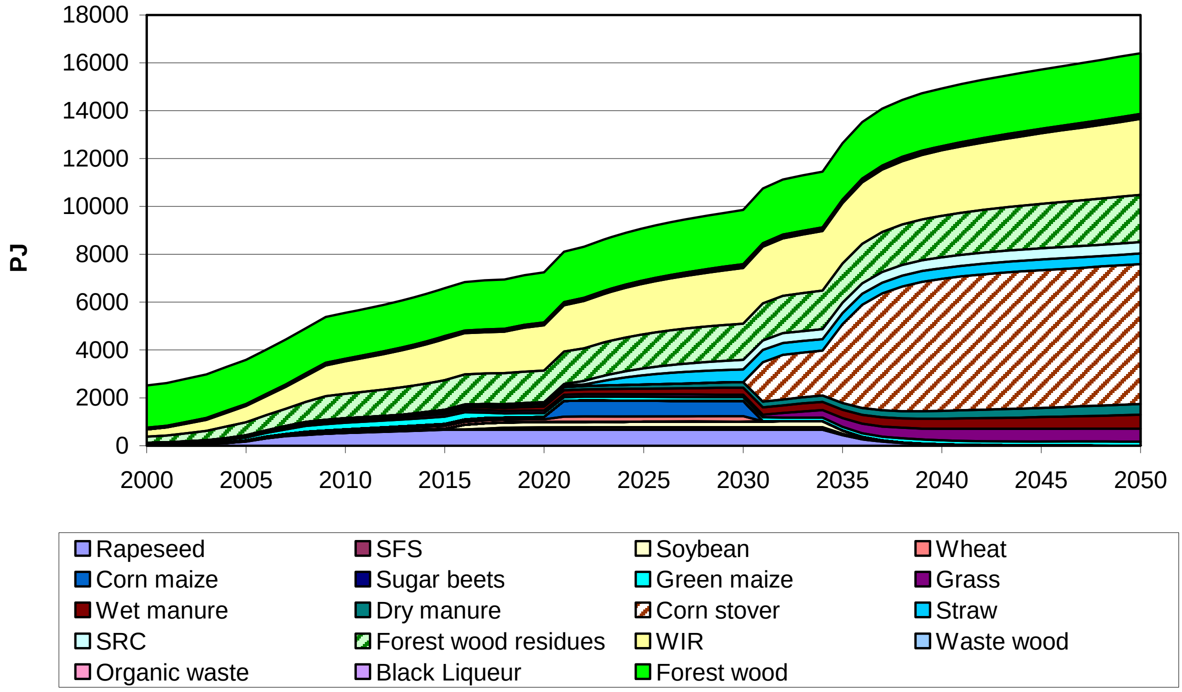

Figure 7. Energy from alternative energy carriers from all biomass resources by type of feedstock, 2000-2050

Next we look at policy scenario without use of additional arable land up to 2050. Fig. 8 depicts the corresponding energy production in the scenario with CO_2 tax, priority for biofuels but *without* use of additional arable land. We can see that in this case the overall potential level is much lower – about 3000 PJ less than in the PLS.

The comparison of the results of all investigated scenarios is presented in Fig. 9. These figure shows energy outputs of different scenarios in 2050 in comparison with energy output in 2010. The major perceptions of this figure are: (i) Scenarios without the use of arable land show overall outputs which are for about 3000 PJ lower; (ii) Scenarios with biofuels priority have slightly better performance regarding overall energy output than those with no priority or with priority for hydrogen. The reason for that is mainly because biofuels 2nd generation (mainly FT-Diesel and SNG) have a better energetic conversion efficiency than other BBAEC; (iii) In the scenarios with no priority electricity has higher shares mainly due to the lower cost and more mature technology.

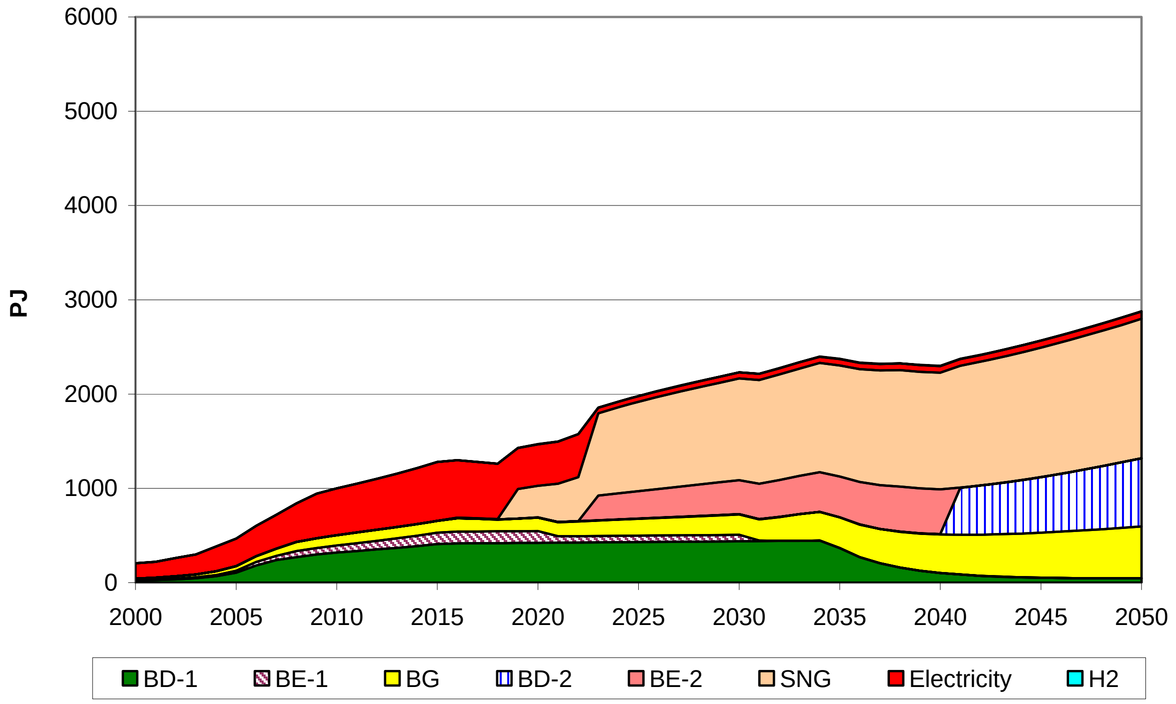

Figure 8. Energy production in the scenario without additional arable land (with CO_2 tax and with priority for biofuels)

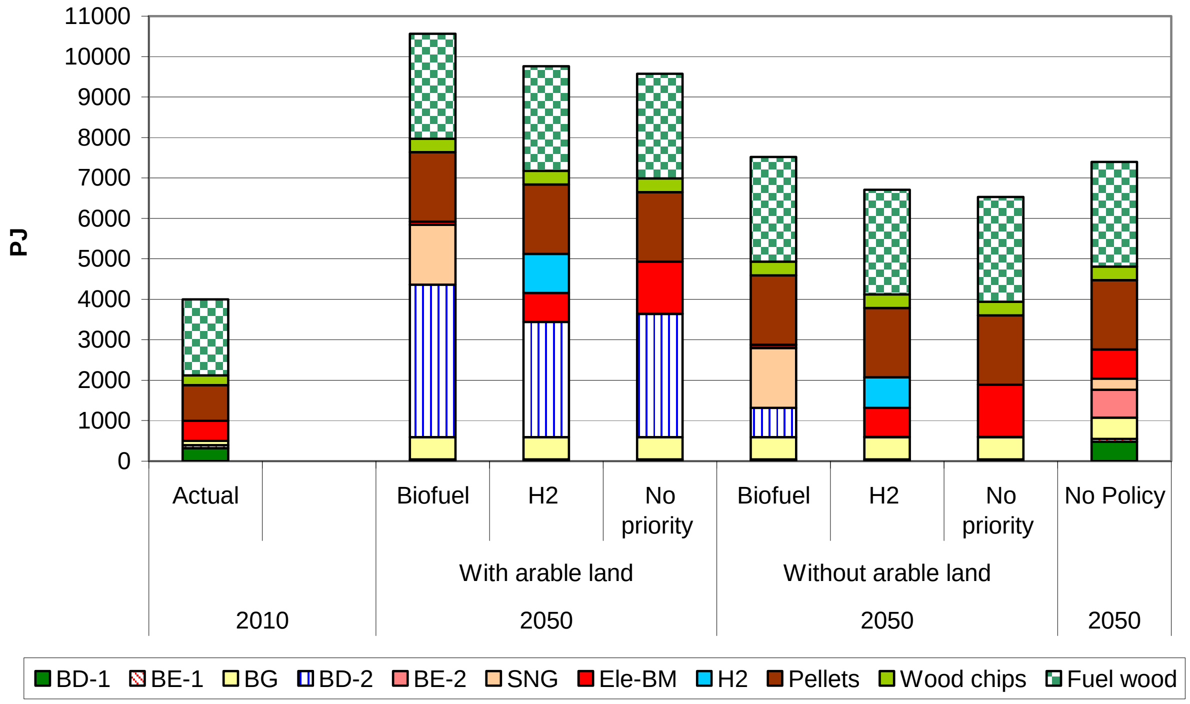

Figure 9. Energy outputs of different scenarios in 2050 from BBAEC in comparison to 2010

CONCLUSIONS

The major conclusions of this analysis are:

- While the economic prospects for the 1st generation biofuels are rather promising – cost-effectiveness under current tax policies exists already – their potentials are very restricted especially due to limited crops areas. Moreover, the environmental performance of 1st generation biofuels is currently rather modest; Up to 2050 the ecological and energetic life-cycle performance of BF-1 may slightly improve but this aspect has to be forced by policy, e.g. by means of introducing monitoring and certification shemes. However, 1st generation biofuels will remain in the market at least until 2030 due to the lower costs in comparison to 2nd generation biofuels;

- 2nd generation biofuels will – in a favourable case given that mature technologies emerges – enter the market between 2020 and 2030. However, their full potentials will be achieved only after 2030. The major advantage of the 2nd generation biofuels is that they can be produced also from resources such as lignocellulose based wood residues, waste wood or short-rotation copies, which are not dependent on food production-sensitive crop areas. From the ecological and energetic life-cycle performance BF-2 can bring about a significant improvement;

- Hydrogen will not become competitive before 2050 and currently no reliable maximum future potentials can be estimated reliably;

The final major conclusion is that only if the portfolio of actions, such as CO_2 tax, ecological monitoring system for biofuels, and a focussed R&D programme for BF-2 and fuel cells, is implemented in a tuned mix it will be possible to exploit the potential of BBAEC up to 2050 in EU-15 in an optimal way for society.

NOMENCLATURE

BBAEC – Biomass-based alternative energy carriers
BTL – Biomass to liquid
BD-1 – 1st generation biodiesel
BD-2 – 2nd generation biodiesel
BE-1 – 1st generation bioethanol
BE-2 – 2nd generation bioethanol
BF – Biofuels
BF-1 – Biofuels 1st generation
BF-2 – Biofuels 2nd generation
BG – Biogas (upgraded biogas – biomethane)
CNG – Compressed natural gas
DDGS - Distillers dried grain with solubles
ELE-BM - Electricity from biomass
FS – Feedstock

FT-Diesel – Fischer-Tropsch Diesel
GHG – Greenhouse gas
H2 – Hydrogen
H2-BM – Hydrogen from biomass
LCA – Life cycle assessment
PLS – Policy lead scenario
SNG – Synthetic natural gas
SFS – Sunflower seed
SRC – Short rotation coppice
TTW – Tank-to-wheel
VAT - Value added tax
WRI – Wood residues from industry
WTT – Well-to-tank
WTW - Well-to-wheel

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