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Cost efficient utilisation of biomass in the German energy system in the context of energy and environmental policies

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ABSTRACT

The possible uses of biomass for energy provision are manifold. Gaseous, liquid and solid bioenergy carriers can be alternatively converted into heat, power or transport fuel. The contribution of the different utilisation pathways to environmental political targets for greenhouse gas (GHG) emission reduction and energy political targets for the future share of renewable energy vary accordingly to their techno-economic characteristics. The aim of the presented study is to assess the different biomass options against the background of energy and environmental political targets based on a system analytical approach for the future German energy sector. The results show that heat generation and to a lower extent combined heat and power (CHP) production from solid biomass like wood and straw are the most cost effective ways to contribute to the emission reduction targets. The use of energy crops in fermentation biogas plants (maize) and for production of 1st generation transportation fuels, like biodiesel from rapeseed and ethanol from grain or sugar beet, are less favourable. Optimisation potentials lie in a switch to the production of 2nd generation biofuels and the enhanced use of either biomass residues or low production intensive energy crops.

1. Introduction

Environmental and energy policy in Germany are closely linked to each other. Current measures for reduction of GHG emissions, e.g. CO_2 certification and cap, are flanked by legislative activities for an enhanced implementation of renewable energy technologies, e.g. renewable energy law (EEG, 2008), biofuel quota (BioKraftQuG, 2006) and renewable heat law (EEWärmeG, 2008) as well as additional public incentive programs with partial payments of investments and low interest loans like the market incentive program (MAP, 2009).

At the end of 2007 the German government updated targets regarding the share of renewable energy in total energy consumption for the year 2020 (GOV, 2007). Accordingly, the share of power from renewable energy in total power provision is aimed to be 30%, consumption of renewable heat 14% and production of transport fuels 17%. The German government committed itself to a GHG emissions reduction of 40% in the year 2020 in comparison to emissions in 1990 (UBA, 2007).

Currently the utilisation of biomass plays a major role to meet environmental and energy political targets in Germany. Biomass is the most important renewable energy carrier and contributes to 68.9% to total renewable final energy consumption in the year 2008 (BMU, 2009) due to high shares in transport fuel (100%) and heat production (93.5%) and medium shares in power production (29.2%). Bioenergy offers a multitude of options with respect to different kinds of biomass (solid, gaseous, liquid), conversion technologies and processes (thermal, thermo-chemical, physico-chemical, bio-chemical) and alternative final energy carriers, e.g. heat, power, transport fuel (Kaltschmitt et al., 2009). Different utilisation options for biomass are associated with different specific GHG emissions and specific production costs as well as varying potentials for emission reduction and substitution of fossil fuels (König, 2009; König and Jenssen, 2010). Thus a concentration of incentive programs, legislative measures and activities on cost effective ways for GHG reduction and for an increase of the share of renewable energy and biomass seems reasonable.

With respect to the techno-economic characteristics of the conversion technologies, to the limited biomass potentials and limited agricultural area for energy crop production the following questions have to be answered for the prospective energetic utilisation of biomass in the German energy system:

- Which bioenergy options are preferable for a cost efficient contribution to the energy and environment political targets when competition amongst different bioenergy options, competition with other renewables (e.g. wind, solar, geo-thermal) as well as with conventional options are considered?
- What are the effects of legislative measures and incentive programs for renewable energy production on the biomass utilisation in the energy system?
- Which GHG reduction can be achieved by implementing cost efficient biomass technologies into the energy system?

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Table 1
Examined raw materials for the energetic use of biomass (Veenendaal et al., 1997; Kaltschmitt et al., 2009).

Energy crops	Waste	By-products and residues
Rapeseed	Manure	Grain straw
Sugar beet	Used wood	Industrial wood residues
Maize	Sewage sludge	Forestry residues
Triticale (grain and whole plant)	Landfill gas	Household fuel wood
Short rotation coppice (SRC, poplar)	Organic waste	

Nitsch et al. give an outlook on a possible future development of the renewable energy untilisation till 2050 in Germany within different scenarios (Nitsch et al., 2004; Nitsch, 2008). The results show relatively high shares of biomass in heat generation and transport fuel production in the year 2030. In contrast to that power production from biomass plays a comparably minor role. Since the focus of the studies is set on the possible development of all forms of renewable energy (wind, water, solar, biomass, geothermal) with regard to effects on climate protection and contribution to GHG reduction targets the analysis does not regard the aspect of a (highly) cost efficient use of biomass.

The German Advisory Council on the Environment (SRU) analyses the potentials of the biomass use for climate protection targets (SRU, 2007) and states that biomass rather has to be used for stationary power and heat generation than for biofuel production in order to contribute effectively to emission reduction. The SRU also draws the conclusion that the current system of incentive programs has to be rethought especially with regard to the rather inefficient use of biomass for biofuel production.

Against this background, the aim of the presented study is to assess competing energy utilisation pathways for biomass based on a system analytic approach with regard to energy and environmental policies as well as cost efficiency aspects to identify promising options for the future development of bioenergy in Germany's energy system up to the year 2030.

2. Scope and methodology

The study covers a selection of current and prospective important kinds of biomass and conversion technologies for the German energy system. Technologies currently available on the market as well as innovative processes and technologies are examined. The methodological approach is a model based scenario analysis under special consideration of energy and environment political frame conditions.

The assessment of the competition of biomass for energetic purposes to food and fodder production was not taken into account and is not an aim of this study.

2.1. Scope of analysis

A choice of currently important raw materials such as wood, energy crops and organic residues was identified and analysed. Table 1 presents a list of the selected raw materials in the three categories: energy crops, waste and by-products or residues.

Realistic process chains for production and provision of heat, power and transport fuel were defined by the combination of the selected raw materials with suitable conversion technologies. The examined technologies are comprehensively shown in Table 2 and explained in detail in the following paragraphs.

Three different technologies for heat only production were taken into account. The majority of wood used in German households is fired in wood stoves and boilers as well as fireplaces. For this reason a wood stove (5–10 kW_{th}) run on fuel wood was analysed. A pellet boiler (10 kW_{th}) run on wood pellets from industrial wood residues stands for a modernized single household heat production. The centralised heat production was represented by a district heat plant (5 MW_{th}) run on either different kinds of wood (used wood, forestry residues, short rotation coppice) or straw.

For power only production a condensing turbine (20.0 MW_{el}) run on wood (used wood, forestry residues, short rotation coppice) or straw was analysed.

For the CHP production also a steam turbine (extraction condensing turbine, max. 6.1 MW_{el} and max. 20.0 MW_{th}) run on wood (used wood, forestry residues, short rotation coppice) or straw was taken into account. For lower capacities an Organic Rancine Cycle (ORC) module (1.0 MW_{el} and 6.3 MW_{th}), also run on woody biomass and straw, was included into the analysis. An innovative technology for the conversion of wood and straw was represented by the thermo-chemical gasification plant (fluidised bed reactor, 9.0 MW_{th}). The product gas of the gasification process is used in a gas engine (2.4 MW_{el} and 3.2 MW_{th}). The agricultural fermentative biogas production (fermenter output: 102 m^3 of biogas/h) from manure, maize and grain for use in an on-site CHP unit (gas engine, 230 kW_{el} and 300 kW_{th}) was analysed with either 40% heat use or in an alternative setting with 100% heat use. An off-site CHP unit (gas engine, 230 kW_{el} and 300 kW_{th}) run on upgraded biogas (substitute natural gas, SNG) with 100% heat use typifies the centralised CHP production from agricultural biogas. The analysed upgrading process (CO_2 reduction) for biogas is a water scrubber. Although the conversion of landfill gas and gas from sewage sludge in gas engines of small capacity as well as the use of organic waste in extraction condensing steam turbines of medium capacity were included into the analysis the focus of this study is set on the utilisation of agricultural and woody biomass.

The most important biofuel in the German transport sector is biodiesel from rapeseed. This conversion and utilisation pathway was represented by an extraction and esterification plant with an output of 300,000 tons of biodiesel per year. Bioethanol is gaining constantly more and more importance in the German biofuel market. Thus the production of bioethanol based on the fermentation process run on sugar beet, grain and straw (for each sugar, starch and lignocellulose) in a conversion plant with an output of 150,000 tons of bioethanol per year was examined. An innovative technology for the use of woody and lignocellulosic material for the biofuel production is the thermo-chemical gasification and Fischer–Tropsch synthesis. This technology is represented by a plant with an output of 15,000 tons of biomass-to-liquid fuel (BTL) per year. Furthermore an alternative use of above mentioned upgraded biogas (SNG) from agricultural biomass as gaseous transportation fuel was taken into account.

2.2. Methodology

The methodological approach is based on a scenario analysis within the energy system model TIMES[1] Germany. TIMES Germany was developed at the Institute of Energy Economics and the Rational Use of Energy at the University Stuttgart and simulates the entire energy system of Germany.

2.2.1. The TIMES model

The economic model generator TIMES, is a linear cost optimisation model for the analysis and projection of long-term energy

[1] TIMES (The Integrated MARKAL-EFOM System) was developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA) based on the energy system models MARKAL (market allocation) (Fishbone and Abilock, 1981) and EFOM (energy flow optimisation model) (Voort et al., 1984).