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Priority order in using biomass resources – Energy systems analyses of future scenarios for Denmark

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ABSTRACT

According to some future Danish energy scenarios, biomass will become one of the two main pillars of the future energy system accompanied by wind power. The biomass can be used for generating heat and electricity, and as a transportation fuel in a future energy system according to the scenarios. This article compares the value of using biomass as a heat source and for electricity generation in a 100% renewable energy system context. The comparison is done by assuming an incremental decrease in the biomass available for the electricity and heat sector, respectively. The assumed scenarios for the decrease of biomass are made by use of an hourly energy system analysis model, EnergyPLAN. The results are shown in terms of system configuration, biomass fuel efficiency, system cost, and impacts on the export of electricity. It is concluded that the reduction of biomass in the heat sector is better than the alternative reduction in the electricity sector in every aspects except biomass fuel efficiency.

1. Introduction

In several future scenarios of 100% renewable energy systems in Denmark [1–3], or parts of Denmark [4,5], biomass is regarded as an important primary energy resource to complement wind power. In official as well as academic plans and scenarios [1–3,6], wind power is set to follow historical trends [7] and increase even further in the future. The presently high and thus also growing penetration of wind power into the energy system can bring uncertainty related to electricity generation. Inherently, wind power is intermittent in its output and the electricity demand is also fluctuating on a diurnal and seasonal basis; thereby creating balancing issues in the demand and production of electricity. Biomass, on the other hand, can be utilized in an almost identical way to fossil fuels; that is, the power from biomass can be dispatchable as long as the fuel can be supplied. In order to achieve grid balance, additional technological solutions can be found, such as HPs (heat pumps), electrolyzers, EVs (electric vehicles), electricity storage, and the reinforcement of the electric grid to neighboring countries [8–12]. However, these solutions are better in the situation of excess electricity than in the lack of electricity in the system, although curbing demand on some of these units in effect corresponds to an upward regulation. Among the relevant renewable energy resources with a potential in Denmark, there are no options to dispatch electricity, especially in a large scale, except from biomass. Therefore, biomass should play a significant role in coping with the grid balancing issue.

Exploiting the biomass resource faces environmental limitations and is also likely to meet opposition in the population. The environmental limitation includes biodiversity issues [13], the lack of land, land use conflicts, soil fertility degradation, erosion, and greenhouse gas emissions from deforestation due to more land cultivation as well as from increased humus degradation due to the tilling of the soil. The public opposition against the extensive use of biomass is mainly related to the results of the mentioned environmental issues, and they are related to people's perception of bioenergy. The political opposition includes NIMBY (Not In My Back Yard) due to potential odors from manure, and ethical issues of using food material for energy or agricultural land for energy crops. These perceptions often derive from miscommunication between the public and the actors implementing the policy, or the inertia of the conventional fuel system [14].

Considering the potential threats to biomass usage and the indispensability of biomass resources to complement wind energy in the future energy sector, which will bring about a high demand, the politically feasible biomass availability is likely to be less than the physically available biomass potential estimated in future scenarios [1–3,6].

Therefore, an evaluation of the biomass usage in the energy sectors is the subject of this article. The article analyzes which energy sector among electricity and heat will be the most valuable choice for using the limited biomass resources in the future Danish energy system. In a cool, temperate climate like Denmark, where

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there is a heat demand except in the summer period, the fuel choice for heat generation is an important issue at present and even more in an increasingly renewable future. At the same time, as explained before, biomass is an important resource, especially in periods with a deficit of RES (renewable energy source) electricity. Hence, this research can be helpful for other countries similar to Denmark in terms of climate and limited biomass resources.

Similar research has been conducted within the field of biomass usage in the energy area. Demirbas et al. [15] discuss the role of biomass in future renewable energy system. Grahn et al. [16] investigate comparisons of two energy scenarios which show different results in terms of biomass usage; one advocates using biomass for transportation, and another advocates the use of biomass for heat production. However, this research is done within a global framework, which means that it is not sufficiently detailed for the analysis of consequences in an actual energy system. Azar et al. [17] assess the fuel choice between biomass and hydrogen for future transportation.

This study is different from the mentioned research in two main aspects.

Firstly it is national scale rather than global scale research. Simulating an energy system on a national scale, which is more detailed than a global energy system, is especially required when analyzing self-sufficient energy scenarios. In addition to that, the biomass resource is less mobile than conventional fossil fuels, which is partly attributed to a lower energy content per unit of volume and weight and partly due to the spatial constraint of the process site and harvest area.

Secondly the time scale of the two models[1] used is not hourly and therefore cannot handle the energy systems dynamics of future high-RES energy systems. The analysis with an hourly model is essential to 100% RES systems and high-RES systems, which must be able to integrate intermittent RES. The most important aspect of using biomass in a future Danish high-RES system is grid balancing. Therefore, a reasonably low time resolution is particularly important as biomass needs to play the role of the storable fuel to complement wind power.

In contrast to the mentioned previous research, this article presents a more disaggregated picture of the energy system with hourly model simulation thus enabling simulations of energy systems dynamics in a high-RES energy system.

This article is organized as follows. Section 2 introduces the methodologies for biomass reduction scenarios. Then Section 3 outlines the reference scenario and how the scenarios are generated. Section 4 details the results of the simulations, and finally, Section 5 draws the main conclusions and discussions.

2. Methodologies

This section represents the research framework and the methodologies for designing the biomass reduction scenarios. A variety of paths can be followed to make the biomass reduction scenarios possible for the year 2050 energy system. Since the time horizon of 2050 is distant from the present time, various assumptions on technological development and behavioral changes of future energy participants are possible. These assumptions are valuable to consider; however, this is beyond the scope of this article. The following subsections present the overall framework (Section 2.1), the choice of alternative options for reducing biomass in either the electricity or the heat sector (Section 2.2), how to define the biomass amount in CHPs (Section 2.3) and the description of EnergyPLAN to be used as a simulation tool in this article (Section 2.4).

2.1. Overall framework

In order to evaluate the system benefit of biomass for the heating and electricity sector, respectively, a certain amount of biomass in each energy sector is artificially reduced compared to a reference scenario. Among the Danish future energy scenarios [1–3], a comprehensive study performed by the Danish Society of Engineers – the so called IDA Climate Plan 2050 (referred to as IDA 2050 henceforth) [3] – is set as a reference scenario for this article.

The two alternative scenarios analyzed are as follows:

- ✓ biomass fuel is reduced in the heat sector by incrementally decreasing 2 TWh from the total biomass amount used in the IDA 2050 scenario
- ✓ biomass fuel is reduced in the electricity sector by incrementally decreasing 2 TWh from the total biomass amount used in the IDA 2050 scenario

The 2 TWh reduction of biomass in the scenarios in the heat and electricity sector, respectively, is attained by an iterative analysis made in the hourly input/output energy system model, EnergyPLAN (See Section 2.4). In this analysis, the system impacts as well as the required installed capacities are assessed. Then these scenarios are compared to each other and to a reference scenario in terms of the biomass efficiency (output from biomass using technologies/biomass input), the electricity export increase compared to the biomass decrease, and the total cost. Electricity export is increased due to the additional RES capacity in the system, resulting in production also when no additional production is required.

2.2. Selection of alternatives to reduce the biomass share in the electricity and heat sectors

This section discusses the selection of alternatives to substitute biomass resources in electricity and heat generation. All the alternatives are already used in IDA 2050. Table 1 lists the possible technologies and summarizes their characteristics.

As seen in Table 1, there are two alternatives which can reduce the biomass use in electricity generation. The first alternative is to increase the share of RES in the system; however, this requires flexible means to cope with the variability of RES. The second alternative is the use of synthetic fuel from electrolyzers, which is in fact not an application of a standalone energy generator but rather an energy carrier. This technology has a relatively low efficiency due to the loss from a series of conversions. In terms of investment, it does not only require electrolyzers but also extra electricity generators to supply the electrolyzers. In conclusion, the increase of RES is an unavoidable alternative when the aim is to reduce biomass use in the Danish electricity sector.

In the case of biomass reduction in the heat production, a greater variety of options can be applied than in the case of electricity. The first option is to employ more HPs. From a systems perspective, the second option – increasing the use of electric boilers – has some of the same characteristics; however, HPs show a better efficiency than electric boilers. The last option is to use synthetic fuel in CHPs (combined heat and powers) and boilers, which has the drawbacks introduced above.

In order to replace biomass, it is necessary to increase the installed capacity of technologies exploiting RES and thus the electricity generated from RES. The problem is which particular RES should be increased. There are a number of RES candidates;

[1] The global energy systems model GET 1.0 developed at Chalmers, Sweden and the BEAP (Biomass Environmental Assessment Program) from the IEA (International Energy Agency).

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