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Comparing the value of bioenergy in the heating and transport sectors of an electricity-intensive energy system in Norway

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HIGHLIGHTS

- Bio-heating is less competitive over heat pump for low quality heat production.
- Renewable energy production meets policy objectives better than system efficiency.
- Bioenergy is more valuable in the transport sector than the heating sector.

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ABSTRACT

The objective of this paper is to identify the most valuable sector for the use of bioenergy in a flexible energy system in order to meet the energy policy objectives of Inland Norway. A reference system was used to construct alternative systems in the heating and transport sectors. The alternative system in the heating sector is based on heat pumps and bio-heat boilers while the alternative systems in the transport sector are based on three different pathways: bio-dimethyl ether, hydrogen fuel cell vehicles and battery electric vehicles. The alternative systems were compared with the reference system after a business-economic optimisation had been made using an energy system analysis tool. The results show that the excess electricity availability due to increased energy efficiency measures hampers the competitiveness and penetration of bio-heating over heat pumps in the heating sector. Indeed, the synergy effect of using bio-dimethyl ether in the transport sector for an increased share of renewable energy sources is much higher than that of the hydrogen fuel cell vehicle and battery electric vehicle pathways. The study also revealed that increasing renewable energy production would increase the renewable energy share more than what would be achieved by an increase in energy efficiency.

1. Introduction

For one or more reasons, the transition from a fossil fuel-based to a renewable energy-based energy system has been a goal for both oil-producing and oil 'sink' countries. Nevertheless, despite its multiple benefits, the shift has its own impact and limitations; new intensive infrastructure requirements and their fluctuating nature (demand and supply mismatch) is just one example. With some exceptions like bioenergy and hydropower, most fluctuate where either expensive storage or a load-following reserve capacity requirement for system integration is inevitable (Østergaard, 2009, 2012) and in effect this slows down the entire motivation for and palatability of a green energy system.

In contrast, hydropower-based energy systems smooth out the transition both technically and economically. Norway is a front-line runner with more than 95% of its electricity originating from hydropower, which buffers not only the local market but also that of the Nordic region through the Nordpool electricity market (Norwegian Water Resource and Energy Directorate, 2013). However, intensive hydropower development in the 1990s impeded the use and synergy effect of other potential renewable resources in Norway, e.g. wind and biomass. The share of bioenergy of total energy consumption is 6% (17 TW h), coming mainly in the form of firewood while the estimated potential is 39 TW h – three times today's use (Trømborg, 2011). Wind-power contributes only 1% of the total power generation as of 2011. Energy service infrastructures are heavily based on electricity as a fuel source. In particular the use of bioenergy in the heating sector has been overshadowed by the hydroelectric 'born' direct electric heating, due to cheap electricity in past decades. As of 2009, 94.8% of households

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had direct electric heaters and 55% of them used them as their main heating source, while 18.5% had heat pumps and 14.8% used it as their main heating source (Statistics Norway, 2011). This shows that the heating sector is dominated by direct electric heating, where high quality energy is destroyed (exergy). Electric heaters are easy to install, compact, and require low investment and little maintenance. Nevertheless, their efficiency is low and they constitute barriers to a flexible energy system (Hagos et al., 2014; Danielski et al., 2012). To this end, deployment of waterborne heating systems would be crucial to weakening the strong electricity to heat bond and would open up an opportunity to integrate new renewable energy sources (RES) into the existing system, in order to achieve the Norwegian energy policy objectives (increased RES share – 67.5%, 14 TW h more bioenergy use and 30% emission reduction compared to the 1990 level by 2020).

In a normal year, Norway is a net electric importer where marginal condensing power plants are used to supply the balancing power. For example, between 2006 and 2012, on average, annual hydropower production shows a 17 TW h imbalance in wet and dry years as compared to production in a normal year (Statistics Norway, 2014a). Over and above this, in case of serious falls in precipitation the transmission capacity may not be sufficient to cover the demand. Sandsmark (2009) concluded that upgrading transmission capacity is more realistic than upgrading existing power plant capacity to cover a supply deficit. Thyholt and Hestnes (2008) showed that buildings connected to district heating in Norway could contribute a considerable peak load shaving and reduction in CO_2 emission than an electrically heated building. Furthermore, Rosenberg et al. (2013) suggested that increasing bioenergy penetration and implementing energy efficiency measures in Norway are the most profitable solutions to cover increased demand. All prior studies strengthen the multi-benefits of waterborne heating system deployment in Norway, ensuring evenly distributed electricity prices between interconnected regions, less intensive investment for upgrading transmission lines and substantial emission reductions as it is a key measure towards peak load shaving. However, most of the studies do not point out the limits and values of new RES from the entire energy system perspectives, i.e. the electricity, heat and transport sectors.

On the other hand, a potential space to increase the use of bioenergy in Norway is the transport sector. The transport sector and offshore oil industries contribute to 23% and 29% of total emissions in Norway, respectively (Møller-Holst, 2009). This is a major challenge for Norway to meet its international obligations regarding emission reduction, i.e. 15–17 Mt CO_2 by 2020 (Norwegian Ministry of the Enviroment, 2009). Several studies have investigated the impact of fossil fuel-based energy system emissions on the environment, both nationally and globally. Zhang et al. (2012, 2013) improved the empirical models used to evaluate particulate emissions, Ma et al. (2011) correlated energy consumption and carbon emission in a regional case study, and Zhang et al. (2014) identified the key factors that affect the climate effects of natural gas versus coal electricity production. However, the state-of-the-art technologies intended to abate vehicle emissions will replace or displace conventional fleets with biofuel cars, electric vehicles (EVs) and hydrogen fuel cell vehicles (HFCVs). As such, electric vehicles are ideal solutions if the electricity supply is from RES. However, their limited driving range (150 km on average) makes them most suitable for conventional light vehicle replacement and fuelling heavy trucks and lorries with biofuels is inevitable. Moreover, to the best of our knowledge, the contribution of EVs and HFCVs for increased RES share and its synergy effect with other RES in an electricity-intensive energy system is not clearly known, and needs to be studied and compared with that of biofuels.

The overall understanding is therefore that to rely 100% on a single renewable resource for electricity and heat generation could not guarantee sustainability, but rather it would impede the penetration and synergy effect of other potential renewable resources in a flexible energy system. Hence, this paper analyses and compares the limits, value and benefits of bioenergy integration in the heating and transport sectors of a flexible energy system as a complement to the existing hydro-dominated energy system. Of the 19 counties in Norway, Hedmark and Oppland constitute Inland Norway characterised by some of the highest energy-consuming households in the country, with large floor areas and a high share of detached households (73%). Electricity is the main commodity in the heating sector. The details of Inland Norway energy use by sector is shown in Table 1. This paper therefore considers the Inland[1] energy system to demonstrate this conceptual reasoning.

Table 1
Inland energy use by sector in the reference year (2009) (TW h) (Statistics Norway, 2013).

Fuel	Household	Service	Industry	Transport	Total
Biomass	1.04	0.23	0.45		1.72
Fossil fuel	0.18	0.17	0.34	5.06[a]	5.75
Electricity-heating	1.93	0.95			2.88
Electricity-appliances	1.04	1.16	1.47		3.67

[a] The annual total road traffic volume covered by the transport demand is approximately 4000 million kilometer: passenger vehicles (3057.4), busses (23.3), vans and small lorries (712.5), and heavy lorries and road tractors (144).

The paper is organised into five sections. The first section provides background information about the existing energy system and its foreseen challenges. Section 2 briefly discusses the methodology followed, presents the modelling tool used for the analysis, the data sources and assumptions used, and the scenario-building in alternative systems for the heating and transport sectors. Section 3 discusses the details of the results and findings. Section 4 summarises the results and draws conclusion and its policy implication, followed by suggestions for future work in Section 5.

2. Methods

A reference system (Ref-sys) based on the year 2009 was created and validated in a preceding paper (Hagos et al., 2014) where two alternative systems in the heating sector were built and analysed as a closed system, without external electricity market interaction. That Ref-sys has been used here to build the alternative systems in the heating sector (Alt-heat) and the transport sector (Alt-trans) as shown in Fig. 1, which illustrates the theoretical framework of the study. The reasoning behind this is that such cascaded formulations would help to better understand the incremental contribution of bioenergy in each sector and form a strong base to compare all the systems, i.e. Ref-sys, Alt-heat and Alt-trans. The Alt-heat system focused on the use of heat pumps and bio-heat boilers in individual and district heating (DH) plants as a replacement for direct electric heaters and air source heat pumps in the Ref-sys. Whereas the Alt-trans system is based on three different pathways: battery electric vehicles (BEVs), hydrogen fuel cell vehicles (HFCVs) and biofuel cars (using Bio-DME (dimethyl ether)). Furthermore, each pathway in the Alt-trans system was compared based on an assumed conventional fleet displacement equivalent to an annual road traffic volume of 1 billion km. The reasoning behind this is that BEVs and HFCVs are

[1] In this paper, wherever Inland is stated, the term refers to the Inland Norway of Oppland and Hedmark counties.