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Comprehensive assessment of the role and potential for solar thermal in future energy systems

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ABSTRACT

The European Union has set targets to increase the share of renewable energy in the coming years. Solar thermal energy is currently expanding and could possibly contribute to achieving the European targets. This paper evaluates the potentials of solar thermal energy from an energy system perspective along with the impacts of installing these potential for four European national energy systems; Germany, Austria, Italy and Denmark. The potentials are evaluated by applying energy system analysis of existing and future energy systems under different conditions such as substantial heat savings, expansion of district heating networks and with high-renewable electricity and heating sectors. The findings in this paper indicate that the national solar thermal potentials are in the range of 3–12% of the total heat supply and that installing the potentials will impact the energy system according to the energy system configurations. Solar thermal benefits reduce when moving towards a high-renewable energy system as other renewable energy sources start competing with solar thermal on energy prices and energy system flexibility. The findings can be applied to a diversity of energy systems also beyond the country cases of the study. The role of solar thermal should be to reduce the pressure on scarce renewable resources and to supply renewable energy in conditions where no alternatives are available.

1. Introduction

Solar thermal technologies have expanded rapidly in Europe in the last five years, more than doubling in production (Eurostat, 2017). This has primarily taken place in individual buildings, but solar thermal for district heating is also growing, particularly in Denmark. The question is however how large the potential is for installing solar thermal and whether solar thermal is a viable solution for Europe to achieve its energy targets, or if better alternatives exist. These questions are thoroughly examined in this study for four European national energy systems; Germany, Austria, Italy and Denmark.

The objective of this paper is to:

- Enhance the knowledge about the role of solar thermal in future energy systems
- Assess the potentials for installing solar thermal from a national energy system perspective
- Quantify the impacts of installing these potentials

Previous studies evaluating the feasibility of solar thermal have researched the integration of solar thermal in residential buildings in Norway (Good et al., 2015), Greece (Tsalikis and Martinopoulos, 2015), Tunisia (Hazami et al., 2013) and for North European housing (Ampatzi et al., 2013). Other studies analyse the potentials for integrating solar thermal in industrial processes such as breweries (Eiholzer et al., 2017), dairy processes (Quijera et al., 2011) or for tuna fish canning factories (Quijera et al., 2014). These studies find potentials for integrating solar thermal on a building scale, but do not reach any conclusions regarding the solar thermal feasibility in a broader scale such as from a national energy system perspective.

Solar thermal has also been analysed for geographical regions such as the Geneva Region (Quiquerez et al., 2015) and the Canary Islands (Gils and Simon, 2017) finding significant solar thermal potentials in these areas. However, these studies focus on the local scale and do not include the national perspective.

Some studies analysed the role of solar thermal from a national energy system perspective such as for Taiwan (Chang et al., 2013), for the United Kingdom (Greening and Azapagic, 2014), for Turkey (Benli, 2016) and more generally as a renewable resource for the future (Seyboth et al., 2008). Common for these studies are that no energy system analyses and quantification of the solar thermal potentials were conducted and that these studies apply more generic arguments for the integration of solar thermal resources.

Only few studies previously quantified the potential of solar thermal

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from a national energy system perspective. For the Danish energy system, a study found that 15% of the heating demand ought to be supplied by solar thermal (Lund and Mathiesen, 2009) while (Palzer and Henning, 2014) found that the solar thermal potential in Germany might be 125–165 GW_{th} capacity. These studies analysed solar thermal in a high-renewable situation where a variety of other renewable sources also influence the solar thermal feasibility. Finally, (Weiss and Biermayr, 2009) analysed the solar thermal potentials for all of Europe as well as for some individual countries (including Austria, Germany and Denmark). Here, it was found that solar thermal fractions could increase to 6–40% in Austria, 6–34% in Germany and 5–32% in Denmark as a share of the low-temperature heat demand.

This demonstrates that solar thermal potentials previously have been evaluated for selected regions and countries. This paper adds to this knowledge by applying a different methodology and by quantifying the impacts of installing the solar thermal potentials.

Hence, this paper adds to the current knowledge through:

- The development of a novel methodology for analyzing solar thermal potentials
- Comparing solar thermal potentials across national energy system
- Quantifying the impacts of installing these solar thermal potentials

This paper contains a description of the methods and materials applied for the analysis of the solar thermal potentials and is followed by a presentation of the main results, including the solar thermal potentials for each country and the impacts of installing the potentials. The subsequent chapter entails a discussion of the methods applied and the possible role of solar thermal in a future energy system while the conclusions are summarized in the end.

2. Methods and materials

The approach for evaluating the role of solar thermal technologies in this paper is founded on an energy systems approach. This implies that solar thermal is analysed in terms of the impact on the energy system rather than on the individual building level and the study differentiates itself by not relying on a levelized cost of heat approach as in other studies (Baez et al., 2016). Hence, aspects such as dynamics across energy sectors, various storage types, the influence of other technologies as well as the energy system flexibility impact the feasibility of integrating solar thermal.

The novelty of this paper is demonstrated by assessing the solar thermal potentials in an energy system context encompassing all energy system dynamics rather than for individual energy sectors or users. Part of this approach is evaluating solar thermal against other renewable alternative technologies such as renewable heating from geothermal and excess heating. The energy systems approach necessitates an energy system analysis tool which includes all energy sectors (heating, cooling, electricity, transport and industry), operates on an hourly scale to accommodate for the variations of solar thermal generation, and is able to quantify the impacts for the indicators selected. For these reasons, the energy system analysis tool EnergyPLAN is applied for this study (Aalborg University, 2014). The main purpose of the model is to assist the design of national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments. EnergyPLAN has been used in numerous papers (Østergaard, 2015) for multiple purposes such as the design of 100% renewable energy systems on a municipal, national and European level (Lund and Mathiesen, 2009; Mathiesen et al., 2015; Connolly et al., 2016).

The indicators for the analysis are based on an energy system perspective and does not consider the individual consumer, as well as the allocation of benefits within society. The indicators are energy system costs (investments, O&M, fuels, CO_2 and electricity exchange costs, excluding all subsidies and taxes and using a 3% discount rate), energy consumption (primary energy supply with a focus on biomass), environment (CO_2-emissions) as well as the flexibility of the energy system (overproduction of electricity and district heating due to a temporal mismatch between demand and production).

The role and potential of solar thermal is analysed in a variety of energy system types. Firstly, four European countries are part of the study; Germany, Austria, Italy and Denmark. These countries vary in terms of climatic conditions with both Southern, Central and Northern European climates, the solar irradiation varies between the countries and they differentiate in terms of energy system design and available resources where some countries have a high share of hydropower (Austria) while others rely on natural gas (Italy) or wind power and district heating (Denmark). Secondly, these four national energy systems are modified by designing five alternative future energy systems for each country. These alternative future energy systems are called; 2010, 2050, Heat savings, District heating and High-RES. These are briefly presented below while further details can be found in Mathiesen and Hansen (2017).

Firstly, a 2010 model of each national energy system replicating the current energy systems is designed. In the 2010 models the solar thermal production is insignificant. Secondly, the 2010 model is projected towards 2050 in terms of energy demands and renewable energy capacities as anticipated by the European Commission when no further policies are implemented (Capros et al., 2014). This model is called the 2050 model and no solar thermal is installed in these models in order to identify the full impact of installing additional solar thermal energy. Next, a scenario is designed based on the 2050 model where substantial heat savings are implemented to analyze whether this factor is significant for the solar thermal integration. The heat savings correspond to 40–50% of the total heat demand in the 2050 models. After implementing heat savings, scenarios are designed with significant district heating expansions reaching heat shares of 40–70% in each country (Denmark already has above 50% district heating share today). This model is entitled District heating. The final model includes a transition to a high-renewable energy system (called High-RES) in the heating and electricity sectors. In this scenario, the measures include a shift of heat supply outside of district heating areas to mainly compression heat pumps and a further integration of renewable sources for district heating (geothermal, waste incineration, industrial excess heat and large heat pumps). Wind and solar power is implemented to meet the majority of the electricity demand while the remaining fossil energy demand is converted to biofuels. In this scenario, all energy demands are supplied by renewable resources, except for heavy-duty-transport. The purpose of these scenarios is to enable the analysis of solar thermal potentials in future high-renewable energy systems rather than designing optimized high-renewable energy systems. An elaborate description of these scenarios is available in Mathiesen and Hansen, 2017.

In each of these energy system types the role and potential of solar thermal is analysed in terms of the maximum solar thermal potential the energy system can accommodate given certain assumptions and thresholds. The first threshold regards the overproduction of solar thermal due to the hour-by-hour mismatch between solar thermal production and heating demands. This overproduction threshold is selected as 5% annually and applies to both solar thermal in district heating areas and in individual buildings. This threshold is based on dialogues between project partners and a sensitivity analysis is performed in Mathiesen and Hansen (2017) indicating that this value only has minor influence on the overall impact of solar thermal. The second threshold is regarding the imbalance of the district heating system supply and demand, also impacted by other technologies than solar thermal (solar thermal can indirectly impact this). This threshold is also selected to be 5% on an annual basis. The amount of baseload technologies installed in the energy system is crucial impacting the energy system ability to integrate solar thermal. The final assumption regards the solar thermal penetration, which is defined as the share of heat consumers that are connected to a solar thermal system, i.e. a solar

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