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The role of energy storage solutions in a 100% renewable Finnish energy system

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Abstract

A 100% renewable energy scenario was developed for Finland in 2050 using the EnergyPLAN modelling tool to find a suitable, least-cost configuration. Hourly data analysis determined the roles of various energy storage solutions. Electricity and heat from storage represented 15% of end-user demand. Thermal storage discharge was 4% of end-user heat demand. In the power sector, 21% of demand was satisfied by electricity storage discharge, with the majority (87%) coming from vehicle-to-grid (V2G) connections. Grid gas storage discharge represented 26% of gas demand. This suggests that storage solutions will be an important part of a 100% renewable Finnish energy system.

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Keywords: energy system modeling; storage solutions; 100% renewable energy; Finland; vehicle-to-grid; power-to-gas

1. Introduction

Variability and uncertainty are inherent qualities of energy systems as supply and demand of energy services vary over time, space and sometimes in unpredictable ways. The challenge of mitigating such imbalance has always required a high level of flexibility, often provided by energy resources, particularly fossil fuels. However, climate

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change and sustainability challenges require that future energy systems have increased levels of renewable energy (RE) generation, much of which is intermittent or variable, creating a different need for flexibility measures that can ensure reliability, stability and quality of energy supply. Moreover, demand must be met in a responsible manner that does not place unnecessary burdens on society in terms of how disruptive or expensive solutions are to implement. Energy storage technologies are increasingly viewed as essential elements of flexibility in future energy systems, capable of bridging "temporal and geographic gaps between energy supply and demand" [1]. Such geographic gaps are filled in such cases when energy storage is portable, or stored energy can be transmitted or transported over distance. Additionally, energy storage may bring reliable energy services to areas that have poor energy infrastructure, or are seen as off-grid.

Finland represents an interesting case study of future energy systems due to strong diurnal and seasonal variation in variable energy generation (hydro, wind, solar) that is typical of countries at high latitudes. What is more, it is a highly industrialised nation with a strong need for a reliable energy supply that meets the needs of individual consumers while also ensuring a competitive industrial sector. Further, Finland has committed to an 80-95% reduction (compared to 1990 levels) in greenhouse gas emissions by 2050 [2].

Finland represents a challenge to high levels of solar photovoltaic (PV) and wind power in an energy system. While there are high amounts of solar irradiation during the summer months, the opposite is true during winter. Moreover, there is noticeable seasonal variation for both onshore, and offshore wind power, with more wind energy produced in the winter months. Further, there is also a seasonal element to hydro power, as the Finnish system is dominated by run-of-river hydro power with limited reservoir capacity of approximately 5.5 TWh_e [3], equivalent to approximately 6.5% of current electricity demand [4]. Hydro power is used as seasonal storage of energy in Finland, as most energy inflow occurs during the spring runoff in May. Reservoirs are kept relatively full until energy is needed during the winter months of December-April. At the same time, it must be remembered that Finnish hydro power experiences interannual variation in total annual production of 10-17 TWh_e, thereby demonstrating its somewhat intermittent nature [4].

On the demand side, the need for energy services in the form of heat and electricity is naturally higher during long, dark Finnish winters. So, finding the flexibility in the Finnish energy system has always been a significant task. In a future energy system based on high shares of variable RE, the need for energy storage solutions (ESS) on a daily, weekly and seasonal basis seems obvious. This extreme situation could then serve as a model for other countries at high latitudes, both north and south, of how variable renewable energy generation can play a role in a highly developed and industrious society.

For these reasons, an energy system based entirely on renewable resources was considered in previous work by the authors [5]. The scenario of a 100% renewable energy system was seen as being highly cost competitive to those with increasing shares of nuclear power installed capacity as well as a Business As Usual scenario. In other work, Child et al. [6] examined the role of solar PV for the case of a 100% RE Finnish energy system for 2050, which showed that storage technologies could play a prominent role in facilitating high shares of solar PV. However, this current study seeks to explain the nature and significance of energy storage solutions in more detail. This will include the roles of Gas storage, Power-to-Gas (PtG) technologies, Thermal Energy Storage (TES), stationary batteries, and Vehicle-to-Grid (V2G) connections. The significance of ESS in this future energy system will be determined by answering the following key questions:

- How much wind and solar PV power is used directly?
- How much of the annual energy demand is covered by ESS?
- How much stored energy comes from stationary batteries and V2G connections?
- How much stored energy comes from TES?
- How much stored energy comes from gas storage?