Polish energy system without fossil fuels and nuclear energy

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Abstract

This study examines the feasibility of transforming Poland's energy system to achieve climate neutrality by 2050 without relying on fossil fuels or nuclear power. In alignment with the European Union's climate goals, this research investigates both the heating and electricity sectors to identify viable pathways for this transition. The analysis includes a detailed evaluation of renewable energy technologies, energy storage solutions, and system integration strategies.

Key findings indicate that heat pumps, biomass, and solar thermal systems will play significant roles in meeting heating demands. For individual heating, heat pumps are projected to cover approximately 70% of the demand by 2050. In urban areas, combined heat and power (CHP) systems utilising renewable sources such as hydrogen will be crucial for efficient energy use.

In the electricity sector, the study explores two scenarios: a conservative and an optimistic approach to wind and solar energy development. The conservative scenario estimates wind power contributing 100 TWh and solar power 150 TWh by 2050, while the optimistic scenario projects up to 209 TWh from wind power, reducing the reliance on solar installations. The integration of large-scale energy storage, with capacities ranging from 16 TWh to 60 TWh, is identified as essential for balancing the intermittent nature of renewable sources.

The research emphasises the importance of regulatory support, continued investment in research and development, and public awareness to facilitate this transition. By implementing these strategies, Poland can achieve a sustainable and resilient energy future, setting a precedent for other nations aiming for climate neutrality

Keywords: climate neutrality, renewable energy, heat pumps, biomass, solar thermal, combined heat and power, hydrogen, energy storage, Poland

Introduction

European Union countries have declared that their economies will achieve climate-neutral status by 2050[1]. At the political and legal level, successive regulations are being prepared that impose obligations on member countries to gradually reduce carbon dioxide emissions, increase the level of use of renewable energy sources, and improve the energy efficiency of their economies. Decisions on how to implement these obligations in terms of the technological solutions used are left to the member countries. In Poland, discussions of the problem primarily concern the electricity subsector, but the binding document "Energy Policy of Poland until 2040"[2], dating back to 2040, does not really give a clear answer as to what the structure of electricity generation would look like ten years later. However, there is no doubt that a large share of nuclear power is envisaged, and there are very optimistic deadlines for the construction of more power plants. Keeping in mind the problems with their construction in other European countries, the authors of the article asked themselves whether it would be possible to achieve climate-neutral energy status in Polish conditions without nuclear power plants.

When considering the problem of climate-neutral power generation, one must consider how to meet the demand for electricity. Indeed, a bigger problem is how to meet the demand for useful heat. Currently, in Poland, the demand for electricity is about 170 TWh [3] and for heat, about 950 PJ (own estimations), or about 260 TWh. It is essential to note the word "approximately" here. While electricity consumption at the national level is a measured figure, in the case of heat generated in individual systems, we can only talk about estimates.

In the article, the authors considered the problems of both heat and electricity supply.

Climate-neutral district heating

The absence of a program for the transformation of the district heating industry in the document "Energy Policy of Poland until 2040" does not mean that work on the vision of a climate-neutral subsector of the economy was not carried out at the government level. In 2020, a report was prepared by a team appointed by the Minister of Climate, which presented a vision of the technological structure of a climate-neutral Polish district heating in the area of supplying heat for municipal needs [4]. The results of this work are shown in Figures 1 and 2 for The absence of a program for the transformation of the district heating industry in the document "Energy Policy of Poland until 2040" does not mean that work on the vision of a climate-neutral subsector of the economy was not carried out at the government level. In 2020, a report was prepared by a team appointed by the Minister of Climate, which presented a vision of the technological structure of a climate-neutral Polish district heating in the area of supplying heat for municipal needs [4]. The results of this work are shown in Figures 1 and 2 for individual and district heating, respectively.

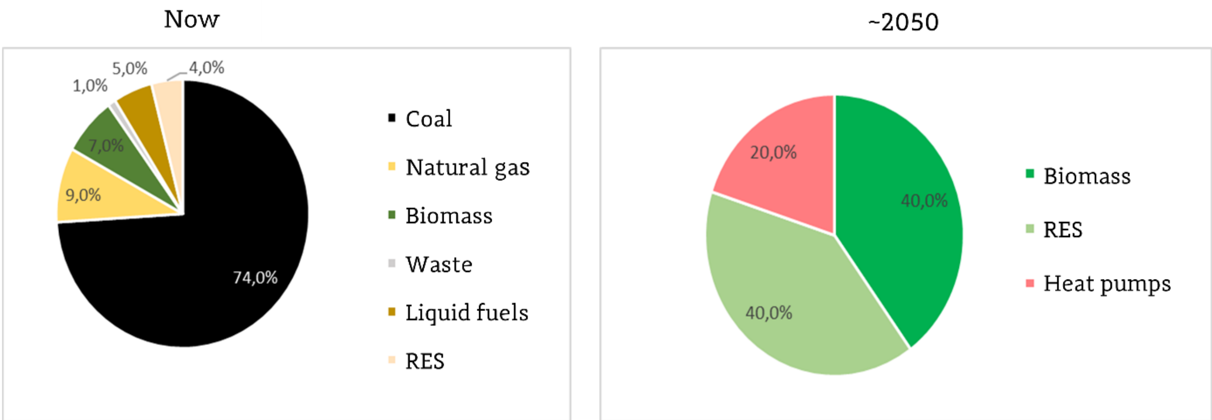

Figure 1. Fuel and technological structure of heat generation in the district heating industry today and in 2050

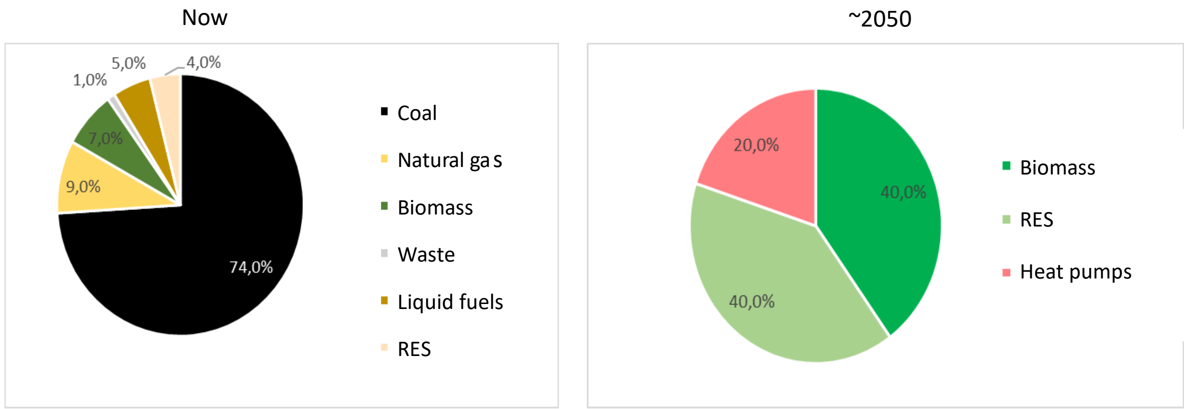

Figure 2. Fuel and technological structure of heat generation in district heating systems today and in 2050

The analysis result presented here is relatively straightforward and unambiguous for individual heating. Nearly 70% of heat will be generated using heat pumps. Technology is already fully developed and cost-competitive. Less than 10% of the heat will be obtained from biomass combustion, and about 4% will be obtained from electricity. The remaining 20% or so includes other renewable energy sources, primarily solar thermal and photovoltaic panels. All of these are proven technologies that are already available on the market today. Technologically, the vision of district heating needs to be more well-defined. Detailed technological solutions, in this case, will be individually selected, taking into account the availability of land for the development of photovoltaic panels, seasonal heat storage, availability and price of fuels produced from electricity obtained from RES (hydrogen, ammonia), etc.

Two examples can be presented here. The first is a practically autonomous district heating system for an estate of multi-family houses [5]. A diagram of such an installation is shown in Figure 3.

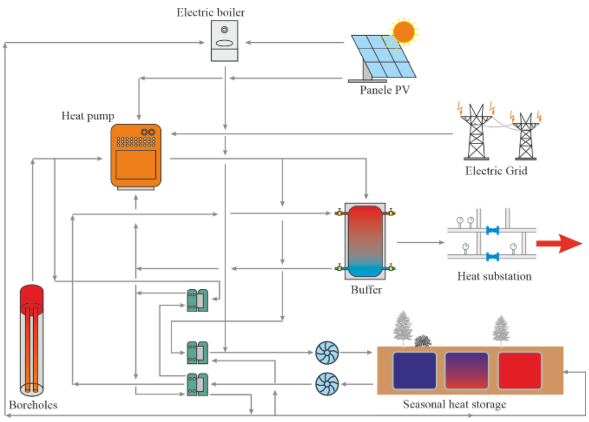

Figure 3. Schematic of district heating system with PV collectors, pumps and seasonal heat storage [3].

The designed system is designed to heat a residential area with buildings with a residential area of about 16 thousand m^2. The peak power of the system is 1.2 MW. The area of photovoltaic panels is 2,900 m^2, their power is 0.6 MW, and the capacity of tanks is 8000 m^3 (8 tanks). Heat pumps (2 units) are powered by 80 wells with a depth of 150 m. The system uses 97% of the energy obtained from renewable sources.

The second example is the concept "Climate-neutral district heating system in Warsaw". So, what could a neutral district heating system look like for large agglomerations with intensive development? Such a case was considered as part of the work [6], and it concerned the district heating system of Warsaw. It was estimated that in 2050, the demand for district heating will decrease from about 32 TJ today to a level of 27 TJ, taking into account thermal modernisation and development of the district heating system. An analysis of available waste energy sources located in the city and usable in the district heating system identified a potential of 14.5 TJ, of which the technically usable potential already accounted for only 9 TJ (Figure 4).

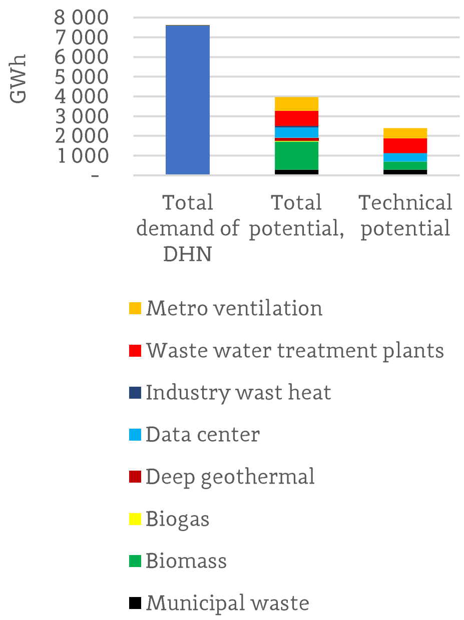

Figure 4. The potential of waste energy usable in the Warsaw district heating system [4].

To some extent, the concept of power supply using photovoltaic cells and seasonal heat storage presented earlier could also be used in Warsaw, but it seems that in the conditions of a large city with high land prices, the possibilities of building such an installation are very limited.

It should be assumed that for most district heating systems, it will be necessary to obtain energy from outside the urban agglomeration. This can be electricity, obviously generated from renewable energy sources or synthetic fuels (hydrogen, ammonia, synthetic methane?). In large systems, there is already a generation structure using fossil fuels in combined heat and power plants. Switching from fossil fuels to synthetic ones would make it at least partially usable.

There is also a more important argument in favour of such a solution. Everyone agrees that the goal of climate neutrality of the electricity sector cannot be achieved without solving the problem of electricity storage, and one of the most promising technologies is its storage in the form of hydrogen. Such a system, however, could be more efficient, as both the generation of hydrogen from electricity and the secondary generation of electricity from hydrogen are associated with significant heat losses. This heat can be used in district heating systems. In addition to CHP plants generating electricity and useful heat, cogeneration electrolysers would be built to produce hydrogen and valuable heat. The energy balance for such an electrolyser plant for the company's electrolysers is given by Siemens [7]. It is shown in Figure 5.

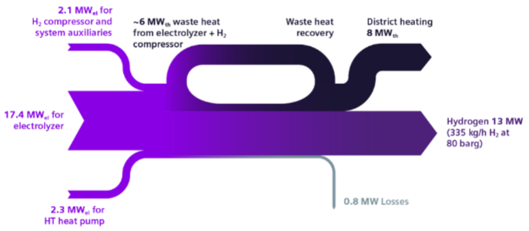

Figure 5: CHP energy balance of an electrolysis plant as proposed by Siemens [9].

It should be noted that electricity is supplied not only for the electrolysis process itself but also to drive the hydrogen compressor and other auxiliary equipment, as well as the heat pump required to raise the temperature of the waste heat stream from the electrolyser and compressor if it is to be used in the district heating system. The efficiency of such a system would be about 99%.

Secondary conversion of hydrogen to electricity, regardless of the technology used (hydrogen turbine, hydrogen engine, fuel cell), takes place at an efficiency of 40 - 60%. The use of a cogeneration system here makes it possible to achieve efficiencies in excess of 90%.

Efficiency at a similar level could be achieved for the entire cogeneration process of electricity storage (Fig.6).

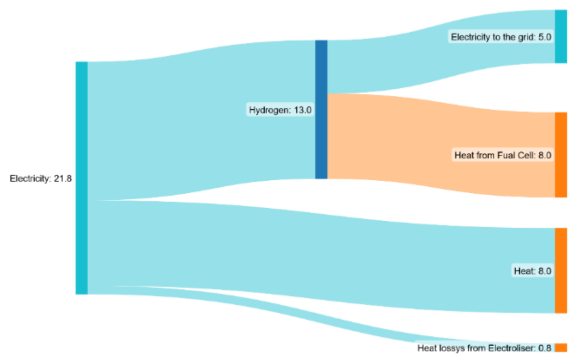

Figure 6. Energy balance for cogeneration electrolysis, hydrogen CHP plant system

For medium-sized district heating systems, biomass technology, which is already well-known and is gradually being introduced in district heating plants, should be particularly preferred. Of course, we can talk about "sustainable biomass" according to EU criteria. The demand for it in the heating industry will be high, and in view of its use also in the electric power industry, it seems reasonable to introduce legal mechanisms that will give heating plants priority in access to this fuel.

However, there is no doubt that heat will be the most widely used device. According to the results of the work [2], heat pumps will provide about 220 PJ of heat, and this means that the demand for electricity will increase by a minimum of about 17 TWh because of this.

Climate-neutral electricity system

Currently (2023), the demand for electricity in Poland is just over 170 TWh. The document "Energy Policy of Poland until 2040" [8] includes a demand forecast until 2040. According to it, demand will rise to 225 TWh by that time (Fig.7). Extrapolating this trend to 2050 makes it possible to estimate that in 2050 it will be about 250 TWh. A simple analysis assuming that the increase in demand is due only to the electrification of the heating sector (about 20 TWh) and the transportation sector (about 60 TWh) and that economic growth is occurring with decreasing unit electrical intensity of industry and the livestock sector, leads to the same value.

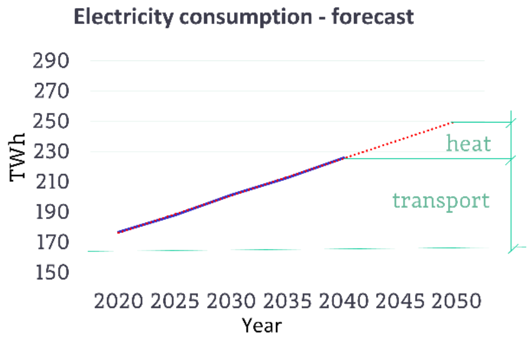

Figure 7 Forecast of electricity demand growth in Poland until 2050

The above forecast raises the question of whether it is possible to meet Poland's electricity demand with just three technologies: Onshore wind turbine, offshore wind turbine and photovoltaics.

Two variants were considered here, making conservative and optimistic assumptions about wind power development (Table 1). In the conservative variant, it was assumed that by 2040, the growth of installed capacity would be in line with [8] and over the next ten, will go through another 50% of installations onshore (up to 15 GW) and 100% offshore (up to 16 GW). The optimistic variant assumes that the potential identified by the Polish Wind Energy Association of 25 GW and 29 GW, respectively, will be used. Depending on the variant, wind energy will allow the generation of a corresponding 100 TWh or 209 TWh of electricity in 2050 (Table 1). It was further assumed that the remaining part of the energy,

Table 1 Summary of key figures characterising the size of RES installations for the optimistic and conservative scenario

Scenario	Conservative		Optimistic	
	Installed Capacity	Energy Production	Installed Capacity	Energy Production
	GW	TWh	GW	TWh
Offshore	16	64	29	140
Onshore	15	36	25	69
PV capacity	170	170	70	70
PV area	**850 km2**		**350 km2**	

One may ask whether it is realistic to build photovoltaic installations of an extreme 170 GW in Poland. It is not unrealistic. As an example, today (March 2023), more than 13 GW was installed in Poland, and in Germany, it is about 80 GW [7].

Thus, from the point of view of the annual energy balance, it can be hypothesised that it would be possible to meet the needs only by using solar and wind energy,

The question of power balance remains. It is clear that energy storage facilities would play a key role here. The question of the needed size of such storage facilities must, therefore, be raised.

i.e. 170 TWh for the conservation variant and 70 TWh for the optimistic variant, would be generated using photovoltaic panels. For Polish insolation conditions, this implies the need to build photovoltaic installations of 850 km^2 or 350 km^2, respectively.

An attempt was made to estimate these quantities for two cases, in which the authors were able to obtain the data needed for the necessary calculations. They were scaled linearly so that the total electricity demand was 250 TWh and was equal to the smelting for three variants: generation with onshore wind only, solar only and optimal value of solar and wind.

The first case is if all the electricity was generated in onshore wind power plants. The second case assumes that it is generated in onshore wind farms and photovoltaic panels in the same proportion as in Poland in 2022.

For this purpose, graphs averaged for 15-minute intervals of instantaneous demand in Poland and similarly averaged generation from wind power plants were superimposed and scaled so that annual demand and generation amounted to 250 TWh. Similarly, calculations were made for generation from panels only and for generation from wind and solar power plants in a proportion that will ensure the minimum size of energy storage facilities. The results obtained are illustrated in Figures 8 - 13.

In the first case, the installed capacity of wind power plants would have to be about 90 GW and storage capacity about 33 TWh. With solar-only generation, their capacity would have to be about 170 GW and a storage capacity of more than 60 TWh. In the case of the optimal structure, the combined capacity of both types of generation sources would have to be about 100 GW and storage capacity would be reduced to about 16 TWh. The wind would then generate 68% of electricity and solar 32%. Interestingly, these proportions are close to those of the 2022 analysis.

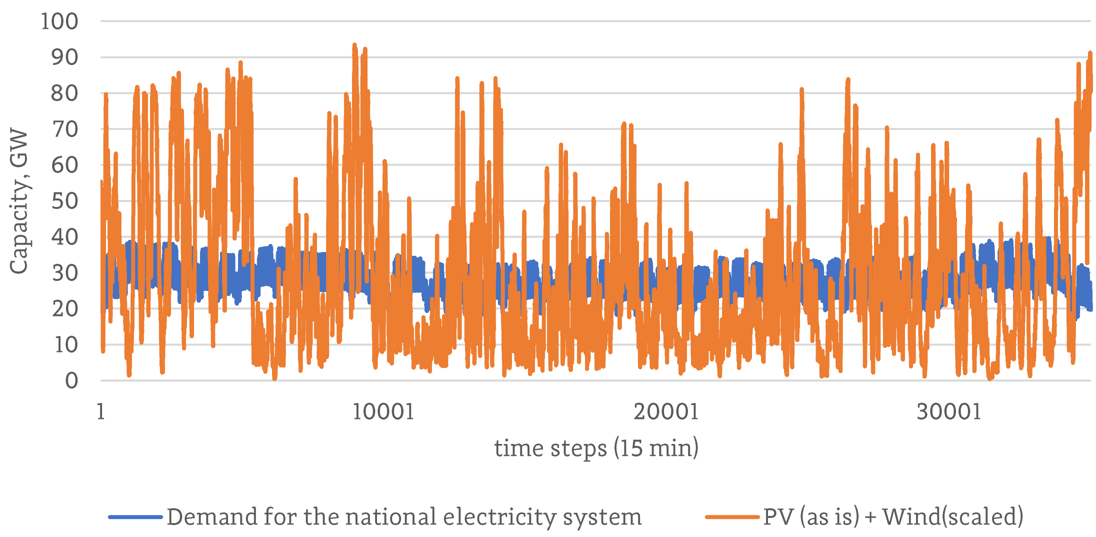

Figure 8. Instantaneous electricity demand and generation from onshore wind power plants (PV capacity as it is, Wind onshore scaled to total generation 250 TWh).

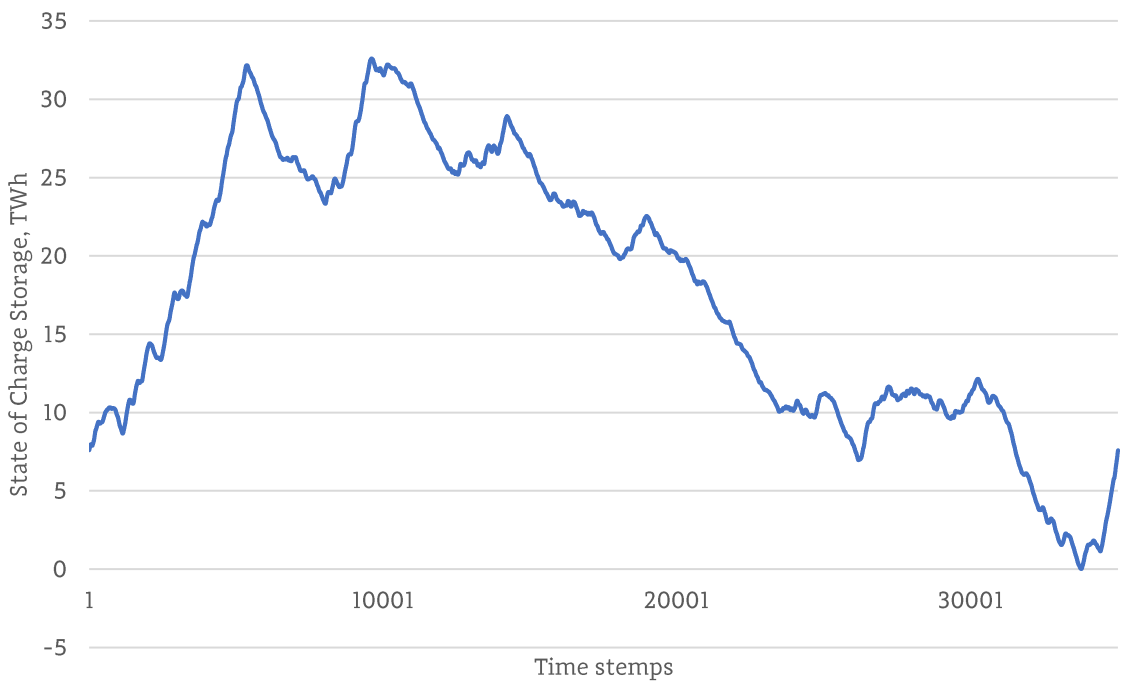

Figure 9. State of charge of batteries during the analysed year (PV capacity as it is, Wind onshore scaled to total generation 250 TWh)

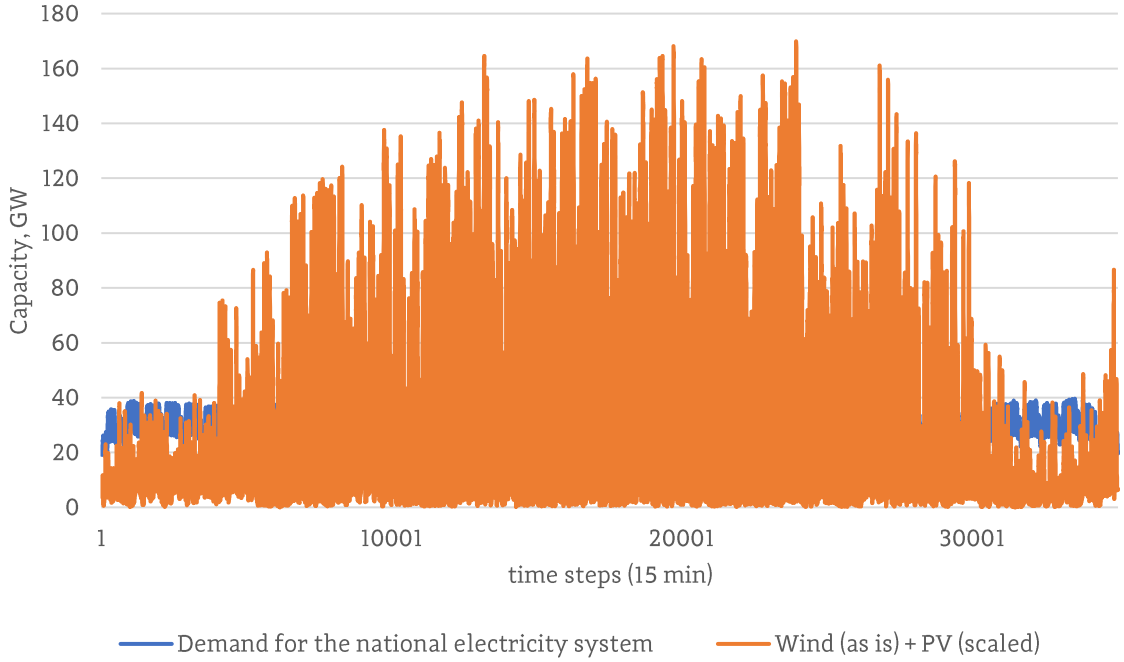

Figure. 10 Instantaneous electricity demand and generation from onshore wind power plants (PV capacity scaled to total generation 250 TWh, Wind onshore as it is).

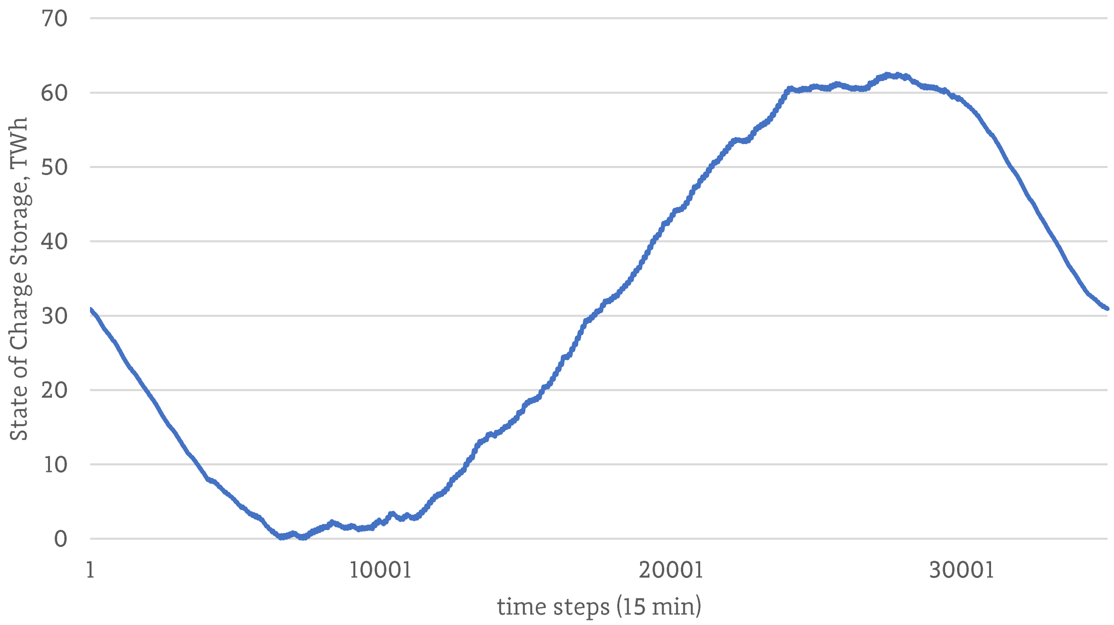

Fig.11 State of charge of batteries during the analysed year (PV capacity scaled to total generation 250 TWh, Wind onshore as it is)

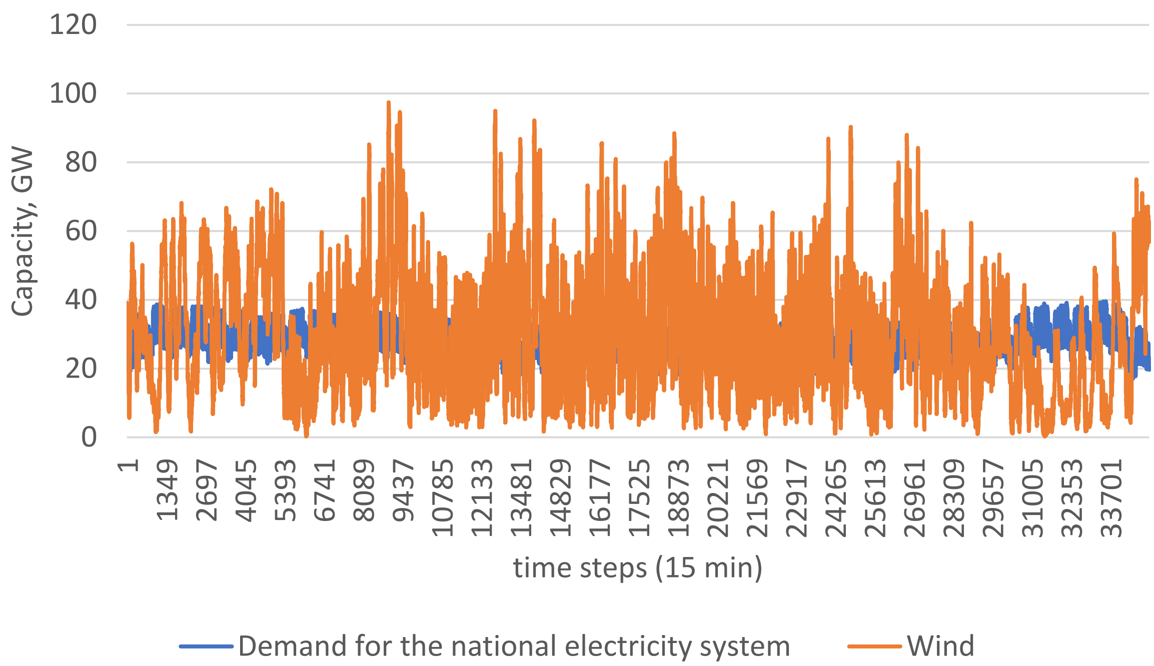

Figure 12 Instantaneous electricity demand and generation from onshore wind power plants (PV and Wind scaled separately to total generation 250 TWh to minimise storage capacity).

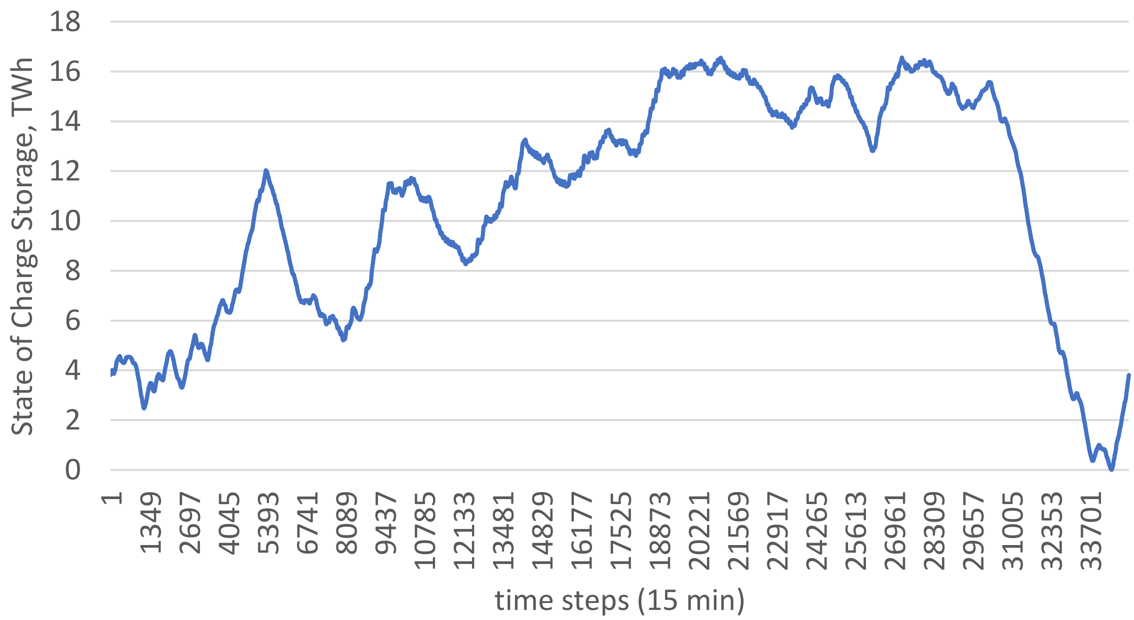

Figure 13 State of charge of batteries during the analysed year (PV and Wind scaled separately to total generation 250 TWh to minimise storage capacity)

It should be noted that the results obtained are for a situation that applies to conditions in one particular year. In practice, both generation conditions and the demand profile will change. The differences may be

The appearance of offshore wind power plants in Poland's power system will significantly reduce storage needs. However, this will remain the same fact, which is that they will be huge.

Conclusions

The transition of the Polish energy system to a climate-neutral state by 2050, without relying on fossil fuels or nuclear power, is a complex yet feasible goal. This study has explored the necessary transformations in both the heating and electrical sectors, considering current technologies and future advancements.

Based on a simple simulation, it has been determined that achieving climate neutrality in Poland's energy sector by 2050 requires significant infrastructure changes and advancements in renewable energy technologies. The primary focus is on increasing the installed capacity of weather-dependent renewable energy sources, such as wind and solar power, to exceed 60 GW. This is a crucial step to meet the projected electricity demand as the country transitions away from fossil fuels.

A key element in this transition is the need for substantial energy storage capacity. The simulations indicate that storage capacity must be greater than 20 TWh to ensure a stable and reliable energy supply. Without these large storage facilities, it will not be possible to meet energy demand consistently. This highlights the importance of developing advanced storage solutions alongside increasing renewable energy capacity.

The balance between photovoltaic (PV) and wind energy plays a critical role in this strategy. Optimizing the spatial distribution of these resources is essential to maximize efficiency and minimize the need for extensive storage. This involves strategically placing wind and solar installations in locations that leverage geographic and climatic advantages. For instance, coastal areas may be more suitable for wind farms due to higher wind speeds, while inland regions with higher solar irradiance could be ideal for solar power installations.

Furthermore, various activities and technological improvements can potentially reduce the required installed capacity and storage needs. Advances in energy efficiency, grid management, and the integration of emerging technologies like hydrogen production and storage can contribute to this reduction. For example, improving the efficiency of buildings and industrial processes can lower overall energy demand, thereby reducing the pressure on renewable energy sources and storage systems.

Another important consideration is ensuring a safety margin in both energy production and storage. This safety margin is essential to accommodate fluctuations in demand and supply, as well as unforeseen disruptions. For example, during periods of low wind or solar output, having a robust storage system and diversified energy mix can prevent blackouts and ensure a continuous energy supply. This margin will enhance the resilience and reliability of the energy system, making it more robust against potential challenges.

In conclusion, achieving climate neutrality in Poland's energy sector by 2050 is a complex but attainable goal. It requires a significant increase in the installed capacity of renewable energy sources, substantial energy storage solutions, and strategic planning to optimize the balance and spatial distribution of PV and wind energy. Technological advancements and efficiency improvements can reduce the overall capacity and storage requirements, while a safety margin in energy production and storage will ensure system reliability. By addressing these critical factors, Poland can successfully transition to a sustainable and climate-neutral energy system.

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