Integrating Variable Renewables in Poland

Eight points on integrating variable renewable energy to the Polish power system

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Forum Energii is the Polish think tank forging the foundations of an effective, secure, clean and innovative energy system.

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Foreword

The Polish electricity system is undergoing major changes. Modernization efforts regarding grid infrastructure and the retirement of parts of the largely coal-based generation fleet open opportunities to prepare the system for larger shares of variable renewable energies.

Their increase in the Polish power system is highly likely. Fast technology cost decline for wind and solar in recent years and close-to-zero marginal costs of these energy resources as well as their contribution to energy independence will likely accelerate the development of variable renewable energy sources in Poland. Wind and solar power differ from other, also renewable energy technologies since their output depends on weather conditions. Integrating these resources into the power system is therefore a particular challenge – yet one that can be addressed through a range of options.

In the process of choosing and implementing these options, Poland can benefit from the positive and negative lessons of other countries who have integrated larger shares of wind and solar PV into their systems and from the experience Polish stakeholders have already gained. Already now, Poland has deployed 5.8 GW of onshore wind and, according to declarations of the Polish Ministry of Energy, considers to deploy around 2 GW of solar PV in coming years.[1]

This study presents eight main areas of action that facilitate the further integration of these variable renewables in the specific context of a changing Polish power system. Not all integration options will become relevant for Poland at the same time. It is, however, crucial to engage in an open discussion early on to raise awareness and to avoid adverse effects of acting too late. The present study aims to contribute to this process by providing a basis for debate.

Yours faithfully
Joanna Maćkowiak Pandera, PhD
President, Forum Energii

2. Results in a Nutshell

- The share of variable renewable energy sources in Poland is set to increase over the coming years. The characteristics of these electricity sources require greater system **flexibility** both on the demand and on the supply side to respond to fluctuations in generation. Poland is at an important crossroads to introduce needed flexibility into its generation fleet and has started to take promising steps to flexibilize demand.
- Poland has taken first steps to introduce flexibility into its energy system. A demand-side response (DSR) programme was launched in 2017. There is a further need of consecutive development of this programme and other system services.
- Aging grid infrastructure and generation units will require **modernization** efforts in Poland. This is an opportunity to update and reinforce the grid and generation fleet in a way that facilitates the integration of variable renewables in a cost-efficient manner.
- Poland is not alone in tackling challenges related to changes in its energy system. Continuing efforts to improve **regional cooperation** – in terms of governance, market rules, grid integration and operation – can distribute the challenge of integrating variable renewables over larger areas, helping to smooth operation of the system and increase security of supply.
- In addition to low-hanging fruits and immediately available options to facilitate the integration of variable renewables, more **advanced steps** like coupling the electricity and transport sectors or benefitting from declining prices for battery storage, may become relevant at higher shares of variable renewable energies in the electricity sector.

3. Introduction

The Polish energy mix is changing. On 26 December 2016, wind energy provided almost a third of Poland's electricity demand, reaching a new record.[2] While absolute figures still show a rather small share of variable renewables in the generation mix over the year (8% in 2016), almost exclusively onshore wind, variable renewables[3] will play a growing role in the future. Wind and solar power have seen tremendous technological improvement and cost declines in recent years. This is reflected in the outcome of auctions worldwide, where, in many regions, these sources of electricity have reached prices making them cost-competitive with conventional generation (see Figure 1). Costs for variable renewables are projected to decrease even further in the future, making them game changers in power sectors around the globe. These developments are likely to lead to the arrival of higher shares of variable renewables in Poland as well, where additional arguments in their favour may prompt their deployment. In particular, renewables as domestic sources of energy can contribute to closing a potential generation gap and to strengthening energy import independency.[4, 5] Their contribution to Poland's emissions reduction goals – both in terms of climate change mitigation and local air pollution – is an additional factor making the arrival of higher shares of variable renewables likely.

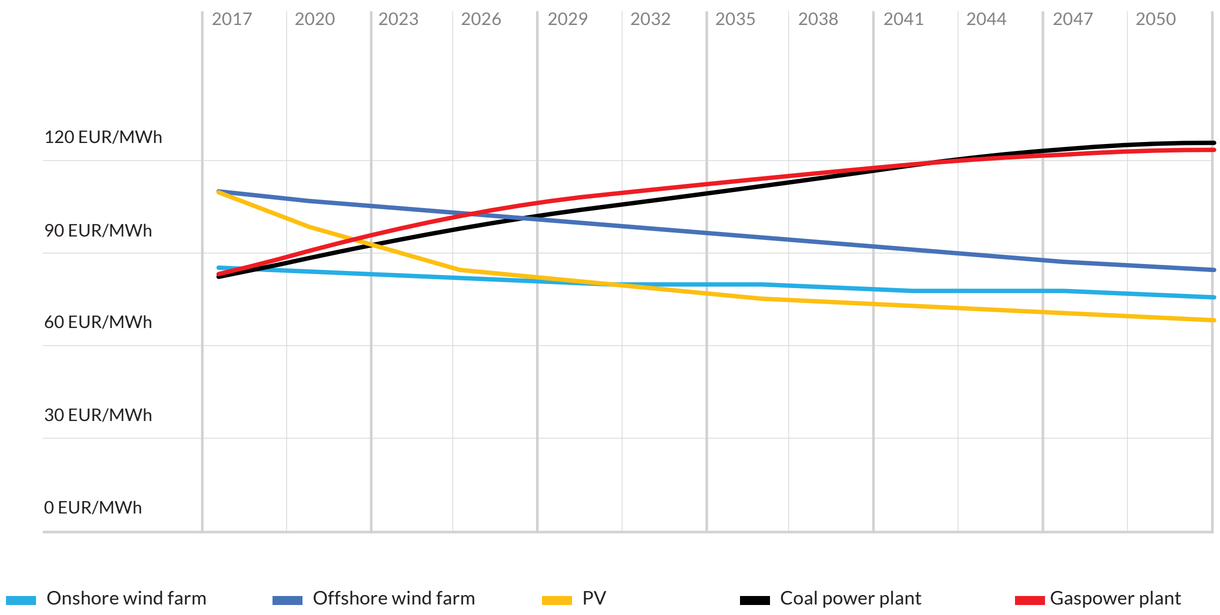

Figure 1: Projected levelised costs of electricity for key technologies in Poland. Data source: Forum Energii 2017a

Despite the manifold positive effects of variable renewables, their inherent features of being directly dependent on the availability of wind and sunlight create challenges for power systems and those who operate them, not only in Poland. The resulting lower capacity value, i.e. the availability of these sources of electricity at any given point in time, can however be mitigated through a range of options. By distributing variable renewables regionally, depending on resouces and grid availability, by enlarging operation areas across countries or by making other components of the power system more flexible, the need for backup capacity that could compensate for a lack of wind or sun decreases.[6]

There is an urgent need to modernize the Polish power system, both on the grid and on the generation side, due to aging infrastructure. Given this need and the experience that has already been made with the integration of renewables, Poland is in a favorable position to facilitate the introduction of higher shares of low-cost wind and solar PV while carrying out a necessary modernization process. The experience of other countries shows that increasing shares of variable renewable electricity generation and a safe and reliable operation of the power system can go hand-in-hand.[7] The present report aims at presenting options that are available to facilitate the integration of the growing shares of variable renewables in the specific context of changes in the Polish power system. Rather than formulating final recommendations, its aim is to provide the ground for a fact-based debate, structured around eight key points:

1. The Polish electricity grid is in need of modernization and efforts are underway to achieve this. Within the process, it is possible to prepare the system for larger shares of variable renewables and facilitate their integration.
2. The conventional power fleet in Poland will undergo inevitable modernisation and replacement. This is an opportunity to ensure conventional capacity is made more flexible to partner with variable renewables.
3. Flexibility is also key when it comes to the demand side. Considerable potential exists and first promising steps are pointing in the direction of ensuring demand responds to market signals, easing the integration of variable renewables.
4. For Poland as for other countries, engaging in European regional cooperation efforts and debates can yield benefits in terms of efficient and stable system operation – including the easier integration of larger shares of variable renewables.
5. Given its large district heating network and growing interest in electric mobility, Poland is well placed to tap the potential of coupling sectors[8] and thereby improving its capability to adapt to variable renewable energy generation.
6. In addition to its good heat storage potential, Poland will be able to benefit from downward price trends in battery storage. These storage options will become more important at higher variable renewable energy shares, potentially providing system services and flexibility.
7. The addition of variable renewables can be regionally steered, through various planning tools. This facilitates coordinated integration instead of uncontrolled development.
8. Variable renewable energies are able to take on system responsibility that further facilitates their integration, e.g. by providing system services, if the relevant markets are designed appropriately.

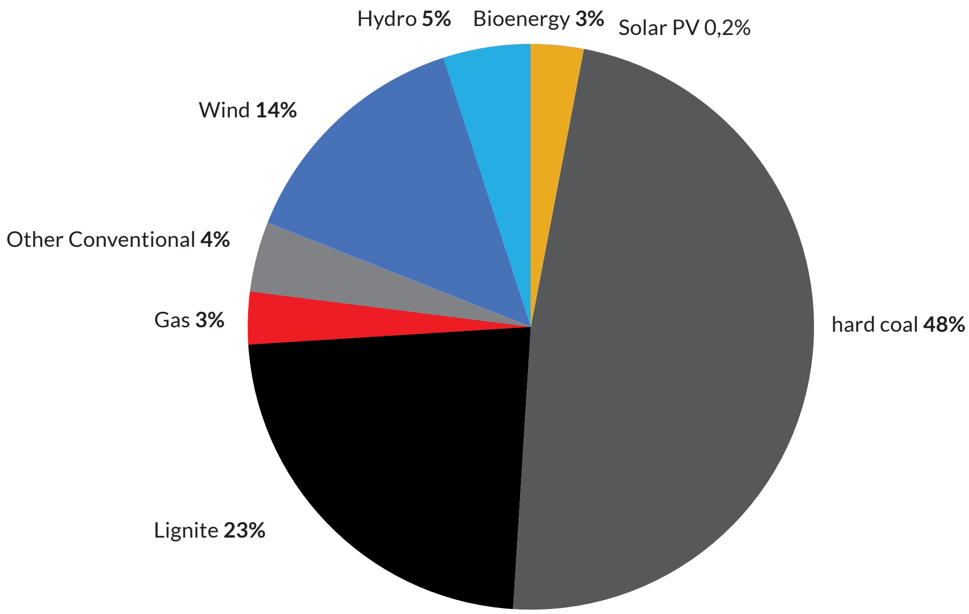

Figure 2: Polish electricity generation - installed capacity 2016. Data source: ARE, 2016.

Poland's electricity mix relies heavily on coal (hard coal and lignite).[9] Renewables, including waste, contributed for 14% of electricity generation (wind 7%, biofuels and waste 6%, hydroelectricity 1%) in 2016, see Figure.[10] By the end of 2016, 8 GW of renewable energy capacity were installed in Poland (of which 5.8 GW wind onshore, 1 GW hydro, 0.9 GW biomass, 0.2 GW biogas and 0.2 GW solar PV) out of a total electricity capacity of 41.2 GW, see Figure .[11] Poland has had one of the fastest growth rates for wind energy in Europe in recent years; installed capacity between 2012 and 2015 doubled.[12] The Polish grid has so far been able to absorb growing shares of variable renewables without major difficulties.[13] However, as the experience of countries with high and growing shares of wind and solar PV shows, challenges in terms of system operation and stability best be tackled early on.[14]

In terms of total energy supply, Poland depends on imports for 30%, mainly oil and gas from Russia, and this number has been steadily growing, from 1% in 1990.[15] In the mid-term future, Polish import dependency is likely to rise due to a predicted fall in production of comparatively uncompetitive domestic coal for electricity and heat by the 2030s.[16] Domestic power production in 2015 was able to cover demand with a small net export share of 334 GWh in 2015 while in 2014 and 2016, Poland imported more than 2,000 GWh of electricity.

Pursuant to the European Union's (EU) 20-20-20 targets, Poland has a goal of 15% renewables of gross final energy consumption by 2020, which for the electricity sector is translated into

19.3% renewable share in gross final electricity consumption. Poland is currently lacking long-term targets for the electricity sector due to delays in the release of a new Polish energy policy strategy up to 2050. The International Renewable Energy Agency (IRENA) has assessed that Poland could achieve up to 25.9% of gross final energy consumption in 2030 and up to 37.7% in the electricity sector.[17] With a current share of 14% renewables in electricity consumption and signs that Poland might not reach its 2020 renewables target[18], this vision seems highly ambitious today.

Beyond these targets, global trends in energy such as the drastic cost decline in renewable energy technologies[19] and the strive for emission reductions[20] as well as local issues like air pollution and import dependence lead to a likely increase in the share of variable renewable energies in Poland and beyond.[21] How these can be integrated while using the opportunity ofthe necessary modernization of the Polish power system will be presented in the following eight points.

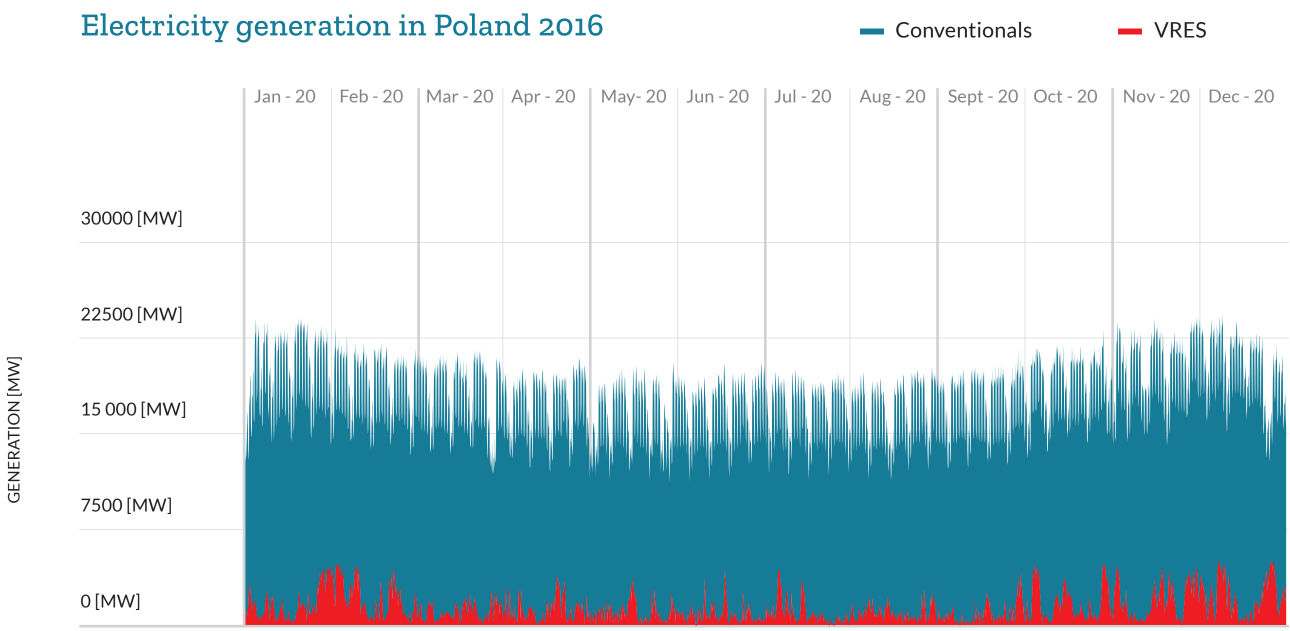

Figure 3: Electricity generation (conventional and variable renewable energy) in Poland in 2016. Data source: ENTSO-E Transparency Platform.

4. Eight Points on Integrating Variable Renewables in Poland

The following eight chapters discuss available options to facilitate the integration of variable renewable energies into the Polish power system.

4.1. Modernizing the national grid to accommodate renewables

The necessary modernization of the Polish electricity grid offers opportunities to accommodate growing shares of variable renewables.

Grid modernization and extension often constitute a cost-efficient means to accommodate variable renewables before other flexibility options are tapped.[22, 23] A reliable national electricity grid is indeed essential to balance demand and supply for power across the country.

PSE, the transmission system operator (TSO), and five major distribution system operators (DSOs) are key actors in the process of modernizing the Polish power grid. Around 80% of 220 kV lines, 56% of 400 kV lines and 34% of substations in Poland are over 30 years old and significant need for investment[24] has thus been identified to secure grid stability in the long run.[25] PSE currently estimates the investment need in its grid to around PLN 13,265 Mio. (€ 3,116 Mio.) from 2016-2025.[26] At the distribution level, the situation is similar, with grid infrastructure being, on average, 30 years old and depreciation reaching 75%.[27] Currently, the quality of electricity supply in Poland – often reflected by the System Average Interruption Duration Index (SAIDI) – is below EU average.[28] The aging infrastructure also leads to a growing risk of brown-outs[29], creating a strong case for modernization.

Another challenge are current waiting times for the connection of additional renewable energy installations. As the Polish energy regulator reports, at the end of 2015, the number of RES units waiting for connection amounted to more than 5,000 units and a total capacity of about 18 GW – roughly twice as much as the currently connected renewable energy capacity in the country.[30] These figures are, however, influenced by the fact that grid connection permits are often requested early on in the project cycle, making it difficult for system operators to plan the grid extension accordingly.

In addition to the age of the Polish grid and current quality of supply, developments occurring outside Poland have put additional stress on the Polish system, in particular increasing renewable energy generation with insufficient internal transmission infrastructure within Germany (see also Point 4).

Efforts to update the grid and implement modernization measures as no-regret options are underway. From 2014 to 2019, Polish DSOs plan to spend PLN 42 billion (EUR 10.07 billion) on the development of grid infrastructure. For example, ENEA S.A. is planning annual investments of PLN 800 to 900 million (EUR 191 to 215 million) and leveraging a loan from the European Investment Bank to build or modernize 460 km of high voltage and 3,800 km of mid- and low-voltage lines in Poland's north-west.[31] Similar investments are planned by Energa, PGE and RWE/innogy.[32]

As is visible from the grid map in Figure 4, additional investments in high-voltage lines are planned in the west and north of the country, some of them – such as the GerPol Power Bridge projects in western Poland – as part of the Ten Year Network Development Plan (TYNDP).[33] The considered construction of the Młoty pumped storage plant in south-western Poland and of a 400kW transmission line to effectively use the flexibility potential offered by the plant[34] is another example for investments in grid infrastructure that will facilitate the integration of variable renewables.

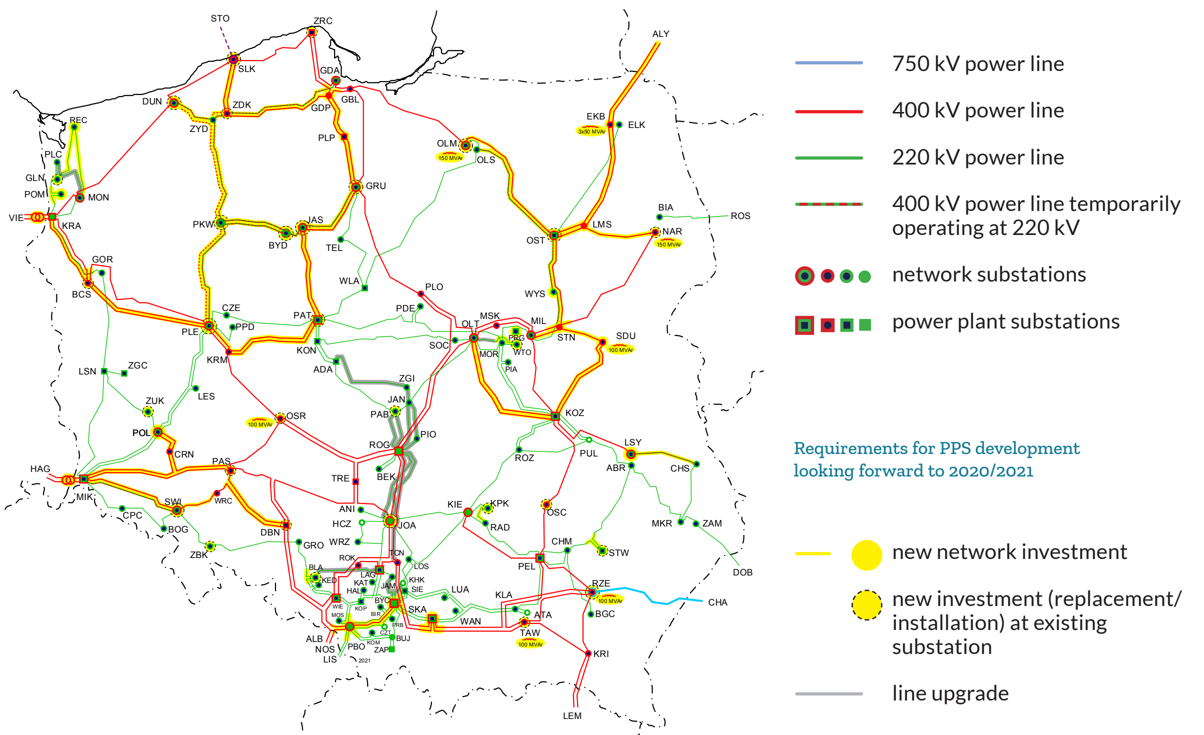

Figure 4: Polish national transmission system and considered development areas for grid expansion and interconnections (yellow). Source: PSE 2016a, p. 57

The implementation of the grid modernization process should take into consideration the distribution of renewable energy potential and should ensure the Polish power infrastructure is based on advanced technology and made "smart", allowing participants in the electricity market to react and communicate in an interconnected manner. Recent projects from German TSOs TenneT and 50Hertz[35] show that innovative technology, such as real-time monitoring of the temperature of power lines or high-temperature power lines, allows to increase the capacity of the transmission system with limited costs and fast implementation.[36]

4.2. Increasing the flexibility of conventional power plants

A system with higher shares of variable renewable energy also changes the requirements for conventional generation, especially in terms of flexibility to respond to variations in electricity generation and demand. Increasing power system flexibility is thus key in covering the increasingly variable residual load that makes up the difference between demand on the one hand and the infeed of variable renewables and from must-run power plants on the other hand at a given point in time.[37]

Conventional power plants need to become more flexible to respond to increasingly varying residual load.

As shown in Figure 5 , higher shares of variable renewable energy lead to more variable electricity production and a decreasing need for (conventional) electricity plants that run without interruption across the year and provide base-load capacity[38]. Conventional plants rather need to be able to react quickly to shifts in demand and cover the residual load[39], which will differ from day to day and season to season. This can be achieved, among other things, by enhancing the operational flexibility of conventional power plants, e.g. by increasing ramping capabilities and reducing the minimum load level.[40]

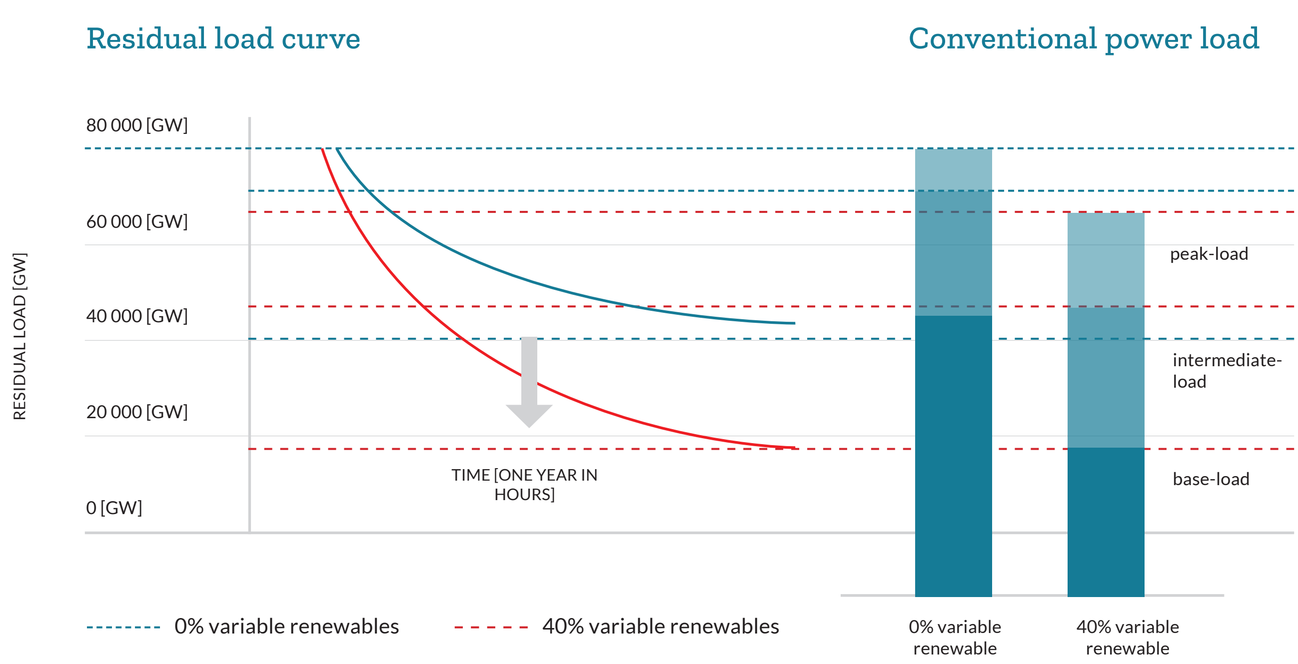

Figure 5: Impact of variable renewables (VRES) on the conventional power plant fleet. Source: Ecofys (2014), p. 39.

The Polish power plant fleet is dominated by inflexible and aging coal-fired plants. The average age for hard coal plants is around 40 years and 30 years for lignite-fuelled plants [41], while some power plants are even over 60 years old. This type of conventional capacity would currently not be able to provide fast and flexible responses to changes in residual load in a power system with higher shares of variable renewables.

PSE has projected that over the next 20 years, between 16 GW and 23 GW of electricity generation capacity will be taken offline and less than 10 GW of new capacity is currently planned. By 2025 already, there will thus be a lack of capacity of at least 3.5 GW even if future capacity additions to be commissioned in a "realistic variant" scenario are taken into account.[42] This increases the likelihood of shortage events such as the August 2015 "brown-out" in Poland. In this event, extraordinarily high temperatures occurred at the same time that many conventional generation facilities were undergoing maintenance or had to be taken off the grid for unforeseen reasons. This, in addition to decreased transmission capacities caused the TSO to cut supply in some regions (brown-out).[43] As the IEA notes, Poland may in the future face challenges especially at night-time when demand is lower, wind is still blowing and coal-fired plants cannot be turned off and ramped up again the next morning. [44] Modernizing the Polish electricity production infrastructure is therefore a necessity to ensure security of supply, independently of the development of renewables.

A long-term plan for replacing old coal-fired power plants, based on a factual assessment of costs and power system needs is thus required. Particular potential in the Polish context lies in combined heat and power (CHP). This type of plants produce electricity as well as heat, often for district heating networks. Many of these sources can be upgraded to become flexible CHP units, which could bring 4 to 8 GW of new and flexible power capacity by 2030.[45,46] Flexible CHP, as in particular the Danish experience with integrating variable renewables has shown, can be an effective mean of adapting conventional sources to a changing power system. This is because the decision of whether the focus of operation of a CHP plant should be on producing electricity or heat can take into account the demand situation in both markets. In case of low electricity prices, which occur when the output from variable renewables is high in relation to the current electricity demand, district heating companies are incentivised to rather produce heat, by bypassing the steam turbines of the CHP plants or shifting heat production from CHP plants to boilers. In the case of low demand for heat, heat storage, locally at the plant or in the context of district heating, is an option for CHP plants to continue their operation.[47] The decision whether gas-fired units, especially as CHP units, are to be added to the system given the more flexible response they can often provide should take into account other considerations such as import dependence.

Examples from other countries like Denmark show that different technical options exist to retrofit and modernize coal-fired plants to increase efficiency and operational flexibility.[48]

These options aim at reducing the minimum load level, increasing ramping capabilities or shortening start up times of conventional power plans. These measures can result in significant improvements as the example of retrofit measures at the lignite power plant Neurath in Germany show: an upgrade of the control system and key components like the boiler, condenser and cooling tower led to a reduction of the minimum load level by 25% and an increase in ramping capabilities from 6MW/min to 12 MW/min (2% Pnom).[49] Similar retrofit measures could be applied to a number of Polish coal power plants, resulting in higher efficiency and flexibility and significant benefits for a system with increasing shares of variable renewables.[50] While modernization of existing plants can increase flexibility in the medium-run, a long-term plan for the replacement and phasing out of capacity currently supplied by old coal-fired units is nevertheless still needed.

4.3. Promoting flexibility of demand

Higher shares of variable renewables in the power system increase the need for flexibility, not only on the side of generation, as discussed in Point 2, but also on the demand side. Demand response provides price signals that incentivize consumers to adapt their demand to the available supply on the power market, thereby smoothening peaks and reducing the need for backup capacity. Stimulating greater participation of the demand side through demand response and demand-side management[51] are no-regret options and a more active participation of the demand side can be a low-cost source of flexibility to the system.[51]

Making demand more flexible can ease the burden of peaks on the system and help integrate renewables efficiently.

Experience from other constituencies such as the United States (California, Oregon, New York) shows that demand response is a potentially very important aspect of flexibilizing systems and integrating renewables. It can be used for load following and frequency regulation for instance and thus reduces costs and the number of times power plants are started and stopped[52] In Europe, France and Belgium are good practice examples for the use of demand response measures. Both countries have opened up their ancillary services for demand response early on. In France, loads are additionally able to participate in day-ahead and intraday markets.[53]

Industrial and household demand for electricity in Poland, as in many countries, is still largely inflexible today. Increasing the role of demand response could help stabilize the system during summer peaks, especially when larger shares of conventional capacity are offline, as well as during the winter when demand is highest. Such a scheduled (and compensated) shifting of load is highly preferable from an economic point of view to unplanned curtailments.[54] The near-term potential for demand-side management in Poland is around 1.2 GW , which corresponds to about 5% of peak load.[55] Most of this potential can be found in the industrial sector. However, the increasing use of air-conditioning in commercial buildings as well as a certain potential in households are also to be taken into account. Promising initiatives like a new programme for DSR (Demand Side Response) by PSE are currently being implemented (Interwencyjne Programy DSR).[56] This program allows bidders to respond to requests from the TSO to shift demand and thereby alleviate strain on the system at specific points in time.

While the contracting of large industrial consumers is a low-hanging fruit for the near-term, demand response of households is a promising additional option in the longer run. To ensure price signals reach consumers, both smart meters and appropriate tariff schemes need to be in place. Poland is well advanced regarding the roll-out of smart meters, which is a sign of a trend towards a more strongly interconnected and communicating power system. To date, close to 10% of all meters are “smart meters” (about 1.3 million individual meters)[57], with plans to increase this number further. Introducing flexible tariffs for electricity instead of the regulated prices that are in place today for households would effectively allow consumers to react to price signals and benefit from incentives to adapt demand.

4.4. Strengthening grid and market integration with neighbours

Larger, interconnected grid and market areas offer the potential to match demand and supply more easily and are better capable of balancing electricity generation from variable renewables. When the wind does not blow or the sun does not shine in one area, energy from other regions and countries can partly make up for this as shown in Figure 6 for the PLEF region. What is true within national borders is also applicable on a European level. Improving the way interconnections to neighbours are used and how regional cooperation is governed can lead to a more efficient use of capacities with positive consequences on prices, the stability of grids and security of supply.

Actively engaging in regional cooperation efforts can help efficient and stable system operation.

As shown on the map in Figure 1, Poland is linked to its neighbors through a range of interconnections totalling about 10 GW (6.5 GW of which to EU countries). However, there is a significant difference between the capacity contracted for cross-border electricity trade and actual physical power flows.[59, 60]

The difference between existing technical capacity and commercial use is largely due to unplanned power flows. These so-called loop flows are largely caused by increasing variable renewable energy generation in northern Germany and a lack of sufficient in-country transmission capacity. The issue has been improving lately and is likely to further improve due to planned internal transmission capacity increases in Germany, the splitting of the joint Austrian-German bidding zone, the installation of phase shifters on the Polish-German border in 2016 and the temporary disconnection, until 2018, of the DE-PL interconnector between Vierraden and Krajnik (until 2018).[61] However, further reinforcing interconnections and their availability through effective market may yield benefits for Poland,[62] as identified by the TYNDP 2016.[63]

An interesting opportunity for regional cooperation for Poland is the Baltic Energy Market Interconnection Plan (BEMIP). BEMIP would be realized first by finalizing the synchronization of the Baltic countries to the European system but also by exploring the potential of wind

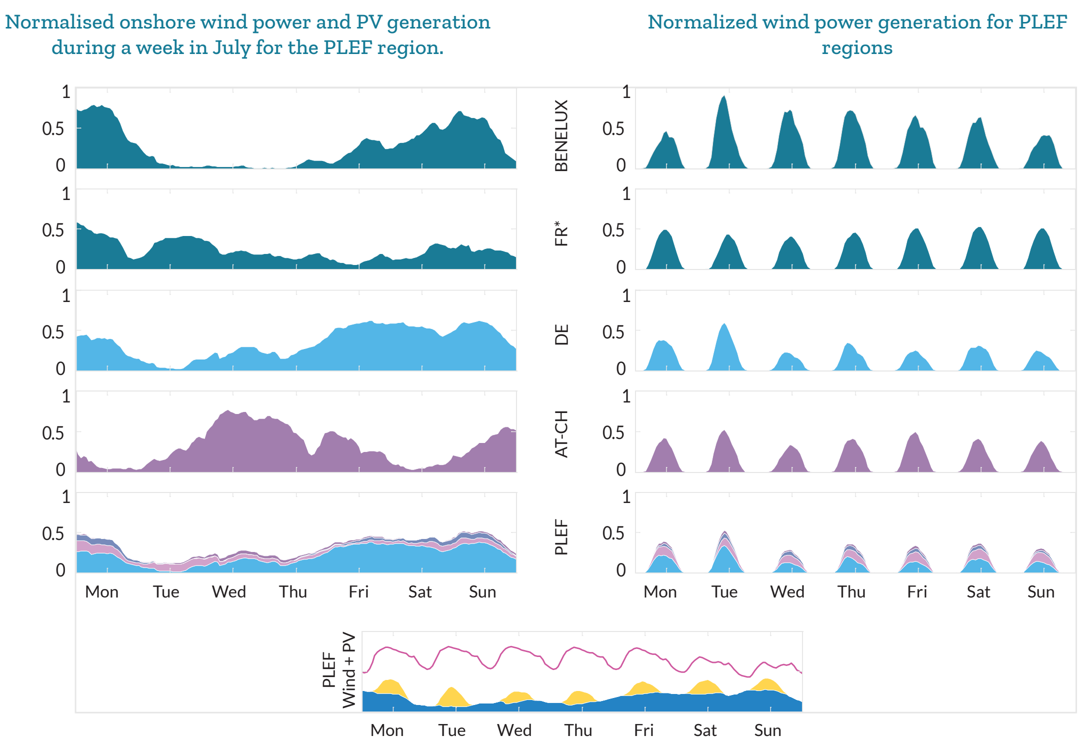

Figure 6: Load profiles as observed in the PLEF region for a week in July, normalised to peak load.. Source: Fraunhofer IWES 2015

offshore in the Baltic Sea.[64] In this region, more interconnection (including offshore interconnection) might help all involved countries increase security of supply.[65] Poland may take into account the outcome of discussions in the BEMIP process, in particular with a view to the increased deployment of offshore wind and development of the northern grid infrastructure.

Another important element of regional cooperation to facilitate the safe operation of grids while shares of variable renewable energies are growing are so-called multilateral remedial actions performed by Regional Security Coordination initiatives. The initiative targeted at achieving this goal in Central Eastern Europe is the Transmission System Operator Security Cooperation (TSC). PSE has been part of TSC since its launch in 2009 and is now part of a network of thirteen Central-European TSOs that mutually provide dispatchable capacity in case unilateral and bilateral remedial actions is not enough to secure grid stability.

On the side of cross-border market rules, important developments are also underway to ease electricity trade across borders. This mainly concerns capacity allocation and congestion management (ENTSO-E Network Code on Capacity Allocation and Congestion Management)[66] and the introduction of flow-based market coupling,[67] for which an implementation process is taking place in Europe.[68] On the EU level, the Clean Energy Package and Energy Union provisions also recognize the importance of regional cooperation in all dimensions of the Energy Union, including renewable energy.[69]

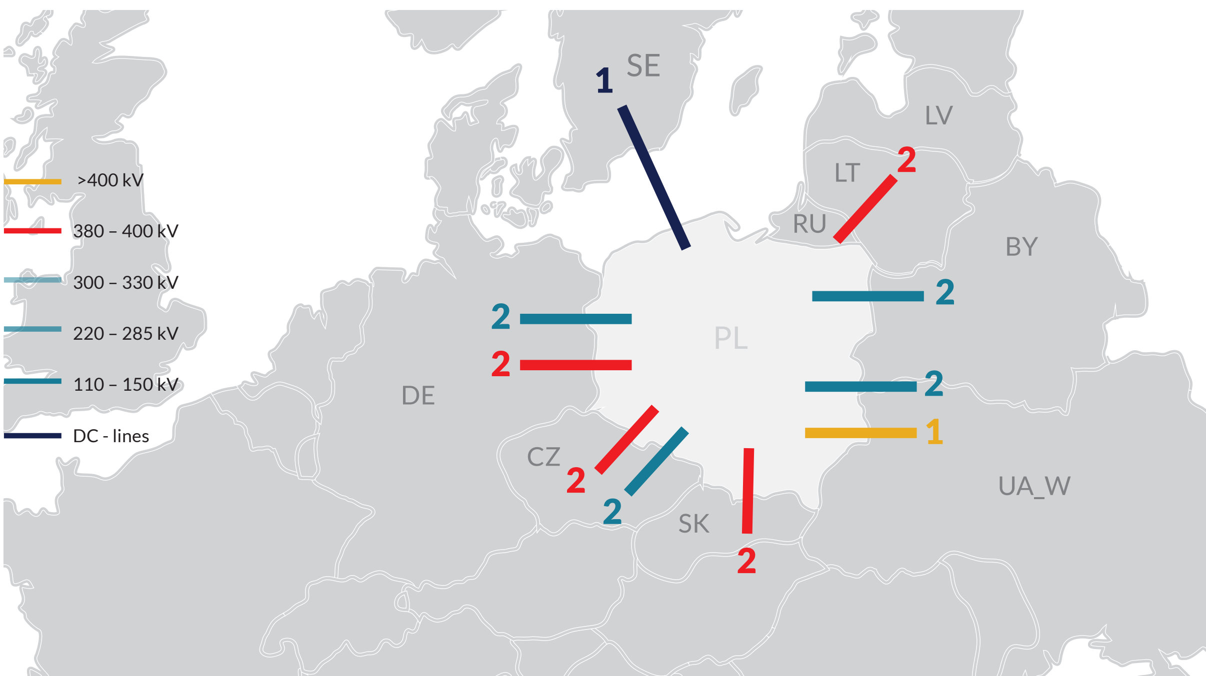

Figure 7: Number of circuits on cross-frontier transmission lines as of 31 December 2015. Source: ENTSOE Statistical Factsheet 2016, p.14

4.5. Coupling sectors to facilitate the integration of variable renewables

Linking different sectors – electricity, transport and heating – can help mitigate the effects of increased electricity generation from variable renewables. Combining these sectors makes it easier to absorb electricity produced when wind and solar plants run at high capacity and to adjust demand when this is not the case.

The power, heat, and transport sectors in Poland, as in many other countries, are today still largely separated from each other, leaving efficiency and flexibility potentials untapped. An option of major importance for sector-coupling in the Polish context is tapping the potential of Poland's district heating system as a source of flexibility.[70] Poland has one of the largest district heating networks in Europe, with 56 GW of capacity distributed across 435 systems, delivering 100 $TWh_{thermal}$ of heat and reaching about half of the Polish population.[71] This puts Poland in a favourable position to use its heating sector in order to balance the output of variable renewables. About two-thirds of heat (and 14% of electricity in Poland) is supplied in CHP plants.[72]

Poland is well placed to tap the potential of coupling the electricity, heating and transport sectors.

Investment is needed in the mainly coal-fired Polish heating sector for it to become a strong partner for growing shares of variable renewable energies. This means converting smaller, inefficient district heating systems to ideally renewable energy-fuelled CHP plants.[73]

The share of biofuels and waste in heat generation in Poland has increased from 1% to 5% between 2005 and 2015, which is a positive trend but leaves room for further improvement.[74] The example of Denmark and its success in linking district heating and renewables development can be an interesting example in this regard.[75] Other options to couple the heating and electricity sectors are electric heat pumps[76], whose number is growing also in other European countries.[77] A reform of the heating sector and a closer coupling of heating to the electricity sector is relevant not only as a source of additional flexibility for the Polish power system, but also due to advantages it may bring in terms of reducing local air pollution.

Besides heating, new sector-coupling options are emerging in particular in the transport sector. Electric vehicles can play a particularly relevant role in this regard. Through the batteries they contain, electric vehicles can act as storage facilities for electricity. They can also provide flexibility if they are charged when generation from variable renewables is high and discharged when demand is peaking, feeding back electricity to the grid. Electric vehicles may thereby provide flexibility, which can create new business opportunities for owners of electric vehicles.

For electric vehicles to not only provide flexibility in the system but also contribute to lowering emissions and thereby reduce local air pollution as well as greenhouse gas emissions, the source of electricity is of course decisive. Another aspect to keep in mind when considering the effects of electric vehicles is their potential impact on the distribution system, where an increased need for grid extension and reinforcement might occur if electric vehicles are deployed in large numbers.[78]

E-mobility has been an important topic for the discussion in Poland and visions on electric vehicle deployment – with an aim of having 1 million electric vehicles on the road by 2025 – are ambitious. A recent agreement signed between the Polish Ministry for Energy and over 40 municipalities and communes on electric vehicle development and the use of electric buses is a signal in this direction. However, so far only about 700 electric cars and 20,000 hybrid vehicles are registered in Poland and only about 300 publicly accessible charging stations exist.[79] In cities such as Warsaw and Cracow, electric buses are increasingly being used.[80] These figures are still low compared to European frontrunners like Norway, where over 100,000 electric cars are registered and over 2,000 charging stations are in place.[81, 82] To get closer to its electric vehicle ambitions, a public consultation took place on a Polish national development plan for electric mobility in 2015.[83]

Focusing on the electrification of the transport sector, in addition to environmental and power sector benefits, can also be interesting for Poland from an economic and industrial policy point of view with Polish companies like SOLARIS or URSUS being active in the electric bus and electric duty vehicle segments.

4.6. Storage as a future partner for variable renewables

Energy storage can be an additional flexibility and balancing option whose importance is likely to increase over time. For high shares of variable renewables[84], infrastructure and market improvements as well as the flexibilization of conventional sources may not be sufficient. It is important to stress that storage is only one flexibility option in the portfolio available and that systems can be run with high shares of variable renewables even if storage is not used extensively. [85, 86]

Prices for new storage technologies have decreased substantially over recent years and are projected to decline further. They can thus increasingly be used to smoothen demand and supply peaks by being charged when electricity generation from wind and solar is high and discharged when it is low.[87] From around 600 €/kWh today, average battery system prices (Lithium-ion) are projected to come down to 200 €/kWh by 2035, as shown in Figure 8.[88]

Assuming a lifetime of ten years, this would mean annual costs of 20€/kWh for the battery system. These costs can be covered by using price spreads between peak (when the battery can be discharged) and off-peak times (when it can be charged) and by providing system services, thereby becoming a potentially attractive future business model – especially in combination with rooftop PV.

In addition to available heat storage potential, decreasing prices for battery storage may make this option relevant in the longer run for Poland.

As developments in other markets show, the combination of rooftop PV installations and individual battery storage is becoming an increasingly interesting option for households due to decreasing technology cost. This combination can provide essential flexibility to the system, especially during summer peaks. This, however,v requires that potential incentives for the installation of batteries be designed to be system-friendly and facilitate operation. Alongside Italy and the United Kingdom, there has been a steep increase of such combined small-scale storage systems in Germany, where 34,000 installations with a usable capacity of over 200 MWh were already in place by January 2016.[89] California, a leading market for decentralized solar generation and storage, has seen heavy demand for its recently updated policies to promote small-scale energy storage.[90]

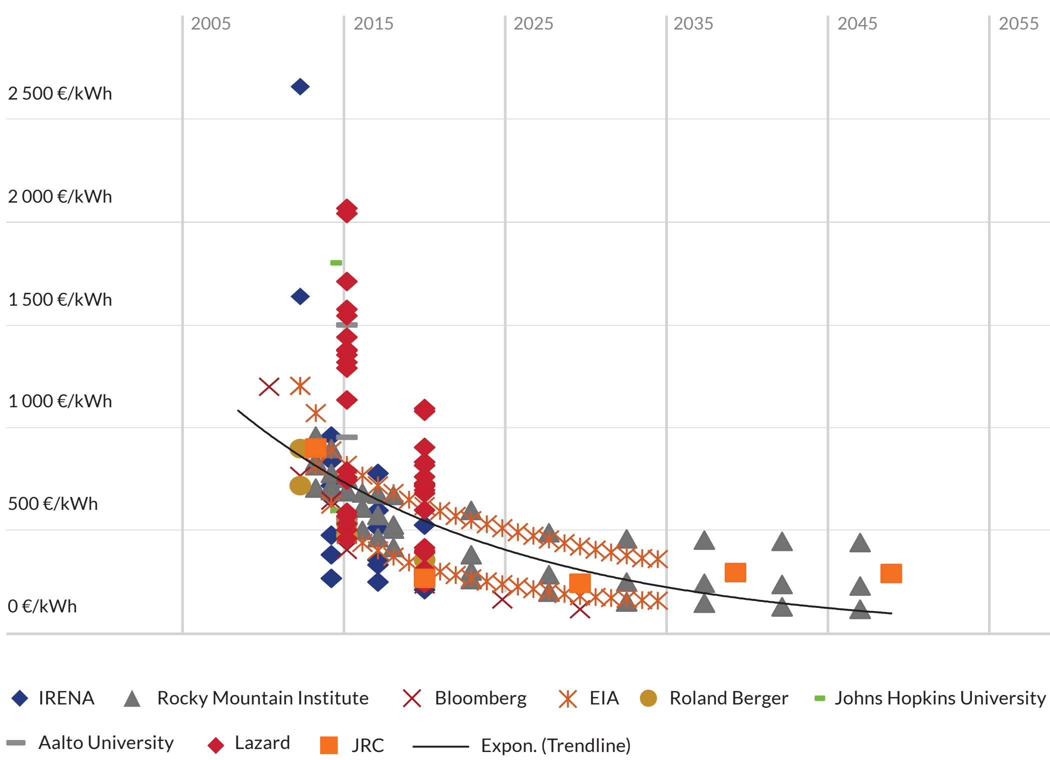

Figure 8: Current, past and projected battery system costs for lithium-ion batteries. Source: Ecofys et al. (2017), p.43

Polish market players are reacting to this global trend. Following a feasibility study phase between 2015 and 2016, PSE and Energa, with the support of the Polish Ministry of Energy, have recently signed an agreement to carry out a smart grid pilot project including hybrid battery storage with Japan's New Energy and Technology Development Organization NEDO and the Japanese company Hitachi.[91] Battery storage is a promising flexibility option especially for the distribution grid level, as it is able to provide frequency and voltage control fast and accurately. Notwithstanding, available lower-cost options for storage in the Polish context, such as heat storage, should be used first from an economic standpoint. Storage in the form of pumped hydro plants has played a role to balance the power system for a long time, for example to use price differentials between day and night-time. The additional potential of hydro storage in Poland is however uncertain, and the currently available potential is subject to seasonal weather effects as well as a need to reinforce the transmission grid in specific cases.[92]

While the importance of storage as a major source of flexibility will increase with high shares of variable renewables, it can provide ancillary services[93] such as frequency and voltage control today. In order to tap the potential of energy storage as a means of facilitating the integration of variable renewables, it must be allowed to participate in the relevant short-term markets to offer capacity. To ensure storage – as well as renewables – can play a role in these markets, the European Commission's Clean Energy Package asks for an opening of short-term and ancillary services markets to these ressources (see also Point 8).[94]

4.7. Steering the regional distribution of renewables

Many countries have successfully managed to incorporate shares of well beyond 30% renewables into their electricity systems, as is the case in Spain and Germany and even beyond 50%, as in Denmark.[95] The development of renewables without considering regional differences of grid infrastructure might, however, induce stress on system operation and thus cause significant need for grid expansion and curtailment of renewables. This is neither optimal with a view to system costs nor security of supply. In addition, uncoordinated development of renewables might raise resistance from local communities and lead to declining acceptance towards renewables. Options exist to steer where renewables are added.

Since in Poland, the share of variable renewables is likely to increase, steering the addition of renewables according to location instead of uncontrolled development is possible taking into account the experience of other countries. For an efficient and cost-effective renewables development it is important to consider different aspects: locational differentiation of renewable energy potential within Poland (wind and solar irradiation potentials), characteristics of different renewable energy technologies, system integration costs at specific locations (e.g. the costs of potential grid expansion)[96] and social acceptance of renewable energy installations.

Planning tools are available to steer where renewables are added and avoid uncontrolled development.

To control where variable renewables are added, a range of planning options exist, many of them already available to Polish decision makers. This is the case for spatial planning, where it is possible to define zones where renewable energy capacity should be developed in priority. The Polish Energy Law already requires communes to ensure electricity supply plans are in place, but this tool is not yet used everywhere. New tools such as Sustainable Energy Action Plans (SEAPs), which more than twenty Polish communes have already developed, further strengthen the role of local entities in planning.

In addition to local planning tools, as the experience of Germany shows, integrating regional differentiation into support scheme design for renewables also offers the possibility to steer where renewables are added. In Germany, capacity additions were long uncontrolled, but there is now a limit on how much additional wind capacity can receive support in certain areas of northern Germany because of transmission constraints.

Some markets, in particular in the US, have introduced so-called locational or nodal pricing [97], in which prices for electricity are defined for a much smaller area than in Europe and the construction of new generation capacity in areas with scarcity or ample grid capacity is thus incentivized. It is important to note, however, that this system is not primarily a tool to steer the addition of renewables and entails a series of issues to be considered.

Another way of steering renewable energy additions are differentiated grid connection charges. Depending on how the respective regulations are designed, charges vary according to whether the grid is already used heavily in a particular area. In Poland, customers connecting to the grid bear the costs of the connection (only 50% of the cost has to be paid by renewables-based as well as by co-generation-based units below 5 MW) but not the cost for grid reinforcement, which is socialized across all costumers served by a given DSO.[98] For this point in particular, it should be kept in mind – as outlined in point 1 – that the Polish grid will undergo major changes due to insufficient capacity and age anyway and that taking into account renewable energy potential in grid planning will reduce the need for measures like differentiated grid charges. Holistic energy system planning, as done by Denmark[99,100] can thus be an inspiration for optimal development of renewable energy resources.

4.8. Renewables as participants in short-term markets

As power systems increasingly integrate variable renewables, these sources of electricity are also set to play a more important part in providing necessary system services, i.e. services that contribute to system stability. To allow renewables to play this part, market requirements and system regulations need to be designed appropriately.[101]

26.12.2016: Day with large share of wind infeed (31%)

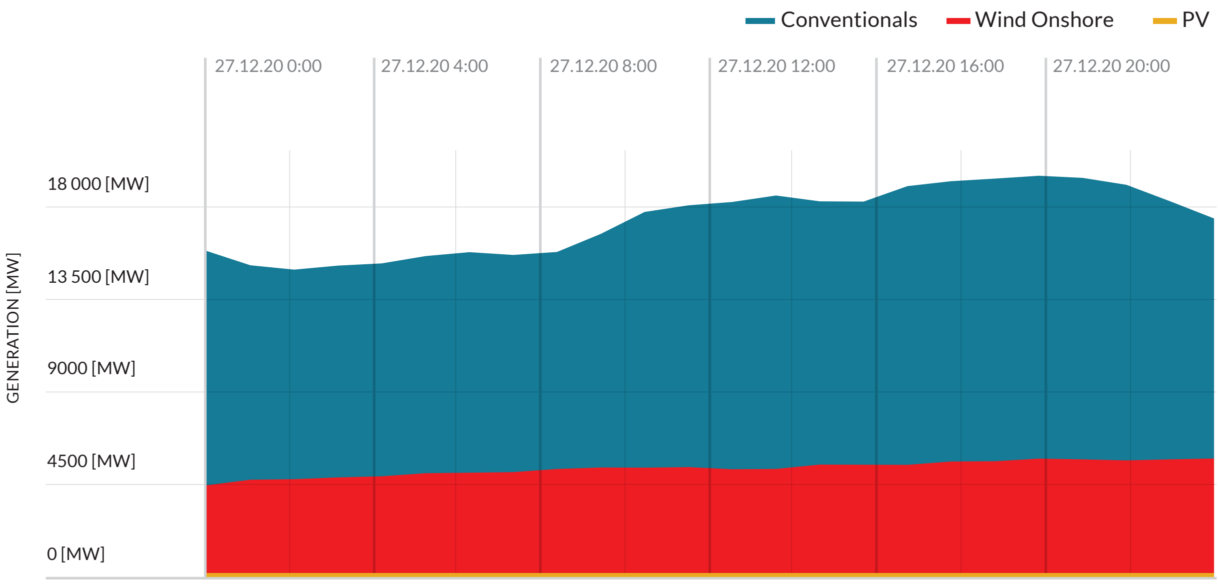

Figure 9: Exemplary day with high wind-infeed in Poland. Data Source: ENTSO-E Transparency Platform

Variable renewables play a growing role in electricity supply. As shown in Figure 9, wind power already today covers a substantial part of Polish electricity demand on windy-days, reaching up to 5 GW and 33.7% of hourly demand.[102] Yet, grid support services such as frequency and voltage control are still provided solely by conventional generation. Yet, as utility-scale wind farms in Poland are based on most up-to-date technology, wind power in Poland is fully equipped to support the grid with a number of ancillary services such as frequency regulation, fast response, voltage control and reactive power.

This shows that variable renewables are able to provide ancillary services, depending on their technological characteristics and the opportunities markets provide.[103] While renewable energy installations comply with the majority of requirements for the provision of ancillary services, no compensation can be charged for the provision of such services in Poland today. The contribution of variable renewables to system stability hence depends on the further development of a market for ancillary services.[104] Opening ancillary services markets to variable renewables and demand response means adding new sources to the pool, potentially increasing competition, hence lowering costs and strengthening stability of system operations. The role renewables and energy storage can play for system stability is recognized by the European Commission's Clean Energy Package, which demands for ancillary services markets to be opened, as well as from the European Network Code on Electricity Balancing.[105]

If markets are designed appropriately, variable renewables can contribute to system stability.

Another requirement for harnessing the potential of renewables to contribute to system stability is the creation of liquid short-term (intraday) markets. Trading on intraday markets facilitates the integration of solar PV and wind since schedules can be adapted to differences between forecasts and actual output.[106] While the share of electricity traded over Poland's electricity exchange, POLPX, has increased significantly, still only 0.3% (i.e. 63.22 GWh) of Polish electricity is traded on the intraday market.[107] To capture the benefits of intraday markets, the design of appropriate regulatory frameworks is key.

The example of Germany shows how renewables can be made responsible market players against the background of more liquid intraday markets. The country has put balancing responsibility on renewable energy producers. These players therefore have a strong incentive to balance their portfolios, improve their forecasts continuously and be active on the intraday market. [108] Balancing costs in Germany have decreased as a consequence of these balancing obligations and increased cooperation between TSOs, while shares of variable renewable energies have increased substantially.

5. Conclusion

Variable renewable energies will be an important building block of future power systems and are already being successfully integrated into the Polish power system. Several **trends and developments are likely to lead to a further increase of the share of variable renewables** in the Polish power system: declining costs of variable renewables, an aging coal power plant fleet, an aim to lower emissions and the changing regulatory environment in Europe. A growing share of variable renewables in the system will however require an **action plan on means to integrate variable renewables into the Polish power grid and market** to ensure a cost-efficient and stable operation of the system. A range of options are available to policy-makers and market actors to achieve this.

Eight of the most relevant areas for action have been outlined in this study. Across the different aspects discussed in this report – from grids to markets, from the regional European perspective to future trends – it becomes clear that there are low-hanging fruits which can help Poland tackle the challenge of integrating variable renewables into its system while carrying out a major, necessary **modernization process**. Renewables can **successfully fill the electricity generation gap** which may occur in the Polish power mix and simultaneously **contribute to reaching policy goals** such as reducing local air pollution, climate protection and energy independence.

Action is needed in several areas to ensure variable renewables are successfully integrated to a reliable and efficient power system. Large shares of the Polish **transmission and distribution grid** are in need of updating. System operators at both levels have recognized this need and have started important investment campaigns. These **efforts can be used to take into account trends such as increasing shares of renewables** as well as digitalization in a cost-efficient manner. A similar argument holds true for Poland's largely coal-based conventional power generation fleet. Here again, retrofits and replacements will be necessary due to the age of infrastructure. These changes should also be used to **increase the flexibility of conventional generation** to respond to residual load. Flexibility is also the key word when it comes to the Polish electricity demand, both at the level of households and, in particular, industry. By **incentivizing consumers to provide flexibility** by adjusting their demand, the overall electricity system becomes better placed to integrate variable generation from wind and solar PV. Additional flexibility, whether it is provided by the demand or by the supply side is important not only to integrate larger shares of variable renewables, but can also contribute to increasing security and quality of supply and to lowering system costs. **Going beyond the boundaries of the power sector** – and coupling it to the heating and transport sectors – will also result in increasing the size of the system over which variable output from wind and solar can be absorbed. Finally, renewables as one of the lowest-cost option for new electricity generation themselves can be seen as pillars of an efficient, secure and affordable electricity system. By **steering their addition at advantageous locations** and by creating market conditions that allow **renewables to provide system services**, they can increasingly become a source of stability and competitive energy costs rather than a challenge in the future Polish power system.

1. See for example www.wysokienapiecie.pl (2016)
2. ENTSO-E (2017). Another record was set on 03.01.2017, when wind power in Poland generated over 5 GW for the first time. However, as total electricity demand was higher than on 26.12.2016, the relative wind share on that day was lower.
3. Variable renewable energy sources are wind, solar PV, run-of-river hydropower, wave and tidal energy. However, wind and solar PV are the predominant technologies among variable renewables and in the focus here.
4. Forum for Energy Analysis (2016), p. 28
5. Forum Energii (2017a)
6. IEA (2017a), p. 10
7. IEA (2017a)
8. 85% of Polish electricity in 2016 was generated from hard coal and lignite plants. Source: ENTSO-E (2017).
9. IEA (2017b), p. 73
10. ARE (2016).
11. PWEA (2015), p. 16
12. IEA (2017a)
13. IEA (2016), p. 24
14. FAE (2016), p. 28
15. IRENA (2015), p. 1
16. Ecofys, Technische Universität Wien (2017), p. 20
17. As highlighted by auction results for renewable energy support around the world in recent years.
18. Source (among many others): IRENA (2017), p. 10 ff.
19. Which is e.g. reflected in the global agreement on climate protection within UNFCCC reched in Paris in December 2015.
20. Source: UNFCCC (2015).
21. Forum for Energy Analysis (2016), p. 14
22. Agora Energiewende (2014a), p. 4
23. IEA (2017a)
24. PSE (2016), p. 56: The sum of planned outlays in 2016-2025 is PLN 13,264.7 M at 2015 constant prices.
25. PSE (2016a), p. 56
26. Polish Ministry of Economy (2013)
27. Council of European Energy Regulators (2015), p. 26. The stated SAIDI values here include exceptional events. Excluding these events would increase the differences between the mentioned countries.
28. a2e, Energy Brainpool (2016), p. 27
29. Energy Regulatory Office (2016a), p. 20 (While solar PV units make up most of the units that are waiting for connection, hydropower plants account for the lion share of capacity to be connected)

30. European Investment Bank (2015)
31. PTPiREE (2015), p. 26 ff.
32. ENTSO-E (2015), p. 43 ff
33. PSE (2016a), p. 63
34. Two of the four German Transmission System Operators
35. Agora Energiewende (2017a)
36. IEA 2017, p. 43
37. Agora Energiewende (2015), p. 49
38. Residual load is the remaining part of the load after the output of must run power plants and variable renewables, wind and solar PV, has been subtracted. It is the share of load to be supplied by other (dispatchable) technologies.
39. The operational flexibility of power plants refers to the ability to change the output of the plant. Relevant parameters to determine the level of flexibility of individual power plants are ramping capabilities, minimum load level, start up times and minimum down time. Ramp rates describe the speed with which the power plant is able to increase and decrease its output, measured in percentual change of nominal capacity over time (minutes). The minimum load level is the lowest load level at which the power plant can reliably operate. See also Agora Energiewende (2017b).
40. A2e, Energy Brainpool (2016), p. 8-9
41. PSE 2016a, p.43
42. Energy Regulatory Office (2016a), p. 12
43. IEA (2016), p. 83
44. Matuszewska, Kuta, Górski (2017)
45. Wnp.pl (2017)
46. Ea (2015), p. 27 ff
47. Blum, Christensen (2013)
48. Agora Energiewende (2017b), p. 65 ff
49. IRENA (2015), p. 28
50. There is no universal definition of these terms and they are often used interchangeably. However, it is important to note that demand response is reactive and generally describes the reaction of the demand side to price signals, whereas demand side management refers to the active control of demand, e.g. by the transmission system operator as part of interruptible load programmes for system balancing measures.
51. Forum Energii (2017b)
52. Lawrence Livermore National Laboratory (2017), p. 168 ff
53. Smart Energy Demand Coalition (2017), p. 11 ff
54. IEA (2016), p.92
55. Forum Energii (2017)
56. PSE (2017)

57. export.gov (2016)
58. Agora Energiewende (2016)
59. Agora Energiewende (2014a), p. 7
60. Forum for Energy Analysis (2015), p. 18
61. PSE (2016b)
62. IRENA (2015), p. 28
63. ENTSO-E (2016) p. 63
64. Kielichowska, I. (2017)
65. ENTSO-E (2016) p. 58
66. European Commission (2015)
67. Flow-based market coupling uses a new methodology to determine available transfer capacity and thus enables a more optimal use of interconnector capacities, especially in a meshed grid. As opposed to the commonly used ATC (available transfer capacity) approach, which determines net transfer capacities for all individual interconnections independently, the flow-based coupling algorithm takes into account the situation of the network, allowing for a more detailed consideration of transport limits.
68. ACER (2014)
69. European Commission (2017a), p. 5 ff
70. Euroheat & Power (2015)
71. Energy Regulatory Office (2016b)
72. IEA (2016), p. 61
73. IEA (2016), p. 61
74. IEA (2016), p. 62
75. Agora Energiewende and DTU Management Engineering (2015)
76. The EU's Energy Performance of Buildings Directive 2010/31 defines heat pumps as installations that transfer „heat from natural surroundings such as air, water or ground to buildings or industrial applications". As underlined by the Heat Roadmap Europe, electric heat pumps can be a particularly efficient solution for heating in rural areas, where DH is less likely to be available. Ground- or air source heat pumps can be particularly interesting in areas with high renewable energy generation.
77. European Heat Pump Association (2015)
78. IEA (2017b), p.57
79. Fortum (2017)
80. ZeEUS (2016), p. 49 ff
81. Norsk elbilforening (2017)
82. Nobil (2017)
83. Polish Ministry of Economy (2016c)
84. What shares of variable renewable electricity can be considered "high" depends on national conditions. Roughly, a renewables share of above 50% could be considered a high share. IEA (2017) sees the "third phase" of renewable energy development as a stage with high shares of renewables, occuring for example in Denmark with 51% of electricity generation or Ireland with 23% wind and solar in electricity. IEA (2017), p. 41

85. IEA (2017), p. 11
86. Agora Energiewende (2014b)
87. IEA (2017), p.10
88. Ecofys et al. (2017), p. 41 ff
89. RWTH Aachen University (2016), p. 45
90. State of California (2017)
91. Hitachi (2017)
92. PSE (2016), p.63
93. 'Ancillary services' are a range of functions which TSOs contract to guarantee system security. The contracted services include black start capability (the ability to restart a grid following a blackout); frequency response (to maintain system frequency with automatic and very fast responses); fast reserve (which can provide additional energy when needed); the provision of reactive power and various other services.
For further information see e.g. https://www.entsoe.eu/about-entso-e/market/balancing-and-ancillary-services-markets/Pages/default.aspx.
94. European Commission (2017b)
95. IEA (2017)
96. IEA (2017), p.11
97. „Nodal pricing is a method of determining prices in which market clearing prices are calculated for a number of locations on the transmission grid called "nodes". Each node represents a physical location on the transmission system including generators and loads. The price at each node reflects the locational value of energy, which includes the cost of the energy and the cost of delivering it (i.e. losses and congestion). Nodal prices are determined by calculating the incremental cost of serving one additional MW of load at each respective location subject to system constraints (e.g. transmission limits, maximal generation capacity). Differences of prices between nodes reflect the costs of transmission.", Dietrich et al. (2005), p. 13.
98. Agora Energiewende (2014a), p. 26
99. Danish Government (2011)
100. Energinet.dk (2015)
101. Agora Energiewende (2016), p. 9
102. ENTSO-E (2017)
103. European Wind Energy Association (2014)
104. PWEA (2016)
105. European Commission (2017c)
106. Agora Energiewende (2016), p. 67
107. Energy Regulatory Office (2015)
108. Fraunhofer ISI et al. (2015)

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Integrating Variable Renewables in Poland

Eight points on integrating variable renewable energies to the Polish power system

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