Poland: climate neutrality by 2050

Electrification and sector coupling

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Forum Energii is a think tank active in the energy sector. Our mission is to forge the foundation for an efficient, safe, clean, and innovative energy sector based on data and analysis.

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Foreword

In this analysis, we go forward in time to 2050 when the key source of energy will be electricity, the most noble form of primary energy that can be imagined today. Electrification will be a hot topic of the early 2020s. It sets the direction of inevitable changes in many areas of our life, including in the transportation and heating sectors. This will mandate the closer cooperation of these sectors in the future power-generation system, which will be one that is entirely different from today's. The integration of three industries—transportation, heat, and power generation—is the new concept for the operation of the entire energy sector. This approach involves streamlining energy production and consumption, which will deliver financial benefits, reduce emissions, improve energy security, and allow us to discontinue imports of fossil fuels.

Together with Navigant, we prepared models and analysed how near-zero emissions, electrified Polish electricity, and heat-production systems could work in 2050. It is safe to assume no one doubts any longer that the energy sector is bound to be revolutionised. It is easy to picture 2030, as from the sector's perspective we are nearly there. Imagining 2050 is a bigger challenge. Which technologies will be key? How to ensure the security of the system? What to invest in? We will not avoid these decisions because in the European Union, a debate has unfolded about the climate neutrality ambitions as part of the so-called European Green Deal. Businesses and citizens demand that politicians deliver a vision of change. A sound strategy focused on the future will help avoid stranded costs and bring more benefits to the Polish economy and society.

This is why we present our new report, hoping that it will spark a substantive debate on the future of energy until 2050. There is no time to lose.

Have a good read!
Dr Joanna Maćkowiak-Pandera
President of Forum Energii

1. Introduction

The situation in the domestic and global power industry is changing rapidly. The key drivers of change include the need to reduce greenhouse gas emissions, technological advancement, and organisation of the power market, which drifts towards greater use of sources with the lowest variable costs. We claim that in the next 15-20 years, the power market will start to rely on zero- or low-emission renewable sources (in particular, on wind and solar energy generation). The future of other industries will involve electrification, which means that transportation and the heating industry will gradually ditch fossil fuels. Electrification will expand on the back of more widespread use of wind and sun as natural sources with zero production costs. Sector coupling will help resolve issues related to the variability of their operating model resulting from their dependence on weather conditions. States that manage to reasonably couple the sectors and ensure their full electrification will have a chance to build a powerful engine for the economy in the form of inexpensive energy and industrial innovation. The integration of industries and their electrification is a new, developing energy concept aimed at reducing capital expenditure and optimising asset use, which in effect will bring financial benefits, improve energy security, and help cut emissions. Sector coupling as a tool for streamlining resources will become indispensable in light of the growing electrification of the economy.

This report is focused on the following three sectors:

- power generation,
- transportation,
- heating (both district and individual heating).

These have the greatest transition potential. They will be subject to intensive changes triggered by the new energy generation model, a shift in consumer preferences and improved energy efficiency. Electrification of economy and sector coupling generates new technical concepts and models.

"Power-to-X" options have emerged. Based on renewable energy sources (RES), so-called "green" hydrogen and other synthetic gases are produced, which may be used in the production of electricity or to fuel heavy road transport. Technologies based on green gas have double the advantage, improve system flexibility and decarbonise the power, heating, and transportation sectors. Storage of zero-emission gas for use in energy production is the ultimate addition to the range of tools enhancing the flexibility and security of the power-generation system, next to existing traditional energy storage facilities and demand management.

Developing a power-generation system on volatile RES requires an effort to ensure energy security. Although for most of the time the system can operate without disruptions, temporary interruptions in supply balancing may occur when production from volatile RES reaches its minimum.

The key to success will be the use of surplus energy generated in the remaining periods, its effective storage, and flexible cooperation of all sectors on the demand side.

Poland is on the verge of major changes in key sectors of the economy. The challenge is not only to curb the environmental impact but also to upgrade the system to rely on cost-effective energy sources. Thinking about the energy sector of the future, we need to assume that it will abandon a model in which conventional power plants operate on a continuous basis while electricity or heat consumption is passive and predictable. New technologies—electric vehicles, heat pumps, variable renewable energy sources, such as photovoltaics or wind turbines, own energy storage facilities, digitalisation—are bound to alter the existing energy-generation model.

In its search for growth drivers after the COVID-19 pandemic, Poland's strategy should be long-term. The investment projects to be pursued must bring benefits for decades.

In this report, we design the decarbonised and smart energy sector of the future. Based on a vision of its desired condition in 2050, we propose a model of what such a system could look like, what challenges it would have to face, and what benefits it could bring.

2. Why is sector coupling important?

There are many reasons why we should think about a smart, coupled energy system for the future. The most important of these are:

a) Technological progress

The paradigm of operation of energy sectors is changing. Technologies in power generation, heating, and transportation are based on solutions developed a century ago. Digitisation, decentralisation of production units, advanced material technologies, and a shift in customer preferences have led to inevitable changes in these segments. The economy and society are both consistently turning towards a single basic form of energy, which is electricity. It is the common denominator, which naturally promotes a wider approach to energy sectors and the search for benefits from their close cooperation.

b) Saving resources and environmental protection

The striving for technological advancement while limiting the extraction of natural resources make RES—the starting point for electricity generation—less expensive and more readily available. The development of zero-emission technologies and phasing out of solutions based on fossil fuels are gaining pace. However, these more pure generation sources, which use the energy of the sun and wind, are subject to a certain limitation—the dependence of energy generation on weather conditions. Both energy surpluses and shortages are part of the experience. Smart cooperation between energy sectors will ensure balance within the system despite variable operation.

c) Cost reduction

The operation of sectors involving unidirectional electricity flow from the supplier to the customer leads to inefficient management of generation assets and higher cost of electricity production and supply. Full integration and cooperation consisting of bidirectional flow between energy market participants, where the customer temporarily assumes the role of a supplier, make it possible to optimise the level of installed generation and storage capacities. This would translate into a measurable reduction of financial outlays as well as development of the infrastructure and generation assets.

d) Enhanced flexibility of the power system

In tandem with the development of variable renewables, system flexibility becomes a tangible commodity. Given that the growth of variable renewables in the energy sector is unavoidable, we should seek solutions reducing the cost of system balancing. Its isolation from the two other sectors (transportation and heating) limits the possibility to create market products enhancing system flexibility, and that would only lead to a rise in electricity prices. In turn, sector integration and ensuring bidirectional flows will result in the creation of a wider range of services, cost optimisation, and ultimately lower prices of electricity supplied to end customers.

3. Figures and conclusions

What would the system look like and what benefits will be delivered by the integration of electrified sectors by 2050?

FIGURES

Lower consumption of fossil fuels

- 80% of individual heating will be ensured by heat pumps.
- 8% of district heat will be generated with the use of heat pumps.
- 42% of demand for gas in the electricity sector will be covered by domestic production of green hydrogen.
- 82% of all vehicles will be EVs.

Faster integration of renewables

- In 2050, 85% of energy will be sourced from variable renewables, without any disruptions to the security of operation of the electricity system.

More efficient production from RES

- 51 TWh of surplus energy from variable RES will be used to produce green hydrogen.

Reduced emissions

- CO_2 emissions from district and individual heating will be cut by 100%.
- Carbon dioxide emissions in the power sector will be curbed by 90% .
- 64% lower carbon dioxide emissions in transportation.

Enhanced system flexibility

- Demand for peak power will fall by 2.5 GW thanks to management of demand for electricity in the electric transportation industry.

Lower costs of the energy system

- Decarbonisation of the energy sector and electrification of the transportation and heating sectors will cut annual operating costs by PLN 316 billion relative to the scenario of maintaining the current generating structure in the power and heating industries.

CONCLUSIONS

- By 2050, the Polish energy sector can achieve climate neutrality. The primary energy sources in such a system will be renewables and green hydrogen. Ensuring energy security requires smart sector coupling and planning methods of energy storage.
- In the assumed energy generation mix, a challenge that must be overcome will be the balancing of the power system during periods when demand for electricity exceeds the low supply of variable renewables occurring, e.g., on windless days in the winter. The power deficit may reach up to 30% of peak power for several hours during the year.

  The problem can be solved by:

  - different forms of electricity storage,
  - seasonal heat or hydrogen storage facilities,
  - peak generating units utilising green hydrogen,
  - demand-side management,
  - cross-border trade in electricity.

- Electrification of heating and transportation sectors based on domestic renewable energy sources will end Poland's dependence on imported energy carriers. Poland may achieve full energy independence.
- Electrification of the heating sector must be preceded by a significant upgrade of energy efficiency of buildings to a level prescribed by law for new and renovated buildings, which will become effective as of 2021 (WT2021).
- Green hydrogen is the future. Production of it during periods of energy surplus will enable not only replacing some natural gas consumption but also storing energy effectively. Green hydrogen, which will consistently drive out natural gas, will make it possible to cut carbon dioxide emissions from the electricity and heating sectors to zero.
- Solutions enhancing the flexibility of the electricity system will be of particular importance. These will include:
    - management of charging and discharging of EV batteries,
    - management of operation of heat pumps.
- It will be necessary to introduce dynamic electricity tariffs, which coupled with market incentives will contribute to greater flexibility of the electricity system.

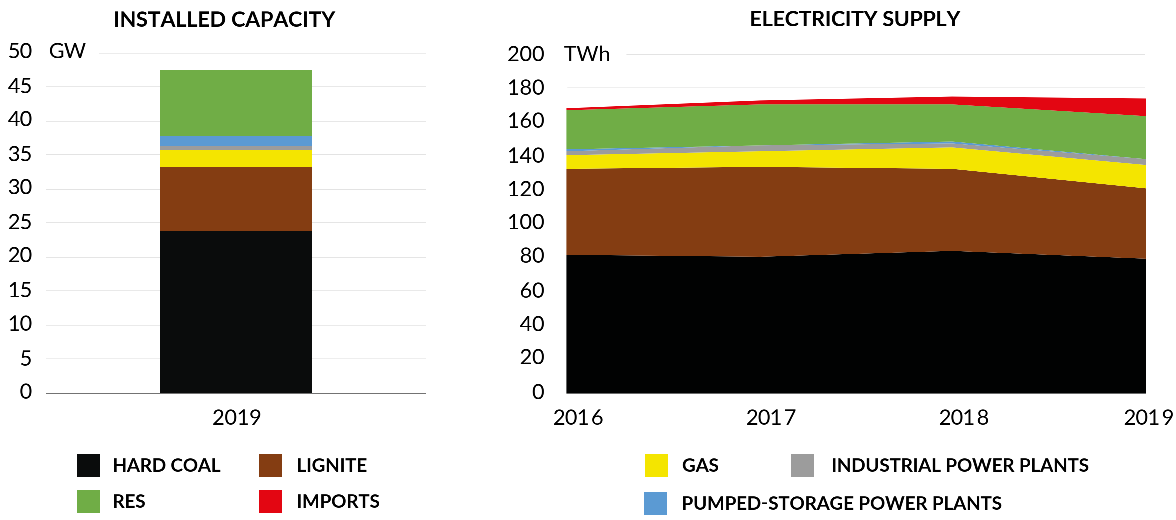
4. Diagnosis of sectors

ELECTRICITY

Installed capacity

In 2019, the total installed capacity in the power sector was 47.4 GW (Fig. 1.). Coal remains the primary energy source used in Poland. In the recent years, the increase in installed capacity was driven by the development of renewable energy sources and launch of new generating units utilising fossil fuels (coal and gas). In 2017-2018, the growth of the RES segment was thwarted by unfavourable regulatory changes—restrictions concerning auctions and distance limits for wind turbines. Only prosumer generation based on photovoltaic energy has grown rapidly over the last year, reaching installed capacity of about 1.8 GW. Poland has a large cogeneration capacity, but the share of high-efficiency cogeneration in domestic energy production has for years remained within the range of 15.5–16.5%.

Fig. 1. Installed capacity in the national power grid (GW) and electricity production (MWh)



Source: ARE, 2019

Emissions

The Polish power sector is largely dependent on fossil fuels, and the power plant fleet is aged. In 2018, the average emissivity of generating units in the national power grid was 792 kg CO_2/MWh[1], with the EU average of about 295 kg CO_2/MWh.

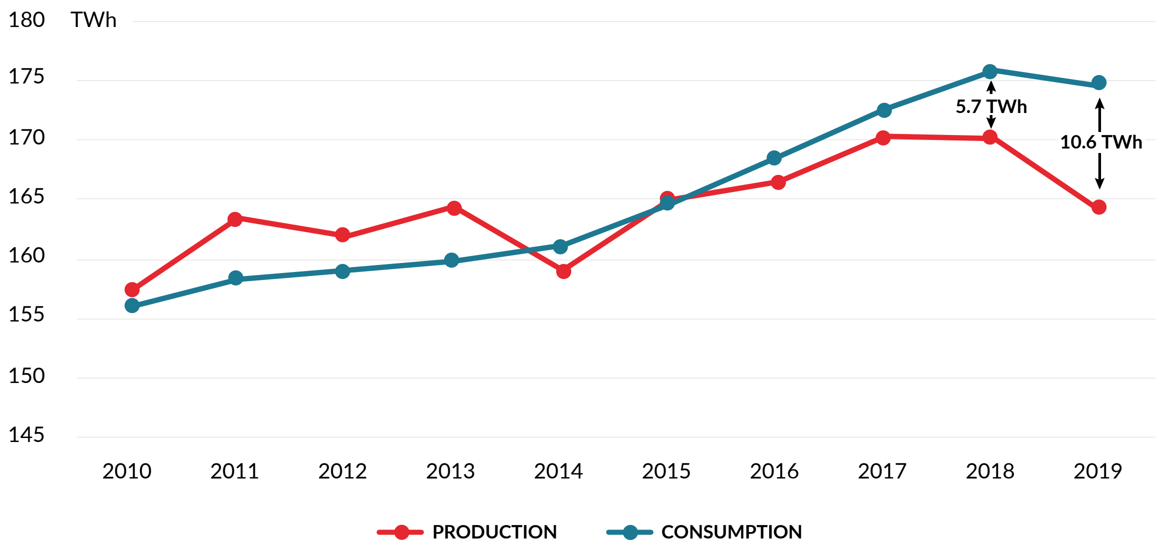
Need for modernisation

The average age of Polish lignite and hard coal power plants is more than 30 and 40 years, respectively. Based on the Ministry of Energy data from 2019, in 2016-2040 about 26.5 GW of generating capacity will leave the market to be decommissioned. The Ministry of Energy's forecast does not take into account the recent regulatory changes involving limited support for coal power plants as part of the so-called power market. As a result, generating units are likely to be decommissioned sooner.

International trade in electricity

Electricity output in Poland in 2016-2019 was stable, while imports consistently grew in connection with high energy prices on the domestic market (due to higher cost of carbon dioxide emissions) and cross-border trade facilitation. In the past, Poland was a net exporter of generated electricity and its main customers were neighbouring countries. Since 2015, Poland has been a net importer. If the high emissions from electricity production remain at the current level, the trend in imports will only strengthen in the years to come. The majority of imported electricity is procured from systems with a large share of generation from RES, i.e., from Germany and Sweden.

Fig. 2. Balance of domestic electricity production and consumption



Source: ARE, Forum Energii, 2019

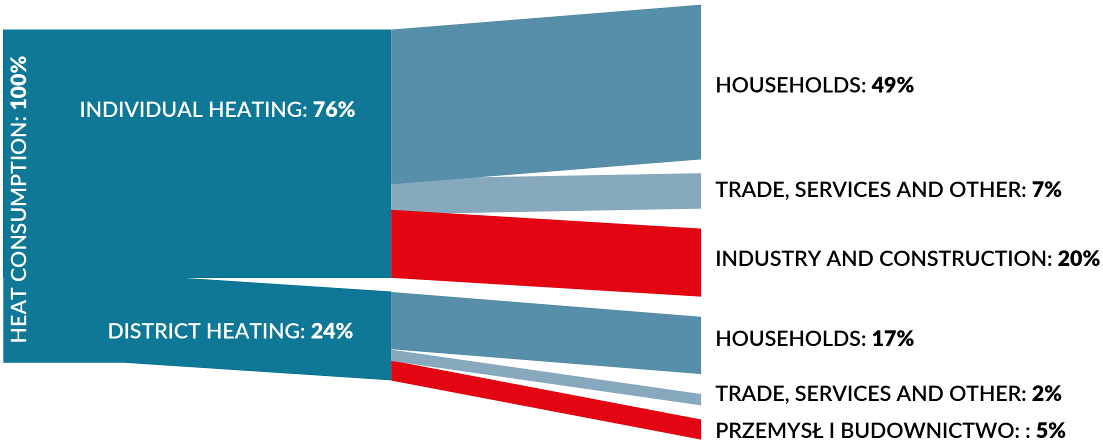
HEAT

The heating market in Poland comprises two separate segments (Fig. 3.):

- district heating, i.e., approximately 24% of heat supply,
- individual heating, which includes individual heat sources used for heating buildings, i.e., approximately 76% of heat supply.

1 https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/wskazniki_emisyjnosci/Wskazniki_emisyjnosci_grudzien_2019.pdf.

Fig. 3. Structure of heat consumption in Poland in 2018



Source: Forum Energii, 2019

Table 1 presents aggregated information on energy consumption, gas and dust emissions, and generating capacity. The heating sector in Poland is based on primary energy amounting to more than 30%.

Table 1. District and individual heating—key indicators

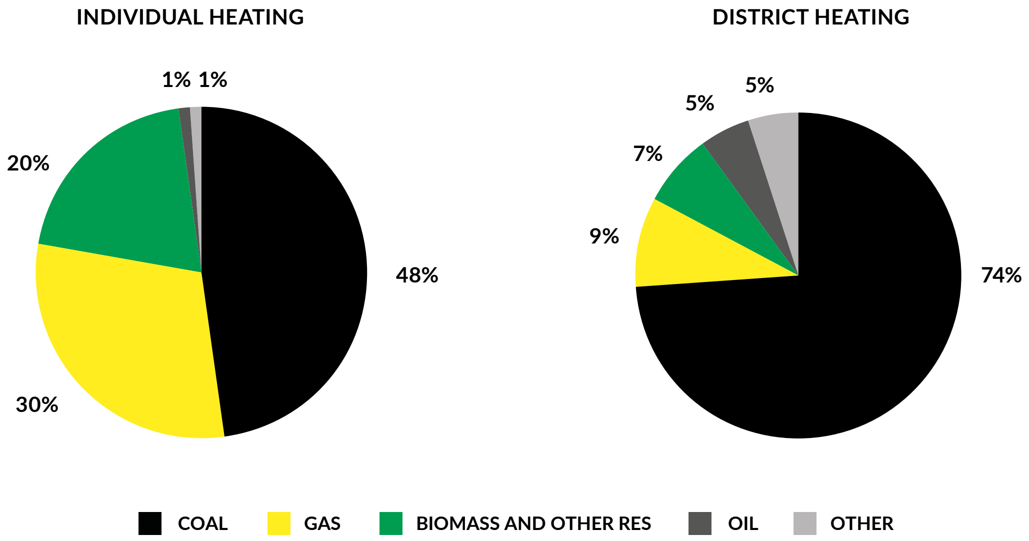
District and individual heating in numbers	
Thermal coal consumption	24-26 million tonnes per year
Gas consumption	4.5 billion cubic metres per year
Biomass consumption (14 GJ/t)	9.2 million tonnes per year
Dust emissions	147 thousand tonnes per year
SOx emissions	254 thousand tonnes per year
CO_2 emissions	68 million tonnes per year
Installed capacity	172 GWt

Source: *Clean Heat 2030* report. *Strategy for heating*, Forum Energii, 2019

Despite its significant position on the energy map of Poland, the heating sector has never been covered by a consistent and ambitious strategy that would indicate how to adjust to the changing reality.

Although district heating has been addressed (albeit to an extent far from satisfactory) in subsequent editions of the *Energy Policy of Poland*, individual heating has been left without any vision whatsoever. In effect, the heating industry is largely based on coal (Fig. 4.), and in the winter season air pollution in Poland is the greatest in Europe.

Fig. 4. Structure of fuel consumption in individually heated buildings and district heating



Source: *Clean Heat 2030* report. *Strategy for heating*, Forum Energii, 2019; *Energetyka cieplna w liczbach.* URE, 2018

A challenge for district heating is the fact that 80% of heating systems are ineffective, as they do not meet the requirements of the *Energy Efficiency Directive*. Because they do not have a share of heat generated from RES of at least 50% or from cogeneration of 75%, they will not receive EU support for modernisation. Due to the fuel structure, dominated by coal, and mounting carbon dioxide costs, heating plants may face gradual decommissioning, as they will not be able to offer competitive heat prices.

TRANSPORTATION

Number of vehicles

The vehicle fleet in Poland currently comprises:

- 24 million passenger cars and light duty vehicles (LDV)[2],
- more than 1 million medium and heavy trucks,
- more than 100,000 public transport buses and coaches.

Development of transport

Average use of LDVs in Poland is very limited compared with the rest of Europe. The EU average is about 12,000 km per annum, while in Poland it is about 6,500 km.

Demand for road transport in Poland grew in 2005-2015 by some 33%. The rise was attributable to vehicles up to 3.5 tonnes (approximately 25%), but even more to trucks (approximately 45%). In contrast, demand for bus transport is on the decline. We assume that by 2050, Poland's share of the EU's demand for transport services[3] will be equal to its share of the Community's population.

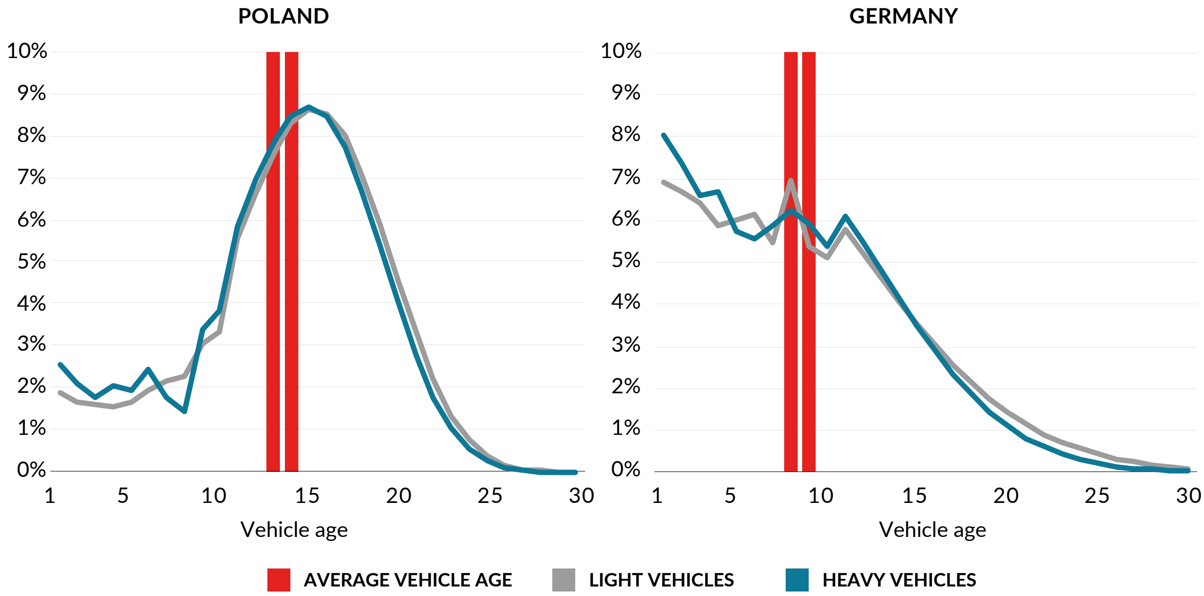
2 The light duty vehicle (LDV) category includes all highway-worthy vehicles with a total weight of up to 3.5 tonnes.

3 Forecast of EU's demand for passenger and truck transport sourced from the ICCT Roadmap Model (International Council on Clean Transportation, 2019).

Age

The Polish vehicle fleet is aged: the average vehicle registered in Poland is 13-14 years old. For example, the average age of vehicles in Germany is estimated at 8-9 years. Fig. 5 below presents a comparison of both vehicle age distributions.

Fig. 5. Vehicle age in Poland and Germany



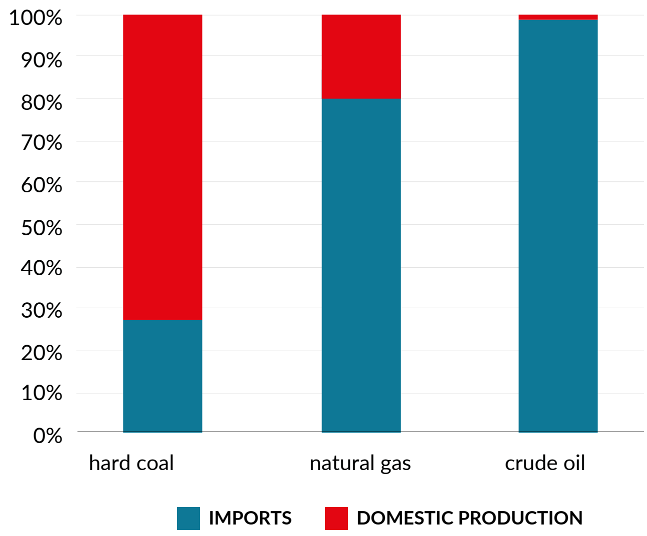
Source: Navigant Research
Age distribution below 10 years based on real data, while data for age above 10 years is modelled.

Clean transport policy

Many vehicles in Poland are bought on the secondary market in neighbouring EU states. This tendency strengthened after Poland joined the EU in 2004. At its peak in 2008, more than 1.1 million used vehicles were brought to Poland, which was three times more than the size of the market of new vehicles at the time. This results from the limited purchasing power of Polish society and a lack of a policy promoting cleaner forms of transport.

To date, the popularity of electric vehicles in Poland has remained far behind other countries in Northern and Eastern Europe. According to industry data, sales of EVs in 2018 was slightly more than 1,000, accounting for less than 0.2% of the Polish market for new vehicles up to 3.5 tonnes. It is expected that the EV market will expand consistently due to the growing determination of the Polish government and more stringent EU regulations on emissions[4].However, the economic crisis caused

Fig. 6. Share of imports by fuel type in Poland



Source: Statistics Poland

4 In early 2019, EU adopted emission standards for 2025 and targets for 2030, which provide for, respectively, 15% and 31-38% reduced emissions compared to current estimates. In addition, new testing and vehicle emission-control standards were introduced, which stimulates the development of electric vehicles.

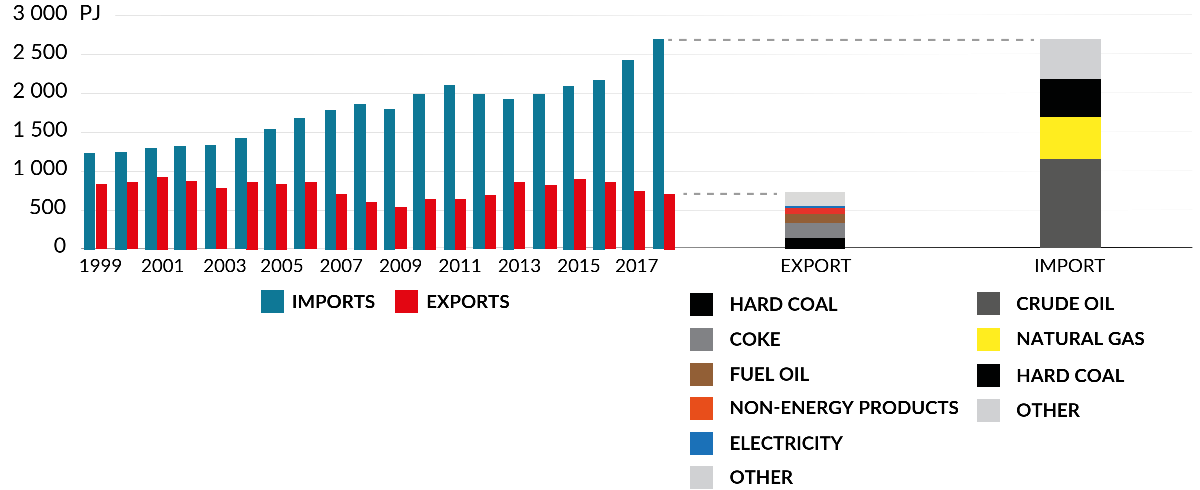
by the COVID-19 pandemic is likely to hamper (at least temporarily) investment in EVs.

Fuel imports

Poland has more and more relied on fuel imports for energy production and transport. The dependency on imports of energy carriers is growing. Fig. 6 presents the share of fuel imports in the national consumption.

Estimates of domestic fuel resources suggest that the upward trend in imports of all energy carriers will continue unless certain measures are taken to improve energy efficiency and increase the share of energy production from renewable sources. The existing drafts of the *Energy Policy of Poland* raise concerns that Poland's dependency on imports will continue to rise.

Fig. 7. Poland's imports and exports of energy and fuels from 1999 to 2018

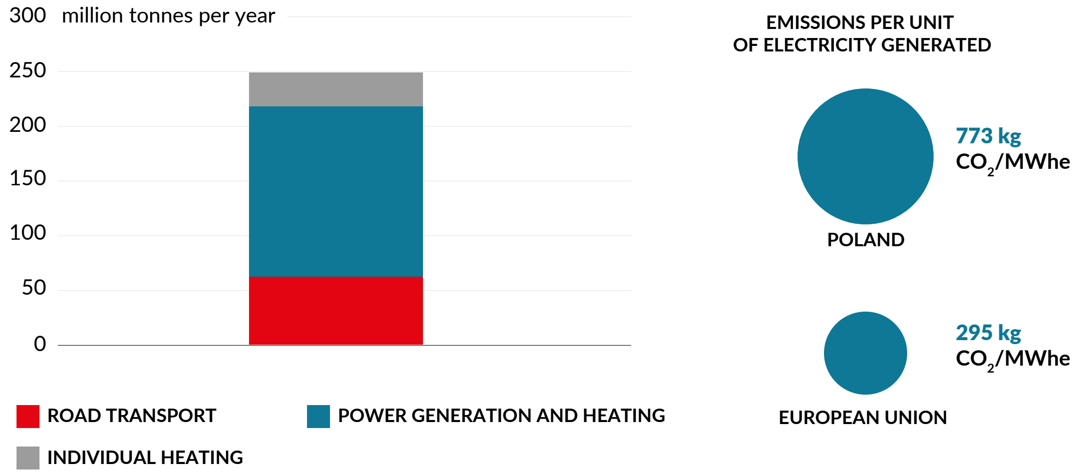


Source: Statistics Poland, 2019

Greenhouse gas emissions

The fuel mix and the age of systems and vehicles result in significant greenhouse gas emissions. Poland's GHG emissions are one of the highest in the EU (Fig. 8.).

Fig. 8. CO_2 emissions in the energy and transportation sector (million tonnes per annum) and emissions per unit of electricity generated in Poland and the EU (kg/MWh)



Source: KOBiZE, European Environment Agency, 2019

Poland's climate neutrality by 2050

Since 2011, EU policy has been focused on achieving climate neutrality by 2050. The *European Green Deal* published in January by the European Commission provides a new growth strategy. Its core elements are the development of resource-efficient and environment-neutral model of economy, in which the society can develop and prosper.

The European Union seeks to change the concept of economic growth based on excessive use of natural resources and fossil fuels. One of the elements of the new approach is to create innovations and green jobs in the industry. The achievement of climate neutrality by 2050 will involve major changes, including—as we believe—in the economy. On the other hand, it can be observed that new technologies emerge but the sectors still require modernisation.

As an EU Member State, Poland participates in the decision-making process regarding the energy and climate targets. It has made commitments regarding energy and climate for 2020 and 2030. Unfortunately, Poland does not have an up-to-date *Energy Policy* that would provide for a strategy for achieving them. The targets regarding carbon dioxide reduction, share of renewables, and energy efficiency improvement for 2020 are not likely to be reached. Poland's contribution to the achievement of targets for 2030 is presented in the *National Energy and Climate Plan*. So far, there is no correlation between the commitments made and plans regarding how they will be met by 2030, as presented in the government's strategic documents.

From the perspective of this analysis, the most important are the EU's and Poland's long-term targets, i.e., those to be achieved by 2050 when the entire European Union would become climate-neutral, with carbon dioxide emissions not exceeding absorption.

Fig. 9. New Green Deal—vision of a zero-emission EU economy

Source: European Commission, 2019

5. Purpose

The main purpose of the analysis is to indicate the benefits and necessary changes related to the integration of electrified heating and transportation sectors with the power system.

Decarbonisation (based on RES), electrification, and smart sector coupling are viewed as the primary methods of achieving climate neutrality in 2050.

6. Methodology of analysis

Electrification of the transportation and heating sectors involves a considerable increase in energy consumption. With the current emission-intensive generation mix, electrification of new sectors means a significant rise in emissions.

In this analysis, we assumed that:

- Poland follows trends in technology and meets international commitments, seeking to reduce its carbon footprint;
- Cheap domestic resources of coal (whose production is cost-effective) are depleting;
- Development of technologies progresses and they are an alternative to fossil fuels.

Given the above, we assumed almost full decarbonisation of the generation mix based on renewables.

Next, we modelled the power system in 2050 to determine the challenges related to its operation.

Key assumptions for 2050:

- **Electricity generation is based on zero-emission renewable sources.**

We assumed that the share of RES will not be lower than 80%.

- **Security of energy supply is a priority.**

The power system based on renewables is subject to significant variability of energy supply, which not always covers the demand curve. In this simulation, the system is designed in such a way so as to guarantee that demand for energy is met throughout the entire year, irrespective of the energy supply from variable renewables.

The entire analytical process involved the following steps.

Step 1: Determination of the demand for electricity and heat

1. We developed a scenario of development of the electric transportation sector with different EV charging profiles and scenarios of electrification of the heating sector with improved energy efficiency of buildings.
2. We calculated demand for electricity in the transportation and heating sectors in 2050, drawing on previous reports prepared by Forum Energii.[5]

   Demand for electricity in 2050 is composed of two elements:

   - base demand of Poland's economy, arrived at based on approximation of the historical trend (226.9 TWh),
   - additional demand for energy required to supply heat pumps and electric vehicles (from 11.1 to 68.7 TWh, calculated for each scenario described in Step 2).

     Demand for heat is 352 PJ for the district and individual heating sectors combined. This calculation takes into account widespread thermal efficiency improvement of buildings in Poland to meet the WT 2021 standard and demand-side management in the heating sector.

5 https://forum-energii.eu/pl/analizy/pep-2040-uwagi and https://forum-energii.eu/pl/analizy/czyste-cieplo-2030.

3. We prepared hourly electricity demand profiles for the domestic power system and individual profiles for electrified heat and transportation sectors in 2050.

Step 2: Supply of electricity and heat

1. We prepared hourly profiles of energy generation from variable renewables, taking into account the weather conditions based on statistics from previous years (wind, air temperature, insolation).
2. We prepared a total of six scenarios of electricity production accounting for shallower (only heating sector) or deeper sectoral integration (heating and transportation sectors) with the power system. In each group, we worked on the "80" and "100" scenario (i.e., 80% and 100% of renewables by 2050).

Group 1. Integration of the national power system (NPS) with the heating sector (H)

Scenarios:

1.	**S1-80** — 80% of electricity generated from RES, no integration of **NPS** with **H**,
2.	**S1-80+H** — 80% of electricity generated from RES, integration **NPS**+**H**,
3.	**S1-100+H** — 100% of electricity generated from RES, integration **NPS**+**H.**

Group 2. Integration of the national power grid (NPS) with the heating sector (H) and electric transport (EV).

Scenarios:

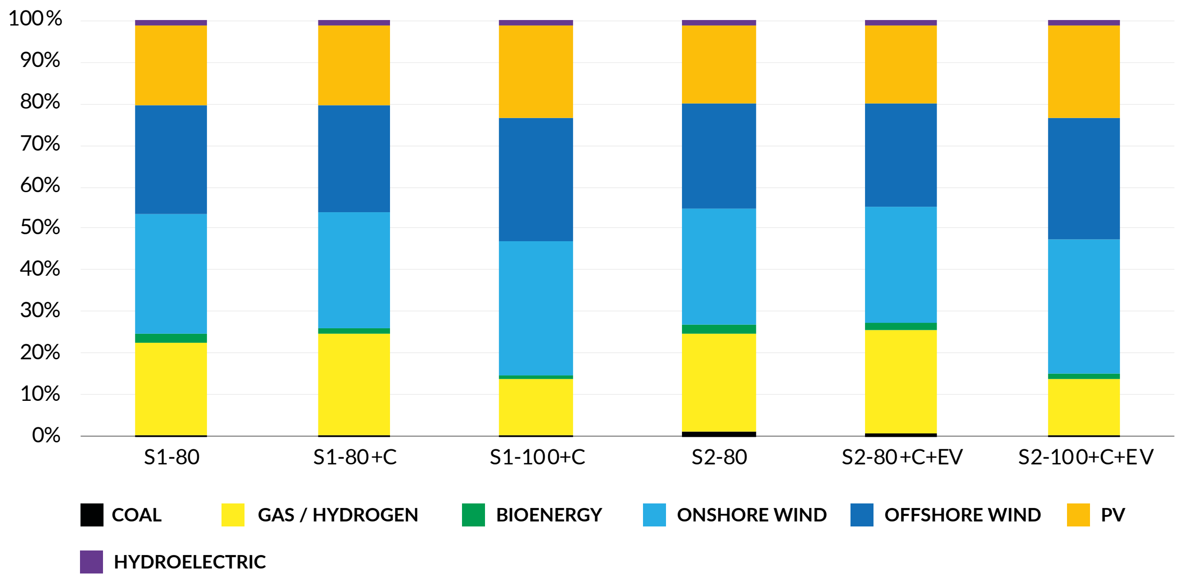
4.	**S2-80** — 80% of electricity generated from RES, no integration of **NPS** with **H** and **EV**,
5.	**S2-80+H+EV** — 80% of electricity generated from RES, integration **NPS**+**H**+**EV**,
6.	**S2-100+H+EV** — 100% of electricity generated from RES, integration **NPS**+**H**+**EV.**

The scenarios were divided into two groups that differ in terms of the extent of sectoral integration. Given the need to supply the electric transport industry, the NPS capacity and energy generation in Group 2 are correspondingly greater than in Group 1. In addition, the "100" scenarios provide for higher installed capacity in variable renewables (compared to the "80" scenarios) as a result of the need to ensure security of energy supply.

The calculation model determined the production capacity at the NPS based on the criterion of minimisation of variable cost, thus technologies with a low marginal cost were used first (variable renewables) and then more expensive technologies were gradually introduced. In the case of heating, scenarios featured the same set of generation assets, installed capacity, and heat consumption. Depending on the level of integration with the NPS, heat pumps and energy accumulators are used to a different extent.

The scenarios thus created made it possible to compare the benefits of sector integration. For a clear explanation of the structure of individual scenarios, Fig. 10 presents the structure of electricity generation. Although it is the outcome of analysis performed in the next step, we present the graphics here to facilitate understanding of our approach.

Fig. 10. Structure of electricity production in individual scenarios by sources of primary energy



Source: Navigant, Forum Energii

Step 3: Analysis

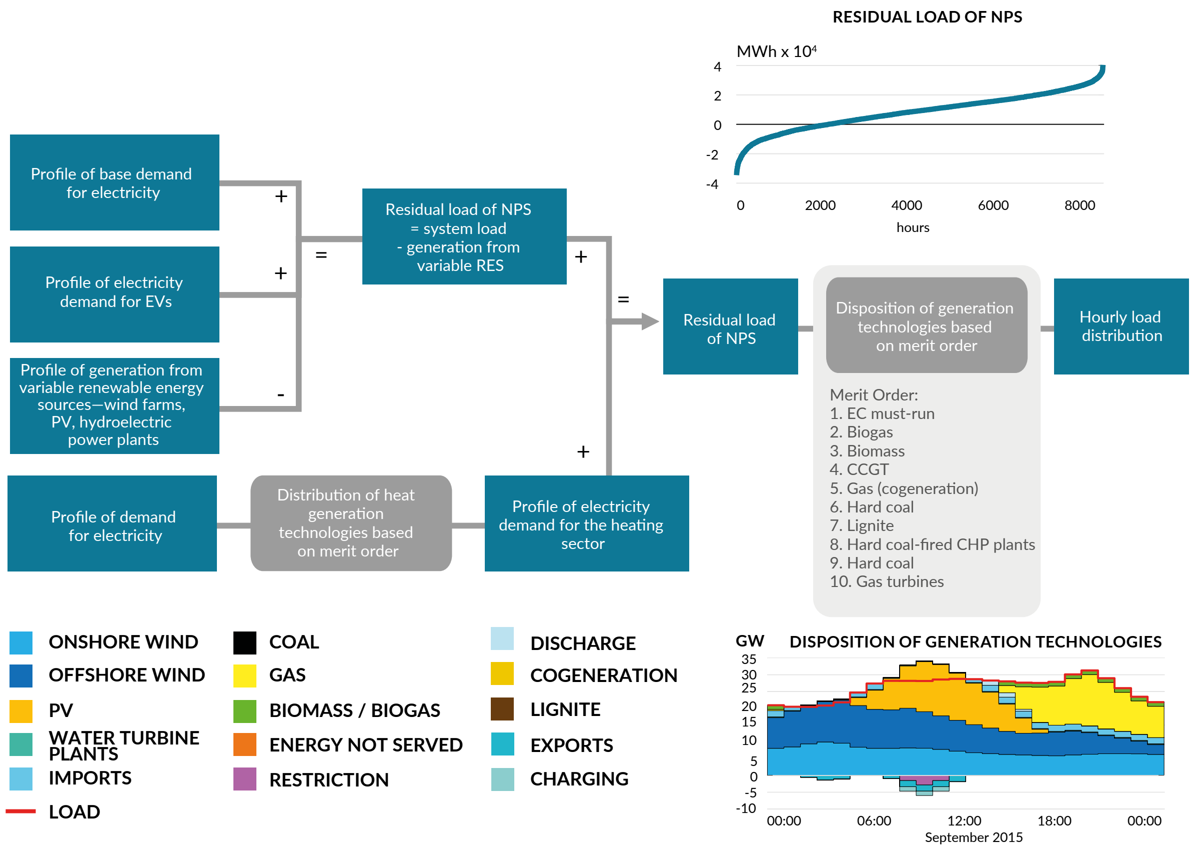
For each out of the six scenarios, we calculated the balance of demand and supply, assuming that demand is fully met at each hour of the year with domestically generated or imported energy.

Based on the presented data and after taking into account the assumptions, for 2050 we calculated:

- installed capacity of electricity and heat generation,
- generation of electricity and heat (economic selection of generating units in the NPS by the calculation model with interactions in the heating and transportation sectors),
- time of capacity utilisation—number of hours of operation at full load for each technology,
- peak load of the power system,
- energy storage capacity required for balancing the power system,
- surplus energy from variable renewables,
- green hydrogen production potential,
- CO_2 emissions,
- imports of electricity and fuel,
- total scenario costs.

The above steps in the analysis process and calculation of the energy balance are presented in Fig. 11.

Fig. 11. Process of analysis of hourly electricity supply and demand balance



Source: Navigant

Step 4: Results

1. We analysed the differences between the scenarios and the effect of sector integration on the cost of energy, environment and the balance of energy imports.
2. We prepared conclusions and recommendations, which are presented further below.

7. Main assumptions

ELECTRICITY

In line with previous analyses by Forum Energii, we assumed that in 2050 demand for electricity in Poland will be 226.9 TWh ("base" demand). We top that with:

- 53-57 TWh for the supply of electric transport (the ultimate demand depends on the flexibility of the fleet and its sensitivity to demand-side management),
- 10.9-12.4 TWh for the supply of the development of heat pumps.

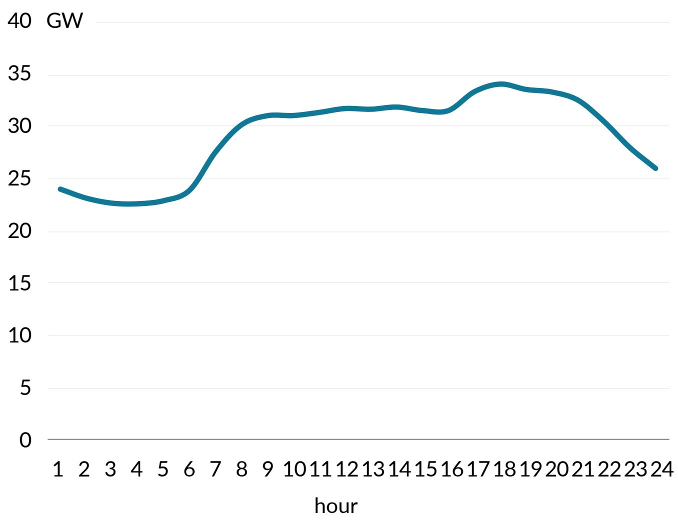
The hourly profile of demand for electricity in 2050 was generated based on data sourced from ENTSO-E reflecting the operation of sources in 2015 and recalculated to levels of demand in 2050.

Fig. 12. presents the profile of demand for electricity in Poland in 2050, excluding demand from electric transport and heat pumps. Electricity demand peaks between 7 pm and 10 pm.

The profile of operation of wind farms, photovoltaic and hydroelectric (water turbine) plants was built based on data sourced from the Strategic Energy Technologies Information System (SETIS) managed by the European Commission. Capacity utilisation rates for onshore and offshore wind power generation and photovoltaics are sources from the Renewables Ninja platform (S. Pfenninger, 2016[6]). Additional data related to the capacity utilisation rate for 2015 were sourced from the ENTSO-E model.

The chart below presents the residual load curve of NPS, which is the resultant of total demand generated by energy consumers and energy production by variable renewables on a typical winter day in Poland. If the residual load of the NPS is negative (Fig. 13.), generation from RES installations should be restricted to ensure stable operation of the power system.

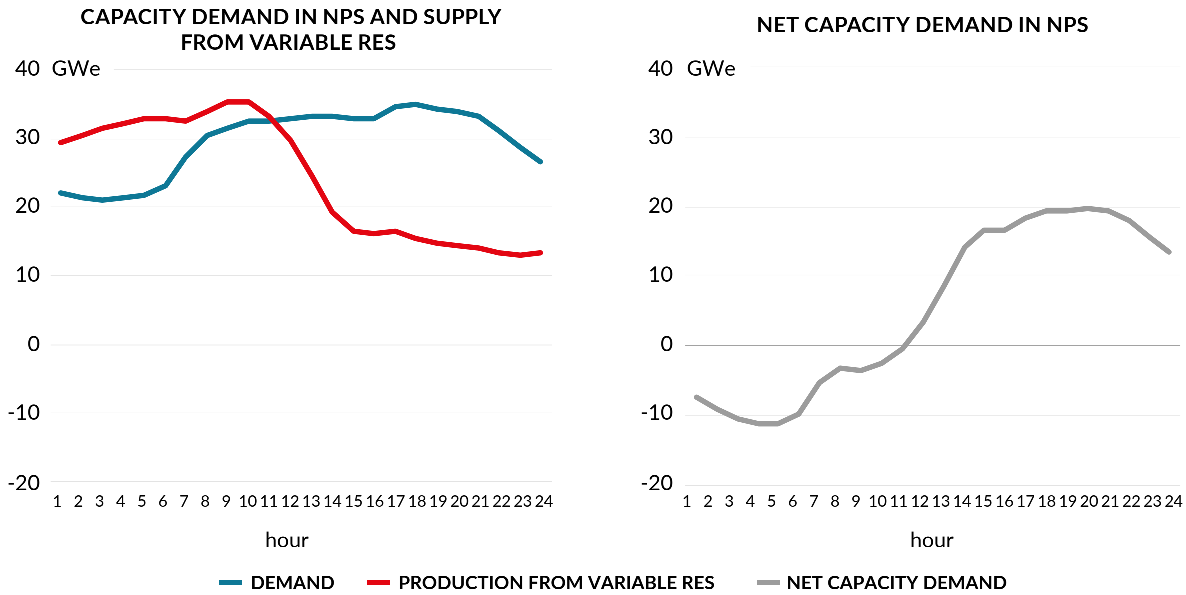
Fig. 12. Curve of demand for electricity in NPS (winter day, S2-80 scenario)



Source: Navigant

A solution better than restricting the operation of RES plants is the use of such surplus energy for the production of green hydrogen through the electrolysis process, or heat, e.g., in electric boilers. In this analysis, the volume of surplus energy was calculated for all scenarios.

Fig. 13. Example hourly NPS load curves, capacity of variable renewables and residual load of NPS (winter day)



Source: Navigant

6 https://www.renewables.ninja/.

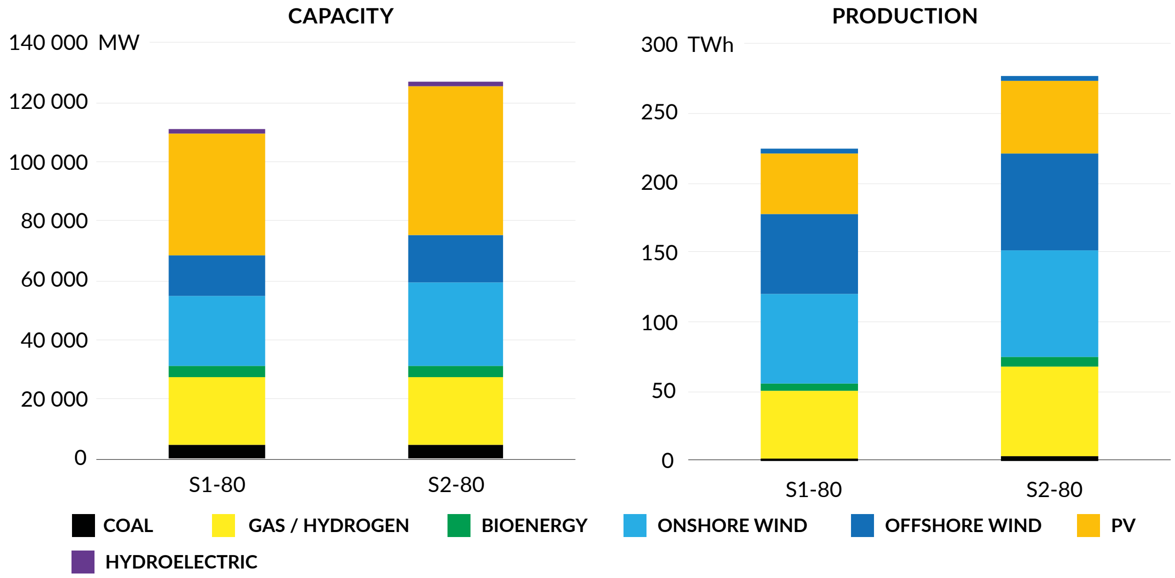
We assume that the NPS will continue to grow based on wind farms and photovoltaic installations because of their zero variable costs, large potential, falling investment expenditure and technological advancement.

We expect that by 2030 the share of variable renewables in total electricity production in Poland will rise to 40%. Complementary renewable energy sources in Poland will be biomass, biogas, and hydroelectric energy. We assumed that the minimum share of energy from RES in OZE in 2050 will be 80%. This assumption is the starting point for two reference scenarios, S1-80 and S2-80. In the alternative scenarios S1-100+H and S2-100+H+EV, we consider a nearly 100% share of RES in the energy mix in 2050. It should be pointed out that in these scenarios, gas plants operate in part on green hydrogen generated from surplus energy from variable renewables. The remaining part of the fuel is natural gas.

In the analysis, we assume that energy sources are selected so as to minimise variable cost (merit order). Due to the high price of CO_2 emission allowances, power plants utilising coal—the most expensive fuel—will be used last for generation. The result of the modelling indicates that in 2050 coal-fired power plants will cover not more than 1.3% of the domestic demand for energy, operating up to several hundred hours per year. Taking into account all fixed costs translating into a small output volume, it can be seen that from the perspective of cost-benefit analysis of the generating source this way of closing the power balance is costly. Therefore, other forms of capacity reservation must be sought, such as further development of RES combined with seasonal energy storage, simple gas plants, or demand-side management.

Fig. 14. presents capacity structure in two reference scenarios in 2050 without sector integration, which are the reference point in comparisons with other scenarios, in which relationships between sectors occur.

Fig. 14. Structure of generation (GW) and production (TWh) capacity in reference scenarios



Source: Navigant

Electricity imports/exports

In accordance with the ENTSO-E forecast for further interconnector construction (ENTSOE, 2019[7]), we assumed that the net transmission capacity in 2050 will be 5.5 GW for imports and 4.0 GW for exports.

The cross-border trade in electricity is a way to ensure security of operation of the national power grid and reduce its costs.

For 2050, we assumed an average price of imported electricity at 26 EUR/MWh.

7 The Global Climate Action 2040 scenario is the most ambitious and therefore the most suitable for this analysis.

HEAT

In 2050, demand for heat will be 41.8 TWh in the individual heating sector and 56 TWh in the district heating sector (conclusions from previous analyses by Forum Energii). Therefore, demand for heat will drop considerably. This will be possible thanks to an 80% thermal efficiency improvement of existing buildings in Poland to meet the WT 2021 standard (energy consumption standard for new and renovated buildings to be effective as of 2021).

Full decarbonisation of the heating sector in 2050 may be achieved thanks to:

- reduced demand for heat following an extensive thermal efficiency improvement of buildings,
- higher share of buildings connected to decarbonised heating systems,
- modification of the heating technology and primary energy source mix.

As a result of these measures, air emissions (both smog and GHG emissions) from the heating sector will be eliminated. This will help reduce to zero external health costs associated with heating.

As regards individually heated buildings, the target will be achieved thanks to:

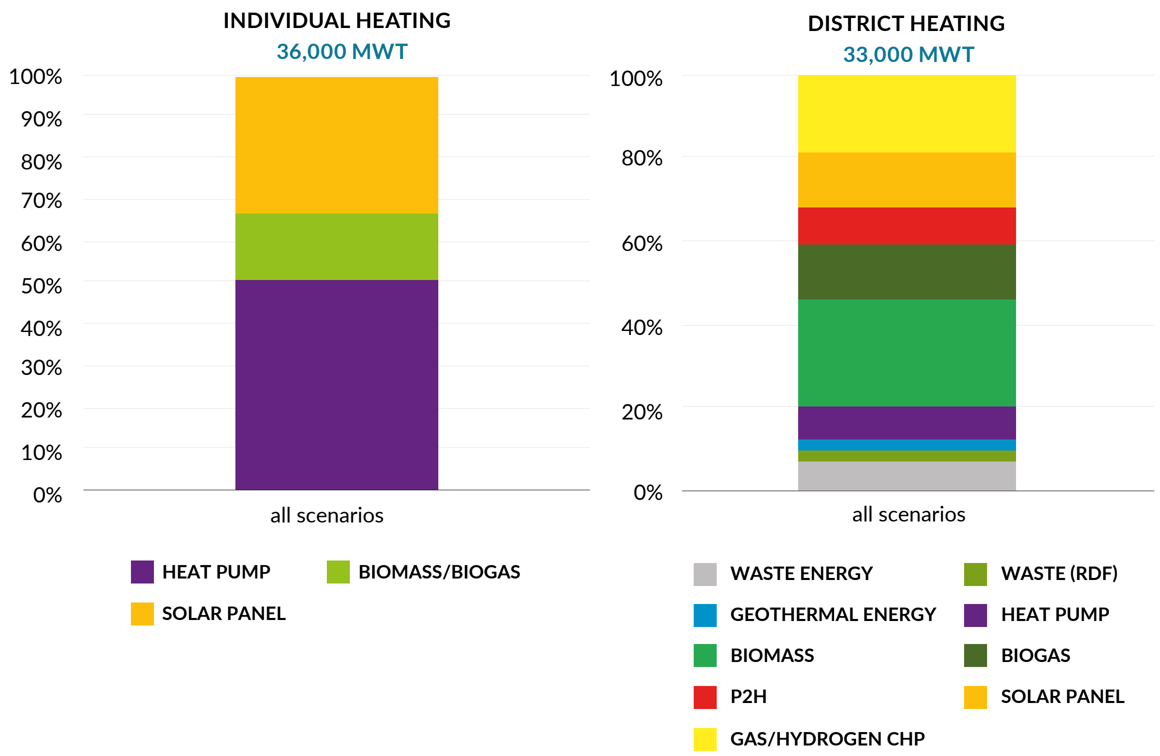
- electrification of heating (heat pumps),
- solar heating,
- biomethane.

In turn, in the district heating sector a wider range of generating units will operate, using the available sources of primary energy, such as:

- biomass,
- biogas and green gas,
- waste energy from technological processes,
- electricity (heat pumps and electric boilers),
- waste (RDF),
- solar energy,
- geothermal energy.

Fig. 15. presents the assumed structure of capacity in the individual and district heating sector.

Fig. 15. Structure of capacity of heat sources in the individual and district heating sector in 2050



Source: Navigant, Forum Energii

The table below presents total demand for heat in buildings covered by district and individual heating systems, as well as the share of residential and non-residential buildings. In the case of residential buildings, two groups of buildings were identified—single-family and multi-family houses, to make an accurate reflection of demand for heat in the residential sector. By analogy, an additional assumption for the creation of profiles of demand for heat is the proportional share of single-family buildings relative to multi-family buildings and the level of renovation of total building stock in 2050.

Table 2. Assumptions regarding the structure of buildings

	value	unit
total demand for heat in the district heating sector (including domestic hot water)	201.7	PJ
total demand for heat other than in the district heating sector (including domestic hot water)	150.6	PJ
percentage of residential buildings	54	% (total floor area of rooms)
percentage of non-residential buildings	46	
share of single-family buildings	64	% (total dwelling surface)
share of multi-family buildings	36	

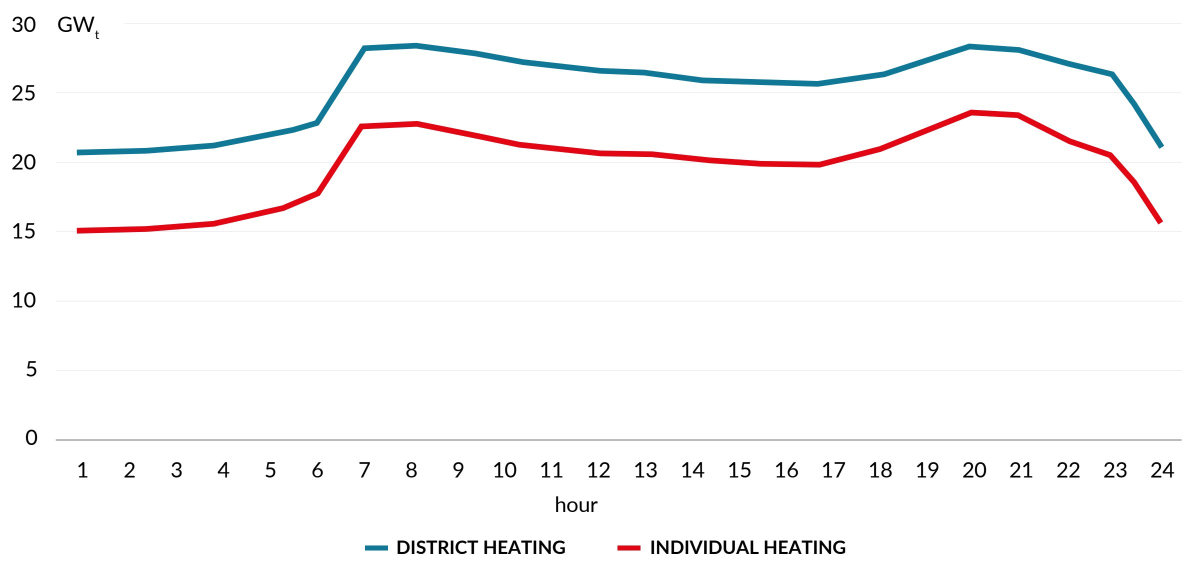
Source: Navigant

Based on the assumptions made, heat demand curves were prepared for both heating sectors using hourly climatological data and corresponding demand for heat.

Demand profiles were developed in the following steps:

- We adapted the model of hourly heat demand for Wrocław-Starachowice—a place identified as having average climate indicators in terms of the demand for heat in Poland.
- We calculated profiles for small residential buildings, large residential buildings and non-residential buildings, and in each of these categories for non-insulated buildings, after a shallow and deep thermal efficiency improvement.
- Next, we combined profiles for different types of buildings into one, taking into account, e.g., the percentage of buildings connected and not connected to district heating systems.

Fig. 16. Heat demand profiles for a winter day in Poland – 1 January

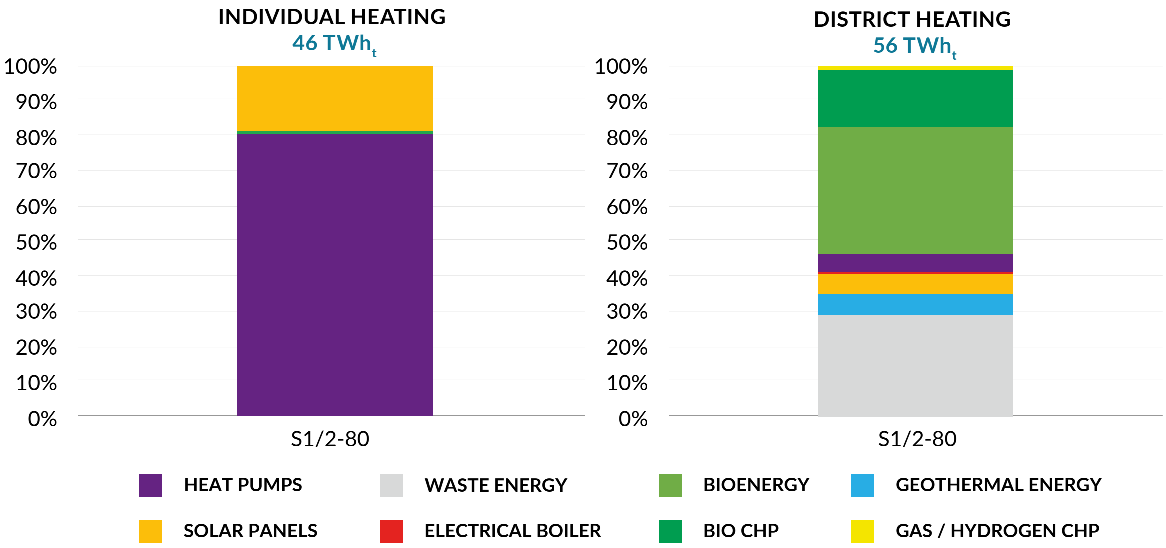


Source: Navigant

Fig. 16. presents building heating profiles generated for Poland for 1 January. The profile represents the sum of indoor heating and demand for domestic hot water. There are no major differences between demand for heat per square metre in buildings connected and not connected to the district heating system, both in the residential and non-residential sector. The profiles are combined into one to reflect total demand for heat for heating purposes in individual categories of heating and building types.

District heating covers nearly 55% of the 102 TWh$_t$ of heat demand. The remaining 45% of the heat supply is generated by individual heating systems. Also, 81% of individual heat supply is based on the operation of heat pumps, which requires approximately 10.8-12 TWh of electricity, with their electrical power amounting to approximately 10 GWe. Fig. 17. presents detailed information on heat generation in the heating sector.

Fig. 17. Structure of individual and district heat production in scenarios without system integration



Source: Navigant

As can be seen in the figure above, in individually heated buildings the dominant source of heat are heat pumps, supported by energy from solar heaters. In the district heating sector, a large share of waste energy and all types of energies from biodegradable sources are noticeable, with a relatively low share of large-scale heat pumps. However, it should be noted that future relationship between energy production from those sources may change to the benefit of heat pumps if the availability of energy from waste or from biomass will be lower for technical or economic reasons.

ELECTRICITY AND HEAT SOURCES USED

Below, we present all technologies used in selected scenarios.

Table 3. Sources of electricity and heat

No.	source	electricity production	district and individual heat production	cogeneration
1	wind energy (onshore and offshore)	X		
2	photovoltaics	X		
3	hydroelectric energy	X		
4	biomass	X	X	X
5	biogas	X	X	X
6	combustion of green gas	X	X	X
7	combustion of natural gas	X	X	X
8	hard coal	X		
9	lignite	X		
10	waste heat		X	
11	waste incineration		X	
12	geothermal energy		X	
13	solar heating		X	

TECHNOLOGY COSTS

For each electricity production technology we prepared average cost assumptions for the entire 2020-2050 period. These are presented below, separately for electricity and heat.

Table 4. Average cost of key technologies in power generation

technology	Investment cost (EUR/kW)	Fixed operation costs (EUR/kW)	Variable costs (non-fuel) (EUR/MWh)	Fuel costs (EUR/MWh)
lignite-fired power generation units	1,800	32	3	78.94
hard coal-fired power generation units	1,600	26	2	66.79
CCGT / gas CHP plants	680	15	2	50
gas turbines (conventional cycle)	360	8	4	50
biomass-fired power generation units	1,850	38	4	29.6
biogas-fired power generation units	1,175	23	3	50
wind power generation (onshore)	1,119	12	0	0
wind power generation (offshore)	2,335	28	0	0
photovoltaics	582	9	0	0
hydroelectric energy	2,375	8	0	0
pumped-storage power plants	3,000	26	0	0
electricity storage (batteries)	160	15	0	0
Power2Gas (P2G)	385	9	0	2.4

Source: Navigant, E3M

Table 5. Average cost of key technologies in heat generation

	technology	Investment cost (EUR/kW)	Fixed operation costs (EUR/kW)	Fuel costs (EUR/MWh)
individual heating	heat pumps	754	34	0
	biomethane	217	4	50
	electrical heating	73	1	0
	solar heating	1,292	13	0
district heating	waste heat	0	3	0
	waste incineration	173	3	0
	geothermal energy	2,265	98	0
	heat pumps (industrial scale)	528	24	0
	biomass	173	3	30
	biogas	173	3	50
	electrical heating	85	2	0
	solar heating	940	10	0

Source: Navigant, E3M

FUEL PRICES

Table 6. Assumed fuel prices in 2050

fuel price	EUR/MWh
hard coal	10.8
natural gas	30.6
biomass	29.6
biogas	52
green hydrogen	73

Source: Navigant

CO_2 EMISSIONS AND PRICES

We assumed that in 2050 the price of CO_2 emission allowances will be EUR 80. Table 7 presents specific carbon dioxide emissions for different energy sources.

Table 7. Assumed carbon emissions intensity ratio for different combustion technologies

technology	electricity generation efficiency (%)	carbon emissions intensity ratio (kg of CO_2eq/MWhth)	carbon emissions intensity ratio (tonnes of CO_2/MWe)
lignite	45	364	0.89
hard coal	43	335	0.77
gas CHP plant	61	204	0.34
gas turbines	42	204	0.48
biomass	35	0	0
biogas	30	0	0

Source: Navigant

TRANSPORTATION

In this report we focus on road transport. In the analysis of its development we took into account different vehicle types, including:

- light vehicles up to 3.5 tonnes, usually classified as passenger cars and vans,
- heavy city vehicles over 3.5 tonnes—city buses, bin lorries, and city delivery trucks,
- heavy long-haul road vehicles over 3.5 tonnes—coaches, lorries, and heavy transport vehicles.

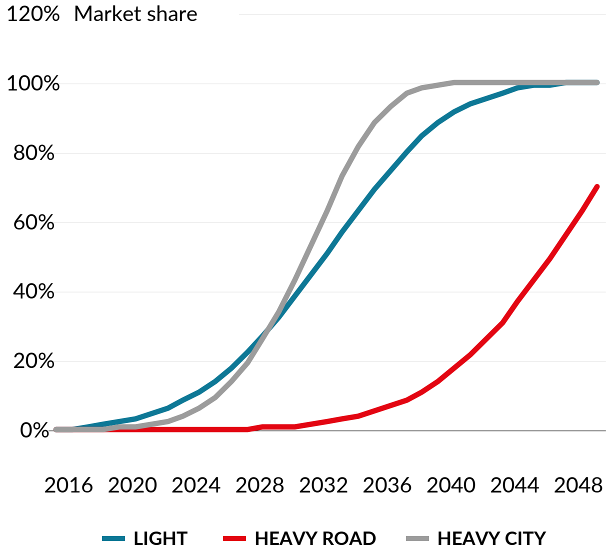
The forecast development of the electromobility sector in Poland by individual vehicle types is presented in the picture below.

According to our forecast, in 2050 some 17.5 million electric vehicles will be driven on Polish roads, including:

- approximately 16.5 million light vehicles,
- more than 450,000 heavy city vehicles,
- approximately 600,000 heavy road vehicles.

In 2050, 82% of all vehicles used in Poland will have an electric drive.

Fig. 18. Share of EVs in the market of new vehicles by vehicle group



Source: Navigant

Manner of use of electric vehicles

We identified three models of EV use, taking into account where they park and the charging method:

- **dedicated:** parking stall in a garage at the place of residence or at the fleet depot reserved for one vehicle,
- **foreseeable:** parking stall on a public car park or in a garage,
- **unforeseeable**: no parking stall—usually on-street parking and charging.

It is assumed that all heavy city vehicles are used in the dedicated mode and full battery charging will take place at the depot.

All heavy road vehicles fall within the “unforeseeable” model and most part of charging will be completed in publicly available fast-charging stations.

Having analysed the parking space status and vehicle charging profiles in Europe, we assume that light vehicles can be split into three parking groups: 35% dedicated, 29% foreseeable, and 36% unforeseeable. Assumptions regarding the use of charging stations depending on the parking status were presented in Table 8.

Table 8. Assumptions regarding the vehicle charging time by parking method (annual share in %)

vehicle type	parking status	charging point				
		place of residence	place of work	public slow charging	public fast charging	depot
	dedicated	80%	15%	-	5%	-
light	foreseeable	-	15%	80%	5%	-
	unforeseeable	-	25%	10%	65%	-
heavy – city	dedicated	-	-	-	-	100%
heavy – road	foreseeable	-	-	-	80%	20%

Source: Navigant

Charging

Electric vehicles may be charged in many ways. Typical EV charging technologies can be divided depending on the use of:

- **AC charging station**, which can offer up to 3.7 kW with a current of 16 A. Use of 400 V three-phase connectors makes it possible to achieve charging power of even 43 kW.
- **DC charging station**, whose charging power is usually higher than that of AC charging stations, but there are also options of low-power DC chargers. The EV charging industry currently introduces charging stations with a power of even 350 kW. An additional DC-charging technology is used only for lorries. It is known as pantograph charging and it is commonly used in rail transport. Another option is intermittent use of pantographs or at fleet depots (to save parking space), or during stops on a regular route—this solution is popular in the case of electric buses. Pantograph charging usually involves power of more than 150 kW.

Vehicle grid integration

EV charging time may be random or planned. In the second case, the EV charging parameters known to the operator help manage the operation of variable renewables in the NPS more effectively. Vehicle grid integration (VGI) means that the grid operator sends signals to the charging electric vehicle with a command to delay or accelerate charging, and in rare cases also to feed energy to the grid. This function is particularly beneficial for the balancing of variable solar and wind-powered generation with the demand for electricity.

The EV parking place and how its charged determines the usage model, which is taken into consideration in our analysis during the creation of electricity demand profiles.

We assume that at present and in the future owners of electric vehicles will prefer charging that maximises their comfort and reduces costs: at home, in the place of work, and during their travel.

As a result, for EVs with a specific parking space, we assumed a low level of use of fast-charging services (thanks to which we reduced the cost associated with the use of fast-charging stations). In the case of cars with no fixed parking space, we assume that they will be using public fast-charging stations to a greater extent. We are aware that the mode of use of EVs may change in the years to come. The charging infrastructure may be located in different places and be used in many different ways. We divided the possible locations into five categories, defined as follows:

Table 9. Charging station categories[8]

category	specification	power (kW)	flexibility
household	household or residential building chargers	5	high, but drops closer to morning before leaving for work
at the place of work	charging stations located in car parks for employees	10	high at the beginning of the working day, drops closer to afternoon before leaving for home
public – slow charging	charging stations located at public parking spaces	10	high, but drops closer to morning before driving to work
public – fast charging	charging stations replacing retail liquid fuel pumps	120 (50-500 range)	electric vehicles are charged on demand, but it is buffered by a local energy-storage facility, which enables the charging station to distribute electricity demand over a period six-times longer than the duration of a charging session
fleet	charging stations located at fleet depots	50 (20-150 range)	flexibility is very low during the day, adjusts to the flexibility of charging points at place of residence and work at the end of the day

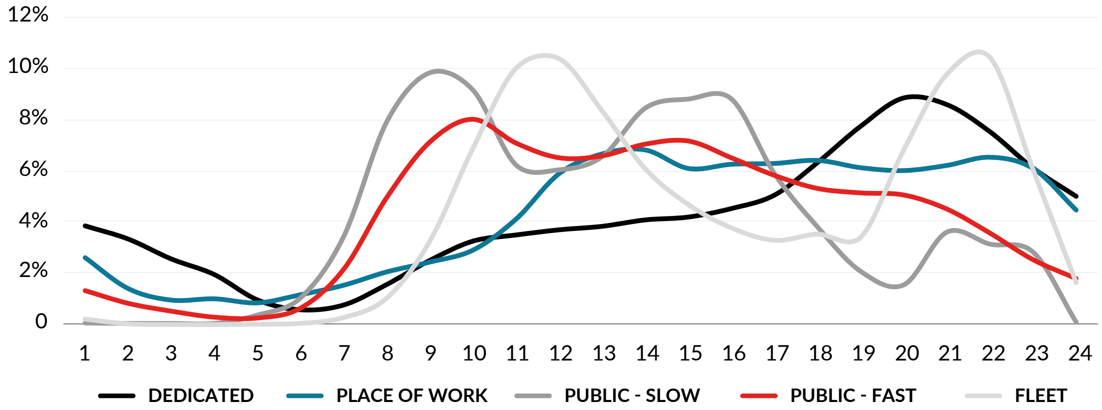
Source: Navigant

Patterns of electric vehicle charging

We considered the charging start time and charge duration as critical elements of charge events. The charge duration specifies when a specific EV load capacity will be connected, while the time of leaving the parking space determines the type of charge management, i.e., the extent to which the delivered power may be delayed or reduced due to temporary overload of the grid.

Use of charging points will change throughout the day depending on the location. For example, EV owners will likely start charging at their place of residence in the second part of the day, after returning from work. Yet the peak demand at public charging stations or at the place of work will occur in the morning or at noon. Our assumptions regarding the charge start time are consistent with the analysis of load profiles for EVs in Europe by charging location (Fig. 19.).

Fig. 19. Charge start time by hour and location



Source: Catalonia Institute for Energy Research

8 The above definitions do not include dynamic charging points, such as wireless charging on the road or pantograph charging. We decided to make that exclusion as it is still too early to determine the efficiency of such charging compared to other charging methods. This area is highly innovative and develops rapidly.

The total of all curves is 100%. The chart reflects the behaviour patterns of EV users. We expect few charge events between midnight and 5 am. The frequency of charge events increases after 5 am. It may be expected that charging at the place of work will start when employees get there. A smaller peak may be observed in early afternoon hours, around the time of arrival of the new shift (in the case of shift workers) or later afternoon. At that time, the charged vehicles make the charge point available to others. Similar behaviour patterns may be observed in other uses of electric vehicles, e.g., late peak for "dedicated" charging stations, which shows that EV owners return home and connect their vehicles to own charging stations.

The flexibility of EV load will change depending on:

- charging location,
- charging station power,
- vehicle type,
- charge time.

Higher power of charging stations and longer charge durations are a resource offering greater flexibility of the power grid.

- **Household or slow public charging points:** flexibility is always high, but it is the greatest in the evening, when all users return home. Flexibility falls in the morning, when EV users drive to work.
- **Charging points at the place of work:** flexibility is high at the beginning of the working day, but drops in the afternoon when EV users return home.
- **Fleet**: flexibility is low during the day, when EVs are in use. If they are charged during the day, demand is instantaneous. At the end of the day and at night, flexibility raises to the level similar to that observed in household and slow public charging points.

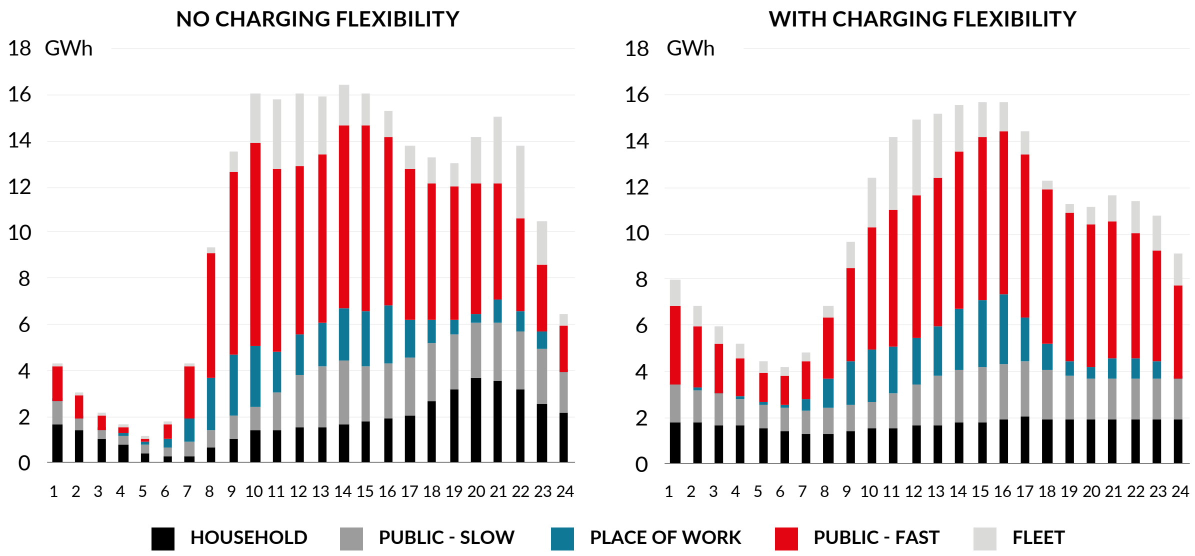
When analysing the likely development of electric vehicles, we built demand profiles based on two approaches:

- non-flexible – owners charge their vehicles whenever they can with a maximum power available,
- flexible – the power of a charge event is adjusted to the state of battery charge and charge duration.

The charts below present load profiles for lower and higher fleet flexibility.

The assumptions referred to above are presented in Fig. 20. For example, an EV connected to a charging station at a place of work between 5 a.m. and 10 a.m. can be fully charged over 8 hours. After 10 a.m., the charge duration shortens.

Fig. 20. EV charge point load profile (winter working day, Poland, 2050).



Source: Navigant

We assumed an average flexibility of charge points at 50%, but we made an additional sensitivity analysis to check how the change in flexibility would affect the peak load pattern.

Electricity demand from the transportation sector

When designing electricity demand from the transportation sector, we made the following assumptions:

- light vehicles: 4.8 km/kWh, 12,000 kilometres driven per year,
- heavy city vehicles: 2.4 km/kWh, 17,000 kilometres driven per year,
- heavy road vehicles: 1.6 km/kWh, 34,000 kilometres driven per year.

To all values related to electricity consumption we added efficiency loss of 10%. The loss results from conversion of alternating current supplied from the grid to direct current used for battery charging.

In 2050, total electricity consumption by electric transport in Poland, depending on vehicle charge flexibility, will amount to 53-57 TWh.

We estimate that electricity demand from EVs will be the highest in the winter and autumn, and the lowest in the spring and summer (Table 10.).

Table 10. Electricity consumption by electric vehicles by season and vehicle segment (average=100)

season	light	heavy – city	heavy – road
winter	102	106	104
spring	95	95	97
summer	99	96	98
autumn	104	104	101

8. Electricity sector modelling results

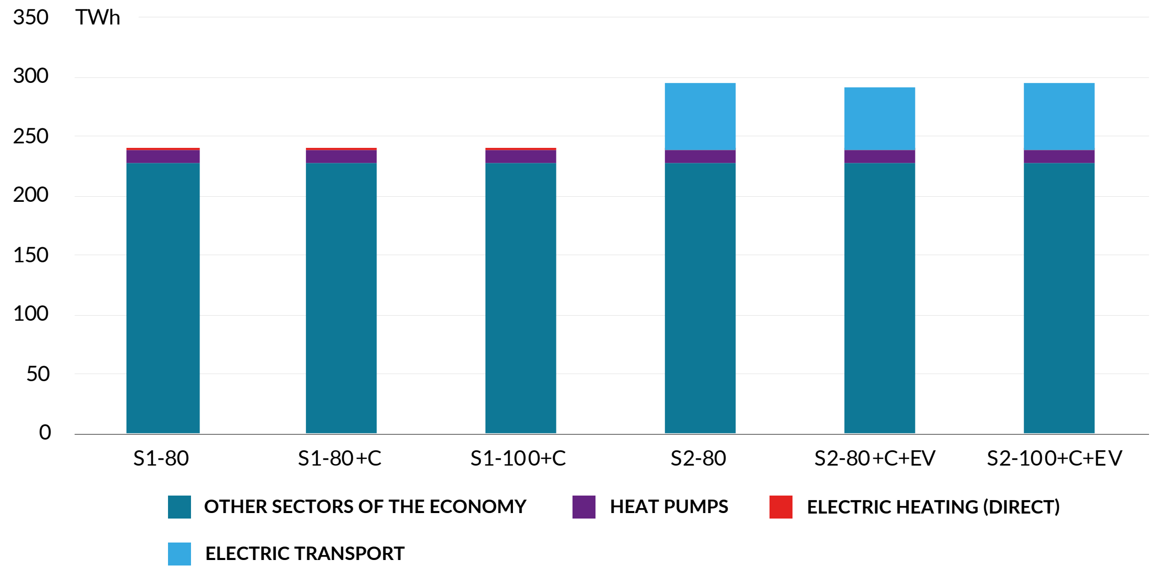
The purpose of this report is to present the benefits from the integration of the transportation and heating sectors, assuming their nearly full electrification based on renewable energy sources. We are focusing on 2050, and by analysing in detail the operation of the power grid we evaluate the challenges related to a change in its functioning.

In this part of the report we present the modelling results.

Electricity demand

- In 2050, base electricity demand in all sectors of Poland's economy (except for e-transport and electrified heating sector) will be approximately **226.9 TWh.** This value is the same in each scenario.
- Demand from the transportation and heating sectors generates an additional energy consumption from **12 TWh** (in S1-80 scenario) to **69 TWh** (in S2-100+H+EV scenario).

Fig. 21. Electricity demand in individual scenarios



Source: Navigant

Fig. 21. also presents the demand for energy needed for direct electric heating. As we can see, it is marginal. This results from the economic selection of generation assets by the calculation model, which takes into account the criterion of minimisation of marginal cost. Direct electric heating is one of the most expensive solutions used in the model.

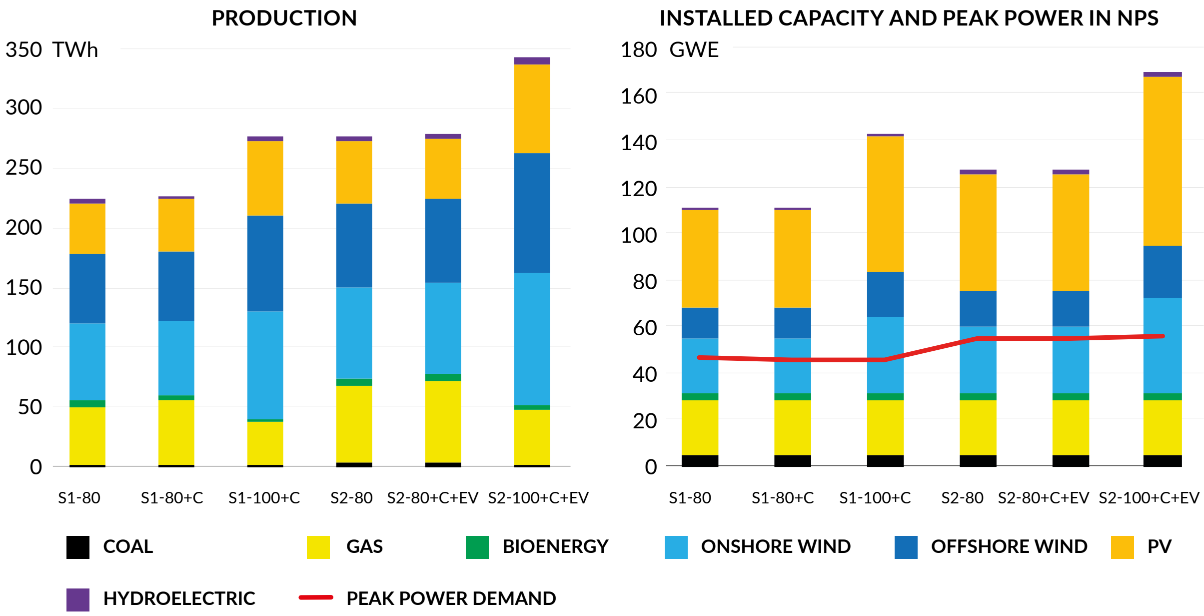
Installed capacity in the national power grid and electricity production

- The total installed capacity in the national power grid increases proportionally to the rise of the share of variable renewables (with lower capacity utilisation than conventional sources) and higher demand from electric transport.
- Wind power generation and photovoltaics are the predominant energy sources in the system, accounting for 70-80% of installed capacity.
- Gas sources provide further 15-22% capacity. These technologies offer significant flexibility, which is crucial for facilitating the integration of variable renewables. In addition, they may use different types of gaseous fuels, such as biogas, green hydrogen and natural gas.

- Replacement of natural gas with green hydrogen will bring to types of benefits. First, carbon dioxide emissions from gas combustion will be eliminated, and second, natural gas imports to Poland will be reduced owed to domestic production of gas (hydrogen) using surplus energy generated from variable renewables.
- Due to high operating costs, biogas and biomass are the last to be included in the technology mix.
- Hydroelectric energy accounts for approximately 2% of installed capacity.
- The proposed scenarios provide for maintenance of one hard coal and one lignite-fired unit based on the assumption that they could be used in the future as part of a strategic reserve. In 2050, depending on the scenario, they will represent 2-4% of installed capacity, but with negligible production.

Fig. 22. presents installed capacity in NPS and energy production in groups of generation assets in further scenarios.

Fig. 22. Peak power and installed capacity in NPS and production of generation assets in individual scenarios

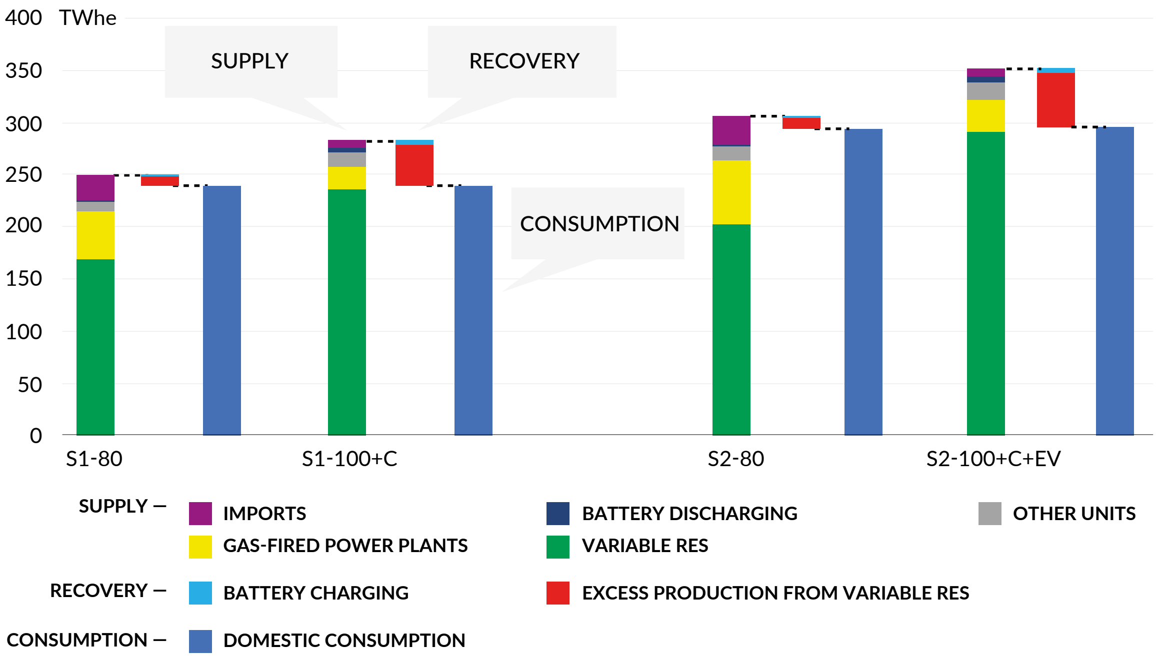


Source: Navigant

- In the 100% RES scenario, gas units use biogas, natural gas, and hydrogen produced in the electrolysis process using surplus electricity from variable renewables.
- When comparing Fig. 21. and Fig. 22., a large surplus of energy in relation to demand is seen, particularly in 100% RES scenarios. It is the effect of a time mismatch between profiles of production from variable renewables and demand and the assumption of full security of energy supply, even in windless winter.
- The hourly analysis shows that in certain periods, despite limiting production in heat-generating units, a surplus of energy in the grid is still observed, caused by wind farms and photovoltaics. In our analysis this surplus is chiefly used for the production of hydrogen and—to some extent—heat in cogeneration units.

- It is worth noting that despite such large energy surplus during the year, theoretically it may occur that without making any changes in the organisation of the energy market at some hours the capacity of variable RES and heat generating units will not cover current demand. In such cases a reserve of energy is used from seasonal storage facilities (e.g., hydrogen storage facilities) or imports are increased. Fig. 23. presents the annual balance of electricity and directions of its use on an example of selected scenarios.

Fig. 23. Annual electricity balance



Source: Navigant

- Despite a significant amount of installed electrical capacity in scenarios (from 111 to 169 GW), in the analysis Poland still remains a net importer of energy to be able to fully cover its demand. The lowest level of import is observed in 100% RES scenarios thanks to higher installed capacity of domestic sources and the largest surplus of energy from sources with low variable costs.
- We also calculated peak demand in the NPS (Table 11) to select the level of generation capacity that would ensure the required security of grid operation and uninterrupted energy supply.

Table 11. Peak load in the power grid

scenario	S1-80	S1-80+H	S1-100+H	S2-80	S2-80+H+EV	S2-100+H+EV
capacity (MW)	46,430	45,758	45,758	55,215	54,387	55,281

Source: Navigant

- The peak load increases by approximately 10 GW with additional demand from electric vehicles compared to the scenarios without electrification of the transportation sector. Application of more advanced options of demand flexibility, such us EVs integrated with the power system and active demand-side management, in the future may lower the peak load.
- Table 12 presents the duration of use of capacities of the contemplated generating units resulting from economic modelling based on the criterion of minimisation of variable cost (merit order). Variable energy sources with zero carbon-dioxide emissions and very low marginal costs represent

a new foundation of the system. Conventional carbon-based sources with a high level of emissions and significant operating costs (costs of fuel and carbon dioxide emission allowances) and fixed costs (maintenance of units and even mines in the case of use of lignite) come online only in periods of peak demand and to a very limited extent. In practice, this would be equal to their withdrawal from service and finding other forms of securing power reserves, such as active demand-side management, increased storage capacities, and interconnection capacities.

Table 12. Full load hours of operation for individual technologies by scenario

	2020	S1-80	S1-80+H	S1-100+H	S2-80	S2-80+H+EV	S2-100+H+EV
lignite-fired power plant	5,077	128	122	80	494	428	270
hard coal-fired CHP plant	2,663	0	0	0	0	0	0
hard coal-fired power plant	2,228	116	111	72	456	392	256
hard coal-fired power plant (new)	5,971	206	196	133	686	613	377
gas CHP plant	4,222	3,215	3,623	2,535	3,741	4,090	2,823
CCGT (new)		1,352	1,434	909	2,149	2,188	1,388
gas turbines (new)		412	467	302	1,119	1,120	677
biomass-fired CHP plants	4,312	1,504	1,024	728	1,991	1,605	1,093
biogas-fired CHP plants	4,848	1,132	627	473	1,550	1,124	760
onshore wind farms	1,821	2,745	2,745	2,745	2,745	2,745	2,745
offshore wind farms		4,350	4,350	4,350	4,350	4,350	4,350
photovoltaics	1,050	1,044	1,044	1,044	1,044	1,044	1,044
hydroelectric energy	2,142	2,138	2,138	2,137	2,136	2,136	2,137

Source: Navigant

Risk of imbalance of electricity production

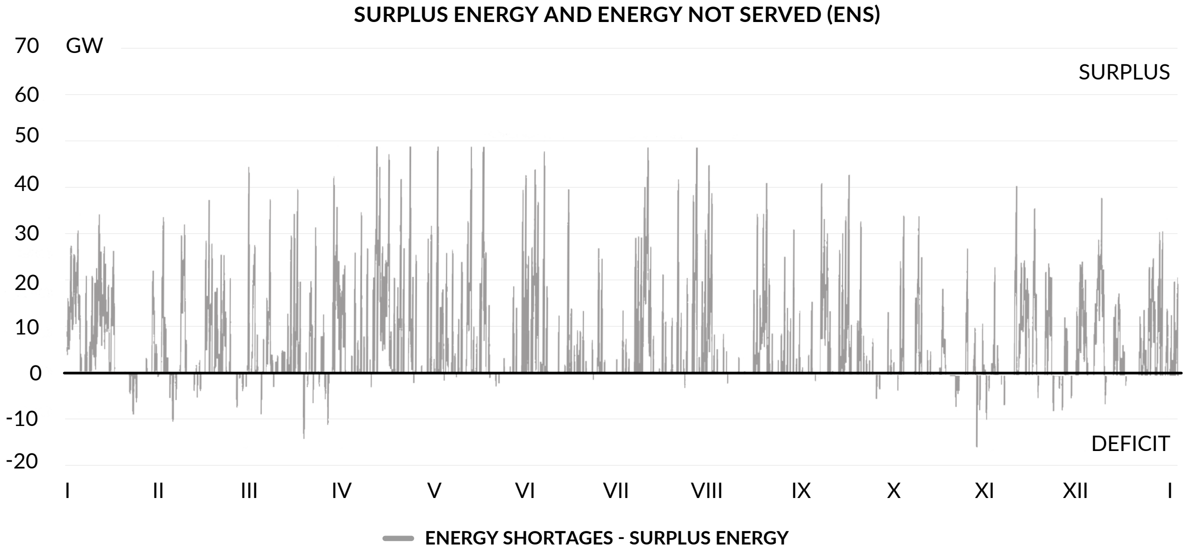
As results from the analysis, with the assumed structure of generation capacity there may be periods (several hours per year), when power deficit will reach 16-18 GWe (ENS — energy not served[9]). Early identification of this challenge should prompt us to take such measures as:

- increase of the volume of energy storage facilities,
- more active demand-side management,
- use of cross-border interconnections,
- construction of peak load gas-fired units.

The selection of future technology mix and measures to be taken should be based on the results of an optimisation analysis that takes into account current cost conditions. This analysis indicates that a significant oversupply of energy occurs as a consequence of a time mismatch between profiles of electricity production from RES and the profile of electricity demand in the NPS. Fig. 24 presents the results of hourly simulation of the balance of supply and demand for the entire year for 100% RES scenarios with the integration of the heating and transportation sectors.

9 ENS is defined as the expected amount of energy, which will not be supplied to customers through the grid in a given period due to insufficient efficiency of the grid or unexpected major interruption in power supply.

Fig. 24. Shortages and oversupply of instantaneous power in NPS in the S2-100+H+EV scenario

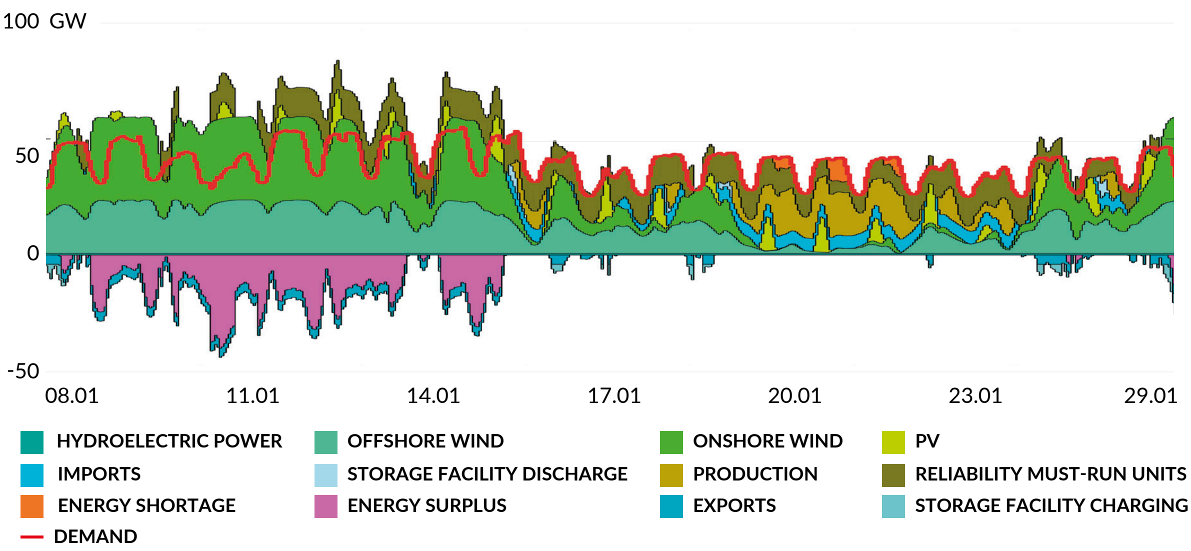


Source: Navigant

Results of hourly balances are represented in the chart by grey columns. Columns above the zero line present a temporary surplus of energy, those below the zero line stand for shortages of energy compared to the requirement of the power system. In the case of overproduction of energy, RES units may be taken offline or the surplus energy may be stored. We suggest using surplus electricity for the production of green hydrogen, which can be easily stored and used to supply gas-fired units.

Fig. 25. presents a more detailed production profile by types of generation units relative to demand for energy. As can be seen, in the presented three weeks of January there is a significant surplus of energy from wind farms, which is represented by the area below the zero line. Part of the surplus is directed for exports, to charge energy accumulators, whose capacity was pre-defined, or to the production of green hydrogen. In the second half of the period, certain energy shortages occur. In the next step of the analysis, a calculation was made of the capacity of storage facilities needed to store the energy and cover the shortages occurring as a result of instantaneous unavailability of generation capacities.

Fig. 25. Energy production and demand balance in three weeks of January in the S2-100+H+EV 100 GW scenario

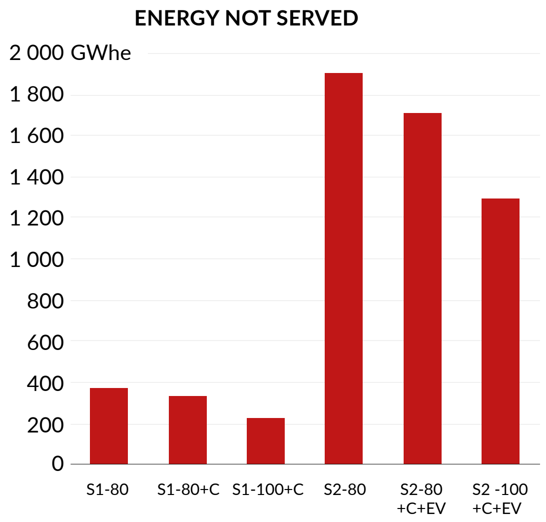


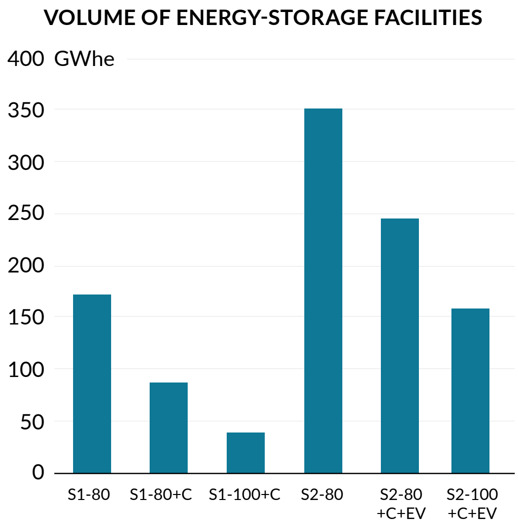
Source: Navigant

Energy storage

For periods of energy shortages, we calculated the required storage capacities that would ensure that demand is met. Fig. 26. presents the annual volume of energy accumulated in additional storage facilities for such needs. These may be used multiple times so their capacity must cover only one-off shortages in short periods of low supply from variable renewables. To complement the description of the electricity-balancing modelling process it must be added that the remaining energy surplus from variable RES are converted in the electrolysis process into green hydrogen, which is then used to supply gas turbines (for more information, see below).

Fig. 26. Annual energy production shortage and capacity of energy-storage facilities needed to balance the deficit

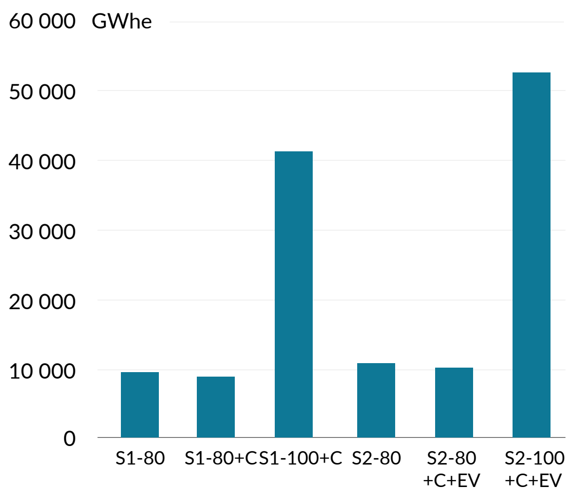




Source: Navigant

The risk of failure to supply energy is the highest in scenarios S1-80+H and S2-80+H+EV, assuming a lower share of RES and at the same time higher demand for energy due to electrification of the heating and transportation sectors (in the second scenario). To fully cover the demand in those scenarios, the installed capacity of generation sources or the size of storage facilities must be increased or the flexibility of demand must be improved through stronger DSM measures.

Fig. 27. Surplus energy from variable renewables in individual scenarios



Source: Navigant

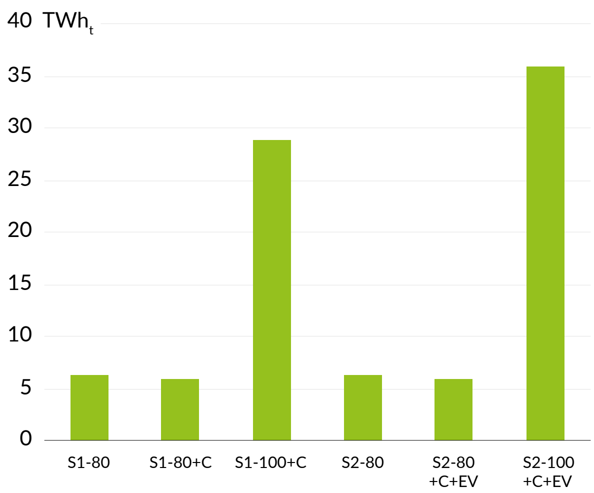
Green hydrogen

In 100% RES scenarios (S1-100+H and S2-100+H+EV), the installed capacity of variable renewables is significantly higher than in other scenarios. This results from the need to ensure a steady supply to customers, including in conditions unfavourable to energy production at wind farms and photovoltaic units. The natural consequence is the occurrence of a significant energy surplus in periods of strong supply and weak demand from the NPS. That is why we suggest using such surplus to produce green hydrogen, which, if stored, may be used at any time to generate energy, e.g., in cogeneration gas-fired plants. Fig. 27. shows the amount of energy per year is left for further use in individual scenarios.

According to the analysis, in the last scenario (S2-100+H+EV) the amount of green gas is the largest, representing approximately **42%** of demand for gas from the power generation and heating sectors. Detailed amounts of green hydrogen production for each scenario are presented in Fig. 28.

It is worth noting that, taking into account the large industrial production, the actual potential of hydrogen production in Poland may be higher, although this would require a separate analysis, which is not covered by this report.

Fig. 28. Green hydrogen production using surplus energy from variable renewables



Source: Navigant

9. Heating sector modelling results

In this section, we present the results of modelling of the heating sector separately for individual and district heating. The results are relevant for 2050 and depict a situation in which 80% of the existing buildings in Poland have undergone thermal modernisation to meet the WT 2021 standard and heat sources have been replaced with high-efficiency and low-emission ones. With those conditions met, we assume a drop in heating consumption by buildings by some 54% compared to the present situation[10].

Heat demand

In all scenarios, the demand for heat is fixed at 41.8 TWh/year for individually heated buildings and 56 TWh/year for buildings with district heating.

We assumed that the number of buildings connected to the heating network would increase by approximately 10% compared to the existing number. That is why the drop in demand for heat from heating systems (relative to the existing demand) is lower than in the sector of individually heated buildings.

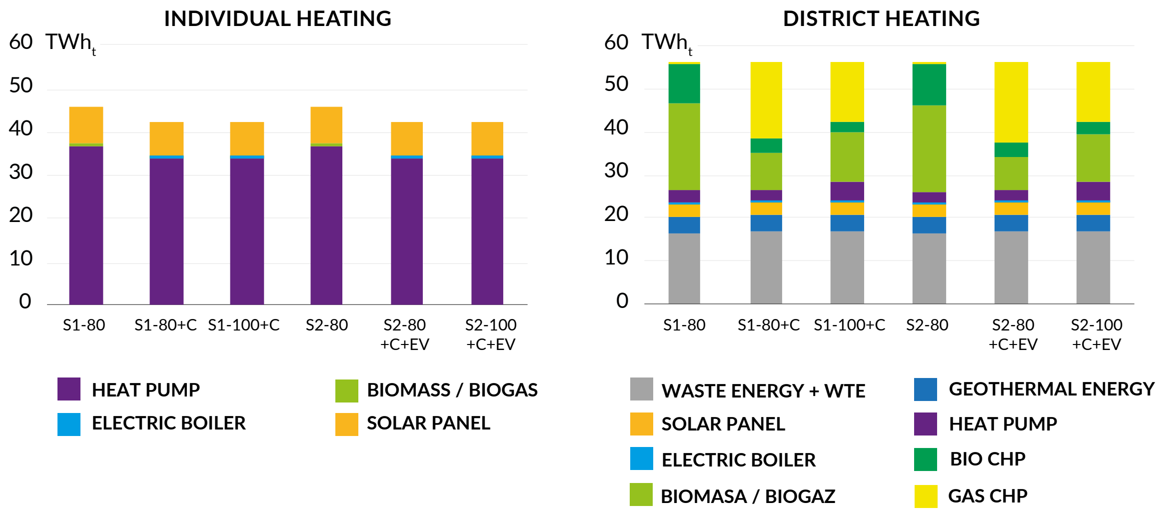
As shown in Fig. 29., in the individual heating sector the generation mix is dominated by heat pumps and solar panels. We expect direct heating with electric heaters and biogas to be marginal. The higher production of heat in reference scenarios (S1-80 and S2-80) relative to other scenarios results from the fact that it would not be possible to consume the entire amount of heat generated by solar panels due to the lack of suitable facilities enabling accumulation of the energy (in those scenarios).

In district heating, more technologies are available. We assume fixed production of energy from municipal waste and recovery of waste energy from technological processes, as well as fixed efficiency of geothermal and solar sources. Other generation units would adjust their output to heat demand. Cogeneration units would operate on a reliability-must-run basis only when heat demand is not met by other sources. In other periods, their operation would depend on conditions existing on the electricity market and energy generation from variable renewables.

Heat from cogeneration is a by-product of electricity production, thus it is more competitive than heating boilers using biomass and biogas due to lower production costs. Heat pumps and geothermal energy cover approximately 5-7% of demand each. Heat storage is always used to ensure security of its supply and energy balancing.

10 With reference to 2016, when primary energy consumption by residential buildings in Poland was 789 PJ; *Clean Heat 2030* report. *Strategy for heating*, Forum Energii, 2019, https://www.forum-energii.eu/pl/analizy/czyste-cieplo-2030.

Fig. 29. Structure of individual and district heat production in individual scenarios

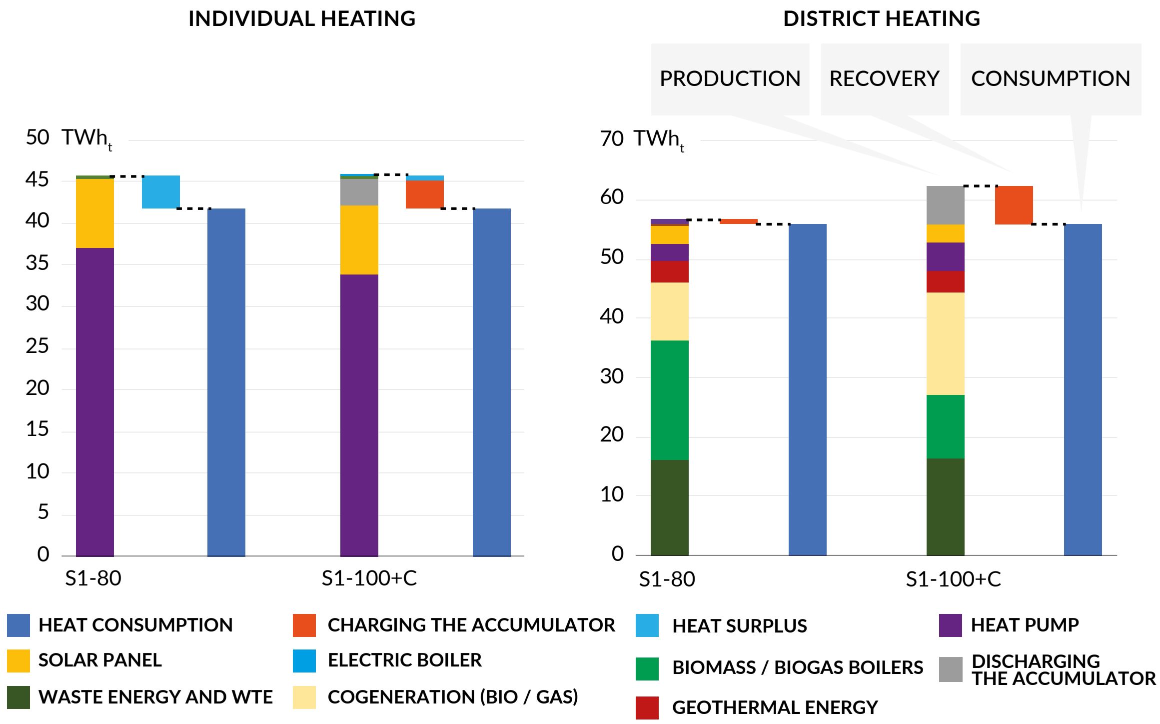


Source: Navigant

Heat balancing

In Fig. 30. we present scenarios of sector integration. The risk of imbalance (i.e., surplus of heat) occurs in reference scenarios S1-80 and S2-80 in the individual heating sector. The reason for that is that there are no heat accumulators in individually heated buildings. In effect, 10% of produced energy is lost. A natural remedial measure is to provide accumulators, which would enable more efficient use of RES and make it possible to reduce heat pump operation and to some extent avoid their operation during hours when energy prices are higher. This situation is reflected by S1-100+H scenario for both heating sectors. In the case of the S1-80 scenario for district heating, no imbalance occurs resulting in a surplus of energy. The mix of generation assets ensures matching supply with demand. The 100% RES scenario provides for a surplus of heat production, which is accumulated. However, this is a consequence of a situation in which the surplus of cheap energy on the wholesale market encourages district heat production and its possible accumulation if there is no current demand.

Fig. 30. Annual balance of individual and district heat production and consumption



Source: Navigant

Energy storage facilities

The table below presents surplus heat in individual scenarios. As can be seen, the reference scenarios (S1/2-80), which do not provide for integration with the power grid, show the highest surplus of unused energy. This results from the fact that there is no storage capacity available and it is not possible to ensure flexible energy balancing.

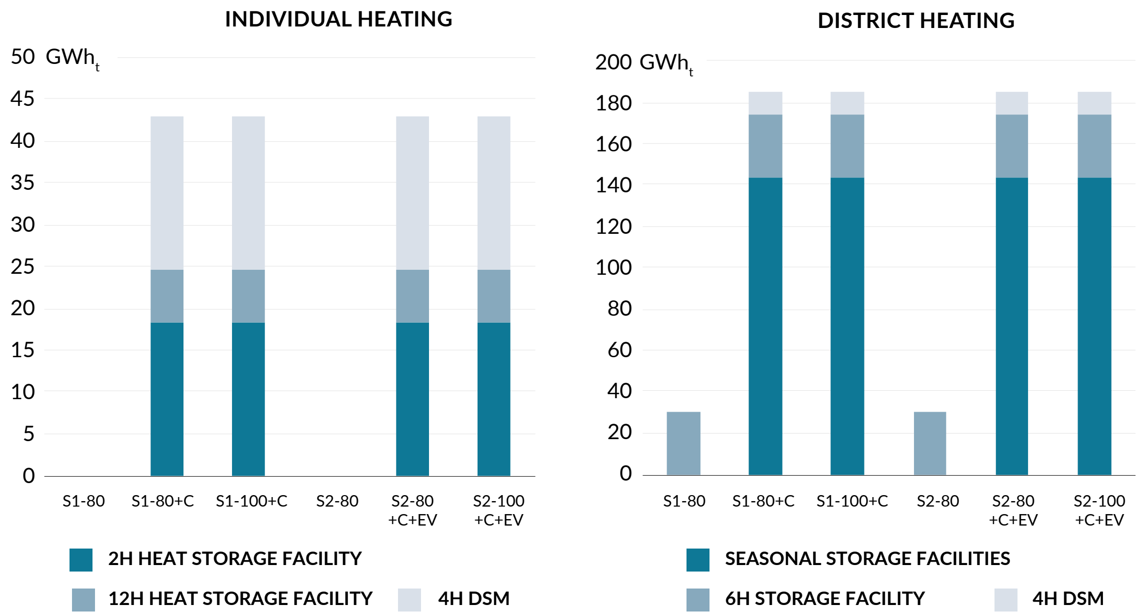
Table 13. Surplus of unused energy in individual scenarios

scenario	S1-80	S1-80+H	S1-100+H	S2-80	S2-80+H+EV	S2-100+H+EV
energy (TWh$_t$)	3.9	0.7	0.7	3.9	0.7	0.7

Source: Navigant

To improve the effectiveness of the use of generation assets, we calculated the capacity of heat storage facilities needed to ensure heat balancing. Fig. 31. presents the utilisation of capacity of such storage facilities. An additional option enhancing the flexibility of the heating sector used in the analysis is demand-side management. It involves the use of thermal inertia of buildings, which ultimately makes it possible to reduce the supply of energy for up to four hours per day in periods of peak demand and a tight balance of generation capacity. For the heating sector, we also assumed the use of storage facilities with a higher capacity to enable balancing of surplus heat for six hours and in the longer term (without defining in detail the technological solutions).

Fig. 31. Capacity of heat storage facilities needed to balance heat demand



Source: Navigant

10. Flexibility options

In our model analysis, we took into account several options to enhance the flexibility of integrated energy systems (NPS – heating system – transportation system). These options ensure higher absorption of energy from variable RES and secure operation of the national power grid thanks to better matching of current supply with demand. The measures to improve the stability of operation of the NPS may be implemented in four areas:

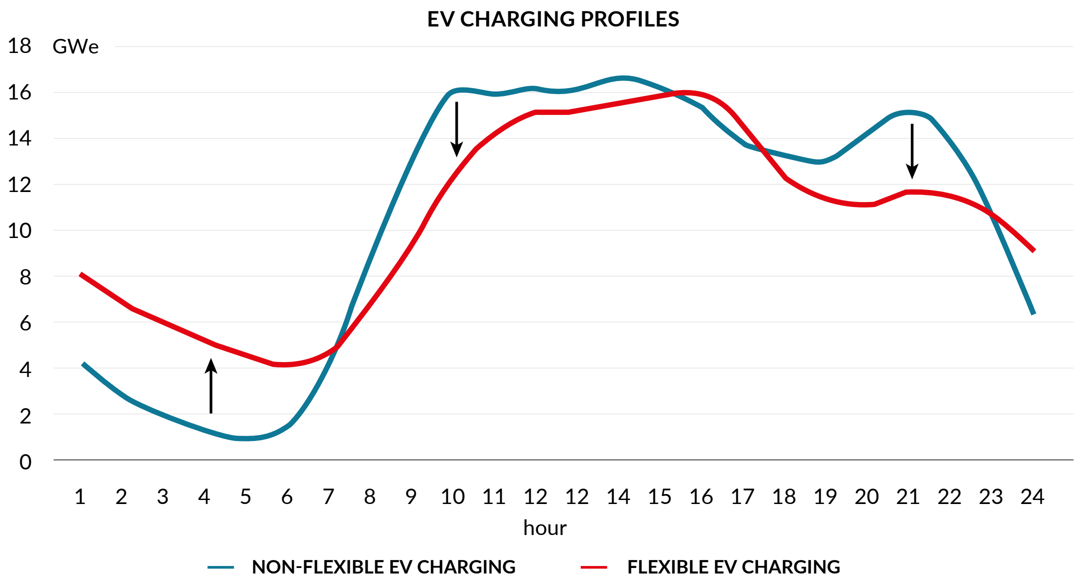
- management of EV batteries (**V2G**),
- electrification of the heating sector (**P2H**),
- demand-side management (**DSM**),
- energy storage (**ES**).

Below, we present a brief description of the solutions applied and their impact on the energy sector, as well as analysis results.

V2G — flexible battery charging

As part of the project, we modelled active demand-side management in the transportation sector, in particular in situations with insufficient supply of energy from variable renewables and concurrent strong demand. The flexibility of EV battery charging depends on many factors, both technological and behavioural in nature, e.g., consumer preferences (fast / slow charging) and availability and types of infrastructure. As described above, in this analysis we assumed a significant share of capacity at fast-charging stations, which adversely affects the flexibility of management of the process. This is because users expect the availability of energy "here and now". The chart below presents the shift of peak demand for charging power assumed in the modelling.

Fig. 32. Demand for non-flexible and flexible charging power

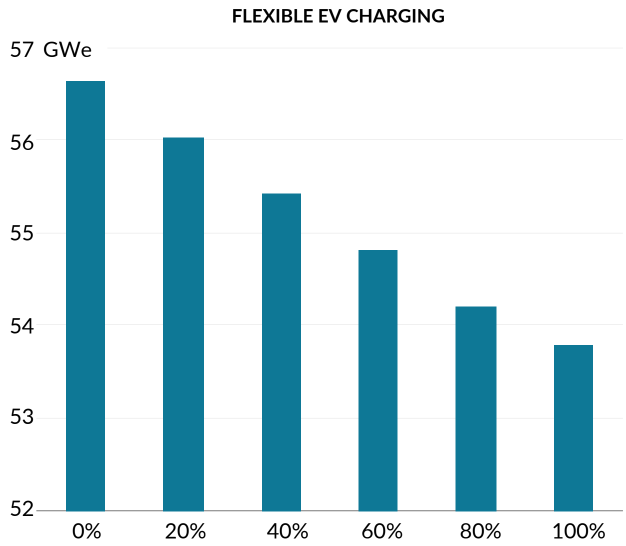


Source: Navigant

To illustrate the impact of EV fleet flexibility on the power grid load, we also carried out a sensitivity analysis (Fig. 33.).

The calculations indicate that in the case of a fully flexible EV sector it is possible to reduce peak load by as much as 2.5 GW (compared to zero flexibility in the EV sector). In periods of the largest shortages of energy from variable renewables (windless winter days), in the transportation sector we used tools to control the demand side, which helped reduce electricity demand from EVs by 40% (1 GWe).

Fig. 33. Change of peak load of NPS depending on the flexibility of EV fleet in S2-100+H+EV scenario



Source: Navigant

P2H — electrification of the heating sector

Electrification of the heating sector is the future. It will be driven by the need to reduce carbon dioxide emissions and smog, limited access to fossil fuels, as well as prevalence and comfort of using electricity for heating purposes. It must be noted that in the future buildings will use very little energy—electricity will be used to provide additional heating instead of comprehensive heating.

In our analysis, we took into account two technologies of heat generation from electricity—heat pumps and electrical boilers. Heat pumps are the key source of individual heat (80%) and a supplementary source in the district heating sector (up to 8%). Thanks to high efficiency, these devices are less sensitive to changes in electricity rates and guarantee the supply of heat at a reasonable price. Their operation can be additionally supported by energy from own sources, e.g., photovoltaic systems. A large number of installed heat pumps, as a tool used by ancillary service aggregators, may contribute to the stabilisation of the power grid operation.

The key condition enabling the provision of such services is equipping heat pumps with accumulators, which would enable achieving a heat reserve of two to four hours. In our analysis, the electric power of heat pumps is 10.0±0.5 GW, while their annual electricity consumption amounts up to 12.1 TWh.

The second solution are electric boilers (resistance heating). Their operating time is limited due to more available solutions, such as heat pumps or solar thermal energy. In the case of individual and district heating, in our analysis the share of heat from electric boilers is small because of high production costs.

DSM – demand-side management

In the modelling we took into account the thermal inertia of buildings, which makes it possible to temporarily reduce the volume of heating energy without any loss of thermal comfort by building users.

We made the following assumptions for our calculations:

- four-hour virtual storage facilities in the heating sector (shift of supply of part of energy beyond the peak).
- DSM in the transportation sector on windless winter days (in the period of low electricity supply from RES and strong demand).

Further considerations of the impact of DSM on demand for electricity and capacity are not covered by this analysis.

ES – energy storage

In the calculations we assumed the operation of storage facilities to enable heat and electricity balancing. The three types of energy storage facilities used in this analysis include:

- heat storage facilities,
- electricity storage facilities,
- seasonal storage facilities (not defined in terms of selection of technology).

The data presented below refer to the storage facility capacity required to absorb the surplus of energy and its supply during periods of insufficient production from variable RES and controlled units.

Heat storage facilities:

- already existing at CHP and heating plants in Poland – 5,000 MWt,
- two-hour storage facilities in individual heating systems – 18,400 MWt,
- twelve-hour storage facilities in individual heating systems – 6,100 MWt,
- six-hour storage facilities in district heating systems – 5,000 MWt,
- seasonal storage facilities – 22,300 MWt.

Electricity storage facilities:

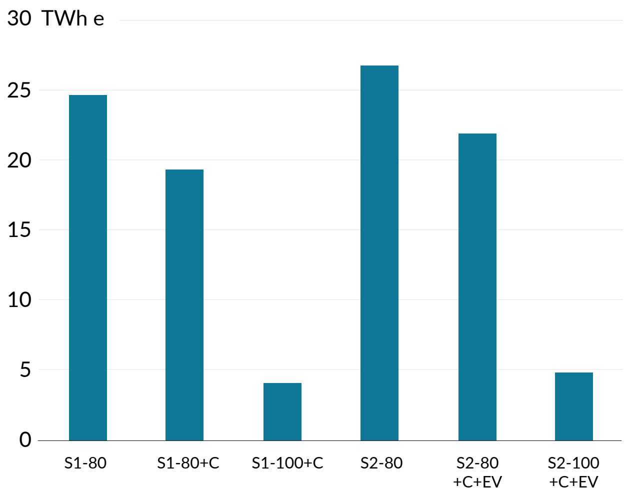
- pumped-storage power plants – 1,300 MWe, with a capacity of 10.4 GWh in a single eight-hour cycle,
- accumulators – 5,000 MWe, with a capacity of 20 GWh in a single four-hour cycle,
- seasonal storage facilities – 0.2-0.5 TWh_t depending on the scenario.

11. What are the benefits of sector coupling? Conclusions

Electrification of the heating and transportation sectors is the future. Both the transportation and the power generation sectors will move away from technologies based on the combustion of fossil fuels. Dispersed, zero-emission renewable energy sources will become a predominant element of the energy mix. Integration of energy sectors will thus be a natural consequence of the changes and a tool enabling optimisation of the power generation system and reduction of energy costs.

Below, we present conclusions from the analysis. We also present the key benefits of decarbonisation and electrification of the sectors and their closer cooperation.

Fig. 34. Net electricity imports to Poland in individual scenarios



Source: Navigant

Security of energy supply

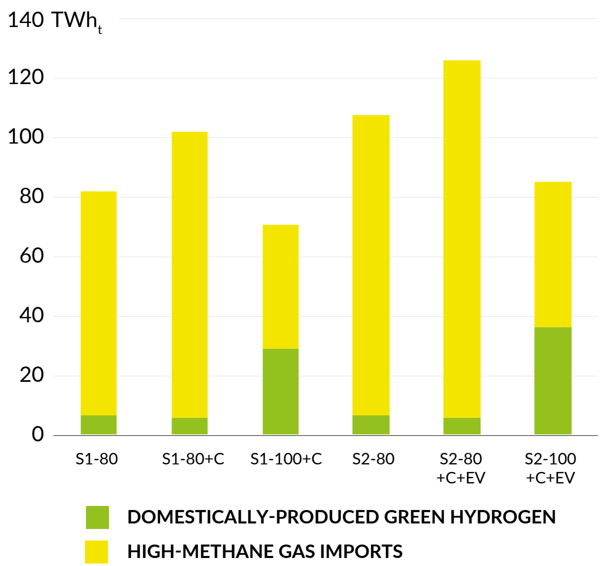
Cutting energy imports to a minimum—assuming that it is an important issue for Poland—can be achieved only in the 100% RES scenario. The share of RES reduces wholesale electricity prices and, in general, electricity flows from countries with lower prices to countries where electricity is more expensive. Given that in neighbouring countries the share of renewable energies rises without changing the share of RES, it must be assumed that the scale of conventional energy production in Poland will decline.

The development of RES will naturally reduce the volume of energy purchased abroad. However, it should be pointed out that Poland's presence in the European energy market also brings benefits. First, it reduces the cost of energy, which is beneficial most of all to the industrial sector. Second, it improves the security of supply—it enables purchasing power if a shortage occurs for any reason. And conversely, Polish energy may help other countries in system balancing. Fig. 34. presents net imports in all scenarios.

Reduction of gas imports

Scenarios in which 100% of energy is generated from RES (in most part, from variable types), involve the need to build very large capacities to guarantee uninterrupted supply. The inevitable consequence of such a system is overproduction. Oversupply results from the specific nature of RES operation and depends on weather conditions. This is the reason why in the comparison of the annual balance of production against demand, a significant oversupply of electricity can be observed. In our analysis, overproduction reaches 51 TWh, or 17% of domestic demand (as described earlier). Naturally, this oversupply can be prevented, e.g., by a temporary reduction of generation by wind farms, but it is not an economic solution for sources with zero variable costs. A better way of managing such surplus energy is to produce hydrogen, which would be a form of seasonal energy storage. In the future, hydrogen can replace natural gas, thanks to which Poland could become fully independent from natural gas imports.

Fig. 35. Gas consumption by energy sector in Poland and imports and domestic production of green hydrogen



Source: Navigant

With the assumed generation source mix in NPS, Poland could produce approximately 34 TWh of energy in hydrogen, which would enable cutting consumption of high-methane natural gas by about 3.1 billion cubic metres.

This represents approximately 42% of the demand for gas from energy sectors in the 100% RES scenarios.

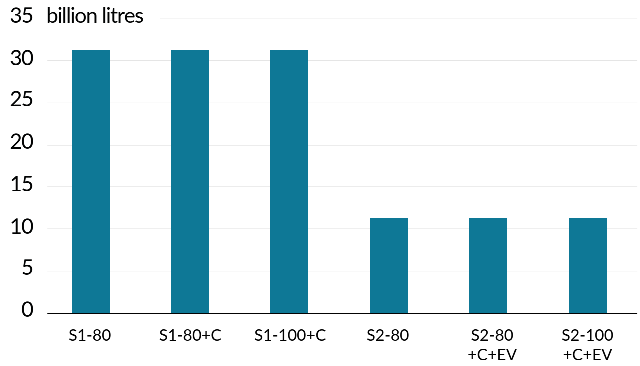
Thanks to significant local production of green gas, risks related to natural gas imports to Poland would be mitigated.

Reduction of crude oil imports

Electrification of the road transportation sector would greatly reduce fuel consumption (crude oil and natural gas) and at the same time transfer demand to other types of energy carriers—electricity.

Reducing reliance on imports is a priority for any country, which is why electricity should come from local renewable sources to the maximum extent. Fig. 36 presents the effect of electrification of the transportation sector on fuel imports.

Fig. 36. Liquid fuel imports for the road transportation sector in Poland



Source: Navigant

Electrification of transport to a level of 82%[11] means an increase in annual demand for electricity by 57 TWh and a concurrent drop in demand for transport fuels by some 64% compared to the base scenario.

Reduction of environmental impact

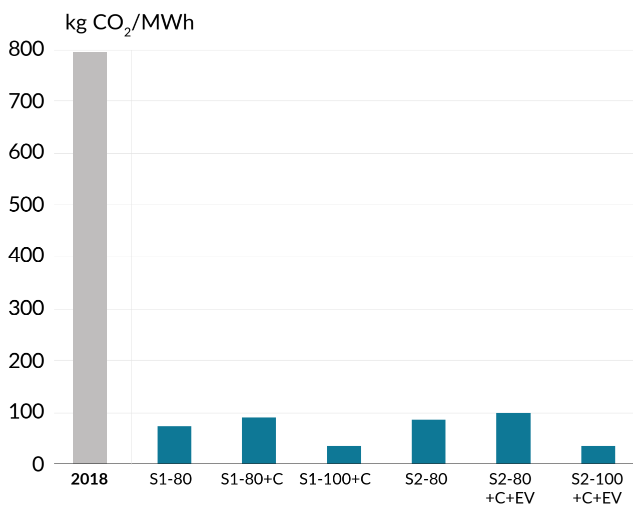
Reduced carbon dioxide emissions means a stronger environmental protection effect. It is also a pillar of sector integration.

The decarbonised generation mix in the power sector in scenarios with the maximum share of RES leads to a reduction of the CO_2 emissions ratio per unit of electricity from the existing 790 kg of CO_2/MWh to 30 kg of CO_2/MWh, a decrease of 96%.

EEmissions in the 100% RES scenarios do not fall to zero for three reasons:

- The assumed scenarios provide for marginal volumes of hard coal and lignite.
- Domestic production of green hydrogen is insufficient to meet the demand for that fuel from cogeneration units. Therefore, a

Fig. 37. Emission rates of the energy sector at present and in individual scenarios



Source: Forum Energii based on Navigant's calculations

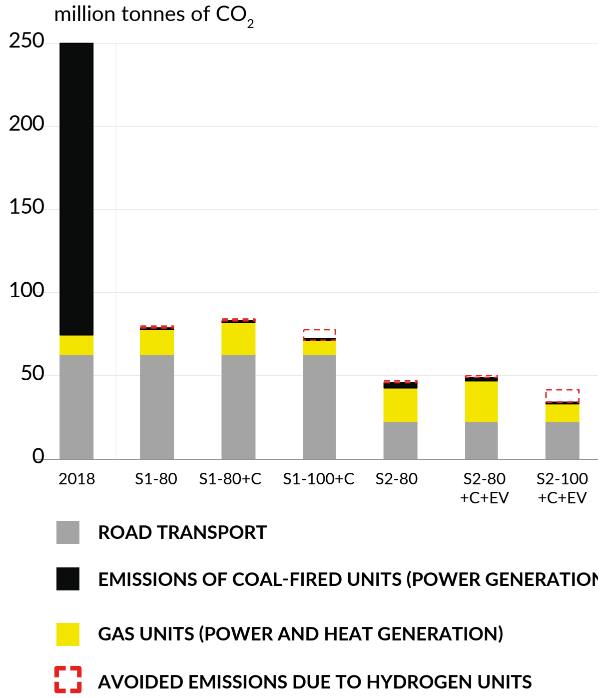
11 82% share of EVs in 2050 means 16.5 million light vehicles, 450,000 heavy city vehicles and 600,000 heavy road vehicles.

certain amount of the gas should be imported. If the green gas is imported, the sector's emissions ratio will indeed fall to zero. In our analysis, we assumed that this would be natural gas, which would entail some carbon dioxide emissions.

Fig. 37 presents the emissions ratio per unit of electricity of the power generation sector in individual scenarios. A considerable drop can be observed particularly in options with the maximum share of RES. Should methane be replaced with green hydrogen, emissions would fall to zero.

When comparing emissions of the power generation sector from 2018 and those assumed for 2050, it should be remembered that electricity consumption will grow from the existing **175 TWh/year** to **239 TWh/year** in the S1-80 scenario and **295 TWh/year** in the S2-100+H+EV scenario. The increase is attributable to electrification of the heating and transportation sectors. The drop of the emissions ratio per unit of electricity to 30 kg of CO_2/MWh should be considered a positive result.

Fig. 38. Total carbon dioxide emissions of the power generation, heating, and transportation sectors at present and in individual scenarios for 2050



Source: Forum Energii based on Navigant's calculations

Actual CO_2 emissions of the three sectors are reduced by 86%, from 250 million tonnes of CO_2 to 34 million tonnes of CO_2 in the scenario providing for the integration of all sectors (S2-100+H+EV).

Road transport cannot be fully based on renewables. In the contemplated scenarios, we assumed that the non-electrified part of the sector still will be using fossil fuels.

System integration costs

The Polish power generation system requires a major refurbishment due to the age of generation installations as well as the emissions ratio and growing dependence on imports of fossil fuels. In our cost analysis, we made an assumption that all contemplated generation units in the power generation sector and in the entire heating sector will be built in 2020-2050. In the power generation sector, the system will be de facto altered and refurbished in total.

Given today's level of decapitalisation of generation assets, it should be considered that this bold statement is very likely to materialise.

Total capital expenditure on alteration of the power generation and heating sector in 2050 amounts to:

- EUR 171-191 billion for 80% RES scenario,
- EUR 211-246 billion for 100% RES scenario.

The increase in capex is related to the need to increase the installed capacity of RES to ensure an appropriate volume of electricity.

In the transportation sector, no investments—which were treated as an element of the demand side—in new vehicles were assumed. Based on the same principle, no capital expenditure on thermal efficiency improvement of buildings in the heating sector was assumed, granting that it will occur in all of the contemplated scenarios.

Drawing on the previous analyses carried out by Forum Energii regarding the scenarios of development of the power and heating sectors, we prepared a BAU scenario for the purpose of comparison. This scenario is based on a very conservative assumption of keeping the existing generation mix in the power generation and heating sectors. Together with the growing demand for power and electricity, new units utilising fossil fuels (gas and coal) will be built with a constant installed capacity of RES. In the heating sector, the predominance of coal-based heat sources will be maintained in line with the existing production structure. The existing buildings will be insulated at the current pace, while new buildings will meet energy consumption standards in accordance with the applicable regulations.

Table 14. Capital expenditure on generation units in individual scenarios (EUR billion)

	S1-80	S1-80+H	S1-100+H	S2-80	S2-80+H+EV	S2-100+H+EV	BAU
power generation	130.29	130.25	171.08	150.73	150.80	206.25	101.2
heating sector	40.85	40.41	40.41	40.85	40.41	40.41	78.3
total	**171.14**	**170.66**	**211.49**	191.59	191.21	246.66	179.5

* Capex was not calculated for the transportation sector because the replacement of vehicles is continuous and not related to energy production.

It should be stressed that higher capital expenditure in the 100% RES scenarios will be offset by lower operating costs resulting from lower fuel and carbon-dioxide emission allowance costs. In addition, revenue from domestic production and sale of hydrogen in the range of EUR 2-2.5 billion will reduce operating costs of the power generation sector.

In the 100% RES scenarios, the cost of electricity production is half that in the 80% RES scenarios. This translates into a further reduction of annual variable costs. In the heating sector, the cost of electricity used to supply heat pumps falls by approximately EUR 0.2 billion, while in the transportation sector the cost of supplying electric vehicles is lower by about EUR 1 billion. In the BAU scenario, we can see a considerable increase of operating costs as a result of higher demand for energy, which is met by generation units utilising fossil fuels. Apart from growing fuel prices, higher costs will be driven by the rising price of carbon dioxide emission allowances. Table 15 shows operating costs in the three analysed sectors. It should also be noted that the 80% RES scenarios provide for a relatively large volume of energy from biogas and biomass, which results in higher variable costs due to the significant cost of acquiring the fuel.

Table 15. Operating costs for individual scenarios (EUR million/year)

	S1-80	S1-80+H	S1-100+H	S2-80	S2-80+H+EV	S2-100+H+EV	BAU
power generation	7 543	7 934	4 662	10 067	10 301	5 833	25 702
heating sector	2 231	1 760	1 667	2 254	1 759	1 663	23 095
transportation	54 600	54 600	54 600	21 608	21 649	20 589	54 600
total	**64 374**	**64 294**	**60 929**	**33 929**	**33 709**	**28 085**	**103 397**

* Variable costs also include the cost of carbon dioxide.

As can be seen in the presented calculations, maintaining the existing structure of electricity and heat generation without modernising the transportation sector (BAU scenario) will lead to a 73% rise in operating costs compared to the scenario of electrification of the heating and transportation sectors coupled with decarbonisation of power generation (S2-100+H+EV).

12. Summary

Poland faces two major challenges: decarbonisation and modernisation of the power generation sector. A modern power generation system can drive the economic revival after the coronavirus pandemic. Climate policy, apart from protecting the climate, reduces our reliance on fossil fuels, whose imports continue to grow by the year. To counteract this unfavourable trend and stimulate the development of industry, Poland should take a technological leap, ensuring a transition from coal to zero-emission renewable sources and hydrogen.

Sector coupling will facilitate this process and yield a reduction in the cost of energy transition. Electrified heating and road transport sectors will not only contribute to curbing air pollution emissions, but may also become a tool for balancing the National Power Grid (NPS) to be supplied with electricity from variable renewables.

The total electrical power of heat pumps and EV batteries represents 45% of the NPS peak power. Appropriate incentives in the form of dynamic energy tariffs will make it possible to manage the process of EV battery charging and operation of heat pumps. In effect, this will reduce demand for power in periods of peak consumption of electricity from the power grid.

The success of the transition in the heating sector towards its electrification largely depends on the reduction of heat energy consumption by buildings. A proper thermal modernisation policy should be developed, which would reduce final energy consumption by buildings by at least 60% until 2050. Without such a significant decline in demand for heating, the National Power Grid, in particular its distribution part, will not be able to supply adequate volume of energy and power in periods of peak demand. This means winter, which also has numerous episodes of low energy supply from variable renewables.

Nonetheless, despite frequent events of unavailability of adequate power in the NPS, over the year excess energy is generated from variable RES at the level of approximately 15% of domestic consumption. Such a high volume of energy should be used effectively, directly to generate heat and charge EV batteries, or stored, e.g., in the form of green hydrogen, for further use. The share of this zero-emission fuel produced from “free” surplus energy may reach as much as 42% of the total volume of gas used by the power generation sector. This would result in a proportionate reduction of gas imports to Poland. Electrification of the transportation and heating sectors, with concurrent use of domestic renewable energy sources, is the foundation of the process of improving the raw material supply security of Poland and reducing its dependence on fuel imports.

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This report (ref. No.: 209221) was prepared by Navigant Consulting Inc. (Stadsplateau 15, 3521 AZ Utrecht, The Netherlands), currently operating under the name Guidehouse Inc. ("Navigant")[12].

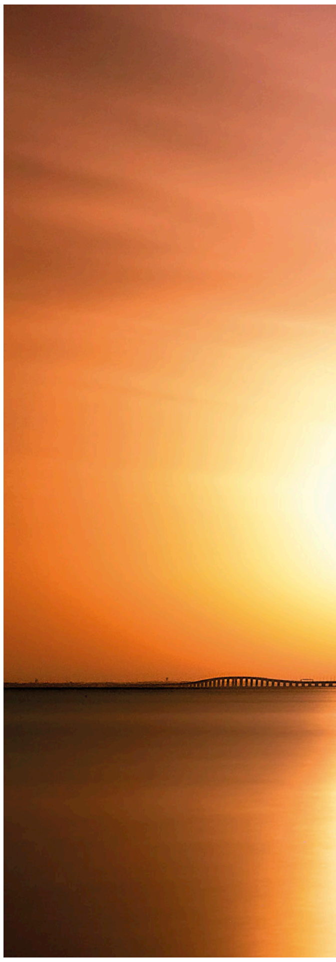
12 On 11 October 2019, Guidehouse LLP completed the previously announced acquisition of Navigant Consulting Inc. In the next few months we will focus our efforts on Guidehouse and Navigant business integration. As part of the measures taken, we have recently changed the name of Navigant Consulting Inc. to Guidehouse Inc.

Notes

Notes

Poland's climate neutrality by 2050

Electrification and sector coupling



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