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ONLINE WEBINAR

PyPSA-PL-mini: an exploratory model of the Polish energy system

24.04.2024

Instrat in a nutshell

Supercharging policies and public opinion with open data and research for a fair, green and digital economy

energy.instrat.pl

PyPSA

Strong R&D fundamentals: in-house energy modelling & data intelligence tools

Strong network with policy makers, investors and campaigners

Poland based, scaling up towards Brussels and Eastern Europe

> 25 researchers, data analysts and policy experts on the same goal

7 years in action on the ground

> 6m monthly media reach in PL
Growing internationally

PyPSA-PL-mini:

an exploratory model of the Polish energy system

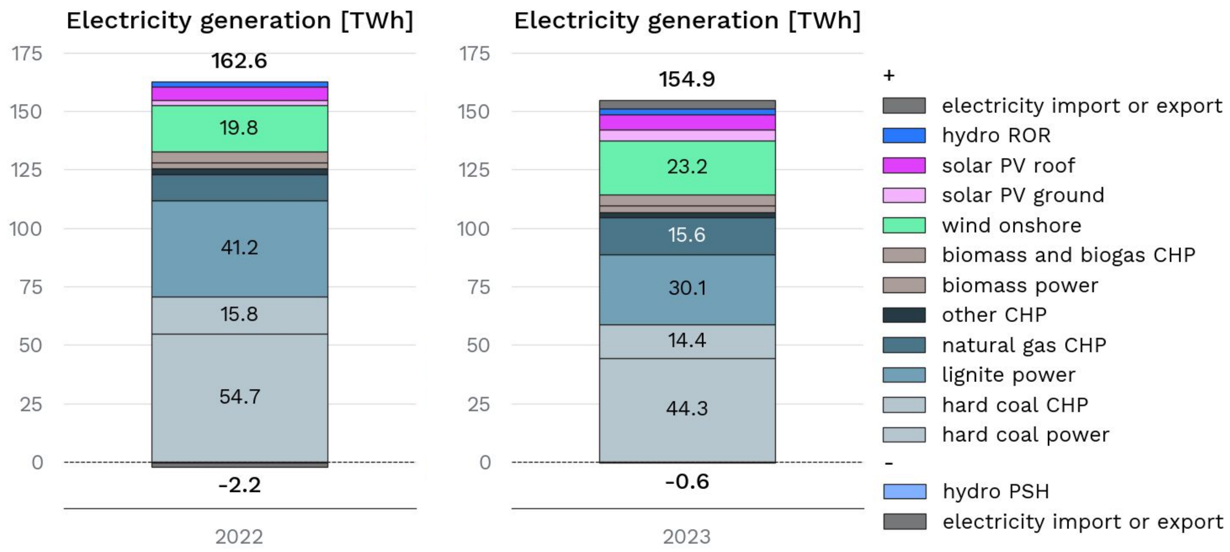
Presenting: Patryk Kubiczek, Instrat

Team: Patryk Kubiczek, Michał Smoleń, Wojciech Żelisko

Warsaw • 24 April 2024

Coal is a diminishing foundation of the Polish power sector

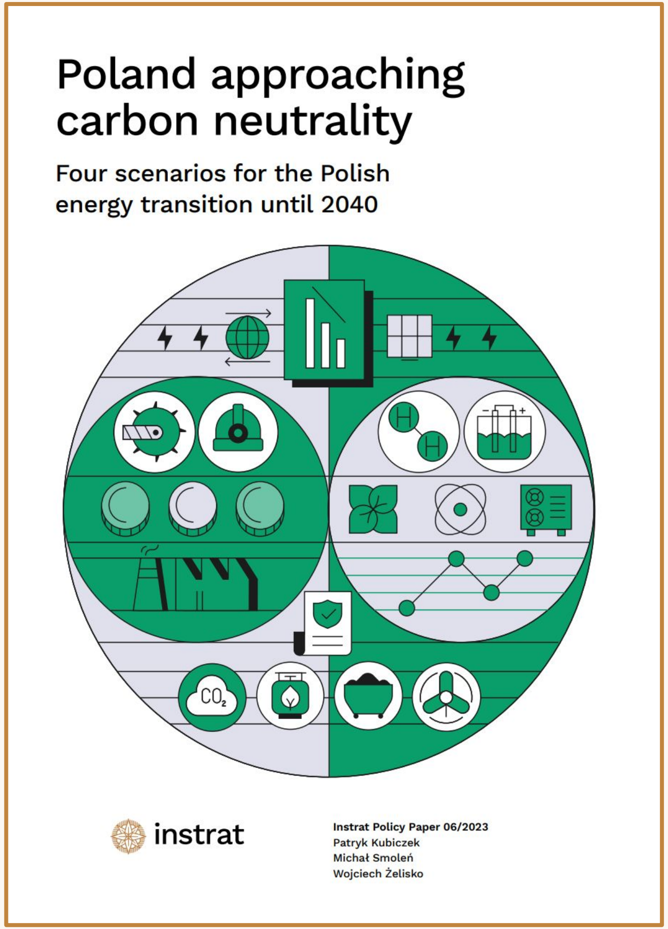
Structure of historical net generation and trade of electricity in 2022 and 2023 (TWh)



Source: Instrat's own analysis based on the historical net electricity production and demand (ARE). Imports are counted towards generation, exports towards consumption. Pumped storage hydropower (PSH) is a net consumer of electricity.

In 2023, CO_2 emissions in the power sector totalled approximately **110 $MtCO_2$**, a reduction of **20 $MtCO_2$** compared to 2022.

Coal's contribution to fulfilling domestic electricity demand decreased from **70%** to **58%**, while renewables' share rose from **23%** to **29%**.


Poland approaching carbon neutrality

Four scenarios for the Polish energy transition until 2040

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Instrat Policy Paper 06/2023
Patryk Kubiczek
Michał Smoleń
Wojciech Żelisko

Instrat Energy Modelling

In 2023, we developed four model-based scenarios for the future of the Polish energy system until 2040.

Our analysis indicates that by 2040, Poland could achieve an **85-90%** share of RES in electricity consumption in the cost-optimal manner. This would reduce the yearly emissions from the power sector to **less than 10 $MtCO_2$**.

→ https://instrat.pl/poland-2040

How can one understand better the logic behind optimisation-based energy modelling?

Agenda

1. **What is PyPSA-PL-mini?**
2. **Use case 1:**
   market dynamics under
   forced operations
3. **Short Q&A**
4. **Use case 2:**
   optimal electricity mix
   in 2023
5. **What do we learn?**
6. **Final Q&A**

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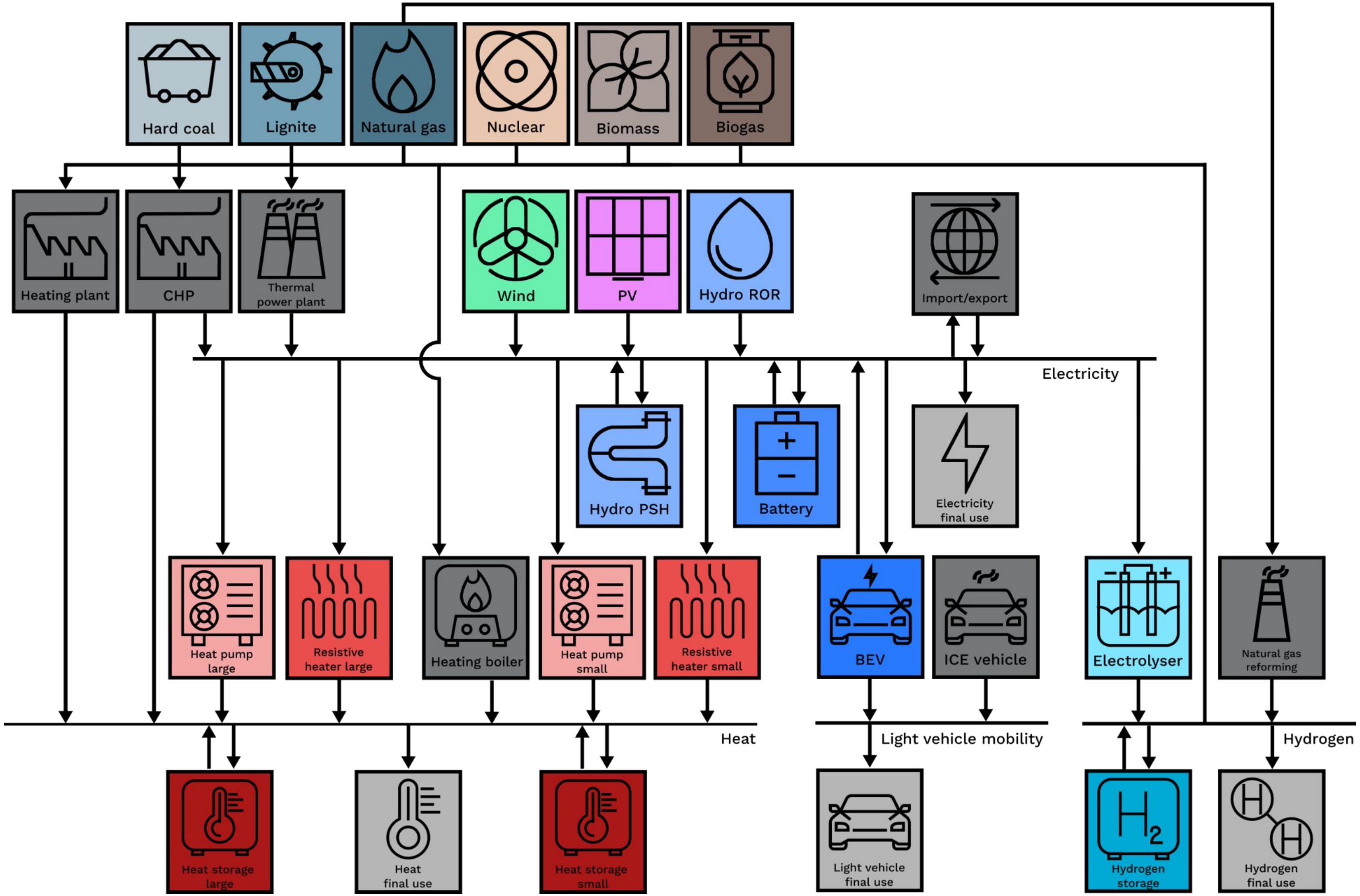
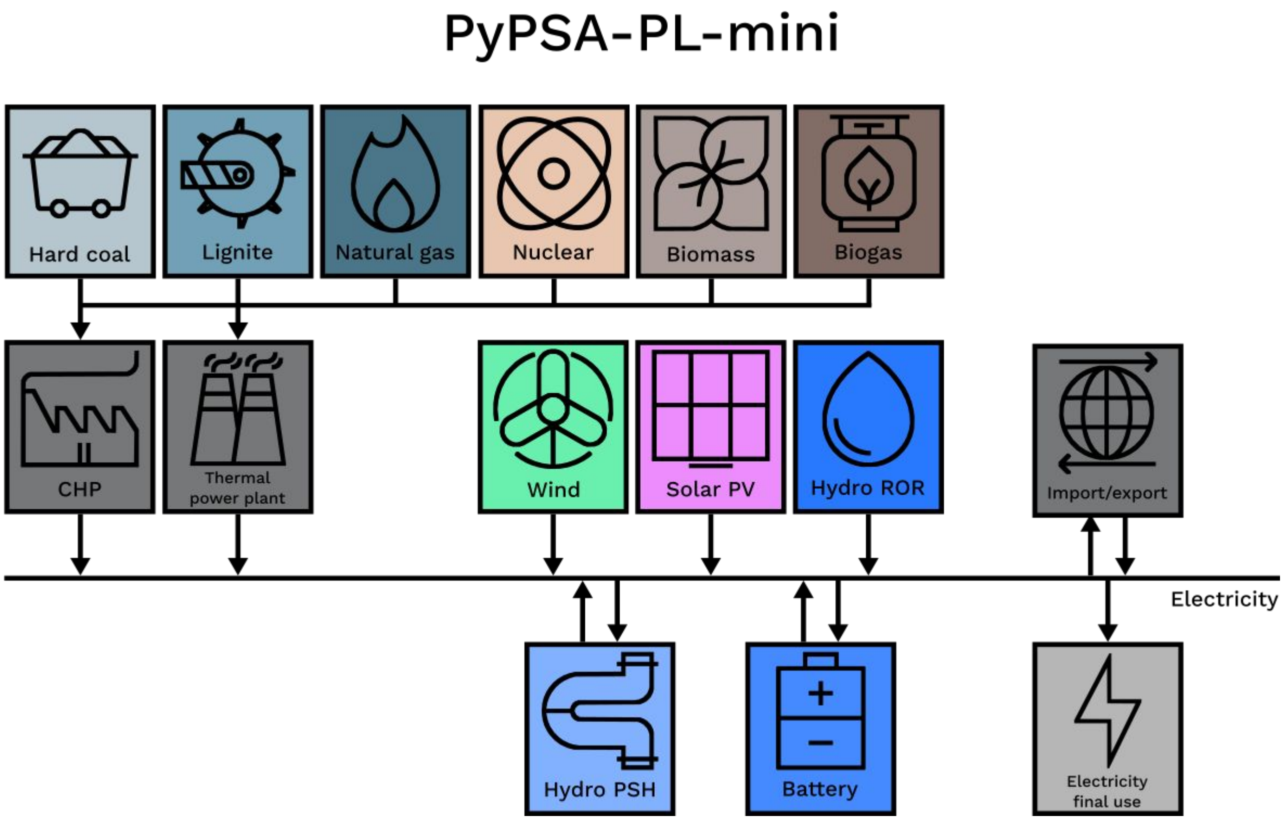
What is PyPSA-PL-mini?



PyPSA-PL is Instrat's in-house open energy system model inspired by the PyPSA-Eur project.

The latest version (v2.1) includes heating, mobility, and hydrogen sectors.

Find out more at github.com/instrat-pl/pypsa-pl.



PyPSA-PL-mini is Instrat's simple optimisation model of the Polish energy system model intended for testing and educational purposes.

Model's source code and data are **open**.

Find out more at github.com/instrat-pl/pypsa-pl-mini.

PyPSA-PL-mini

How do we reduce the complexity?

Power sector only

Let’s start simple and focus on the **power supply only**. CHP plant operation is fixed and not optimised.

Limit the hourly scope

Instead of the whole year, let’s model **4 representative weeks** (one per season) at an **hourly resolution**.

No cross-border flows

Modelling neighbour countries adds significant complexity – let’s skip it for a moment.

Simplify the inputs

Simplify input files and their structure compared to PyPSA-PL → inputs

PyPSA-PL-mini

What do we gain?

Fast model

Reduced complexity means the model runs **in a matter of seconds** and does not require high-end computational resources.

Improved understanding

Model's modular structure and fewer components make it easier to **understand** how the power system works.

Interactivity

The user can **experiment** with the model directly and rapidly **test** new features, e.g. in a Jupyter notebook.

Lower barrier entry

The model can be easily embedded into environments with **minimal or no coding expertise required**.

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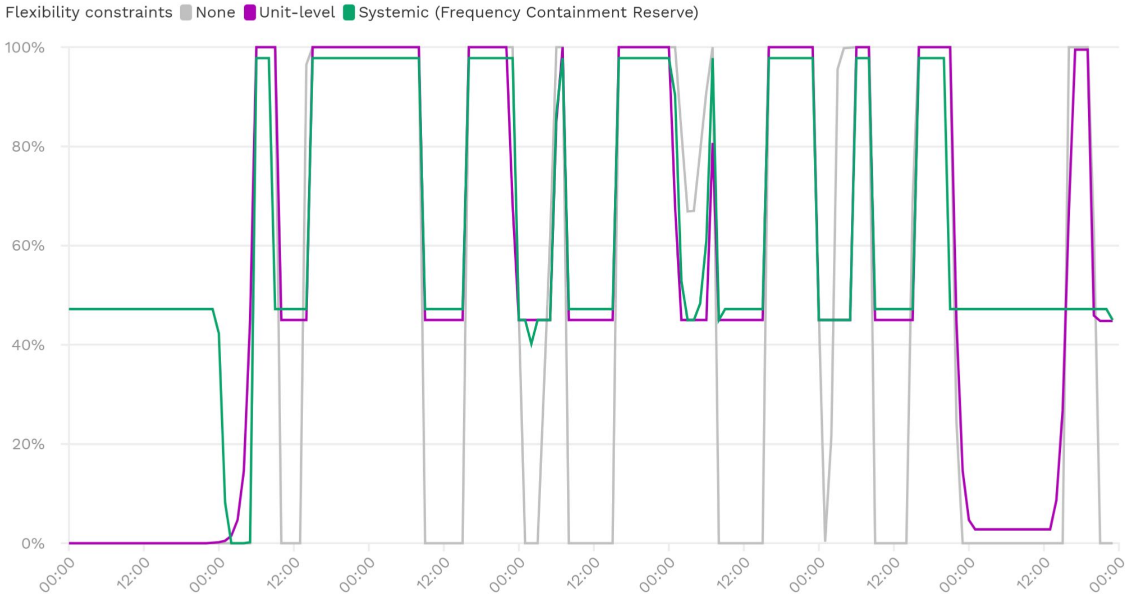
Use case 1:
market dynamics under
forced operations

Forced baseload operation of conventional power plants distorts the electricity market

Load profile of a selected coal-powered generating unit by 2030



Source: Instrat's own analysis based on PyPSA-PL modelling (baseline scenario for installed capacity) • The **unit-level** flexibility constraints are non-zero start-up and shut-down costs, minimum time in on and off state, and minimum stable output level of natural gas, coal and biomass units. Those constraints are implemented in PyPSA-PL in an approximate manner (linear relaxation). • In the variant of **systemic** flexibility constraints, it is assumed that only coal and natural gas JWCD units can provide FCR service, which leads to their production surplus. The condition of a minimum stable output level to provide FCR is implemented in an approximate manner.

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Currently in Poland, only fossil fuel-powered centrally dispatchable units (JWCD) provide system services, such as frequency regulation.

To do so, they need to **operate at least around their technical minimum (40-50%)** – even when the electricity they produce could be delivered more cheaply by RES.

Our analysis suggested that the provision of system services by JWCD has larger impact on RES curtailment than the unit-level constraints.

Learn more:
→ https://instrat.pl/baseload-power

Question 1:

How does the forced operation of conventional power plants impact electricity market dynamics and systemic costs? → notebook

Market dynamics

The question focuses on the short-term market dynamics, not the long-term planning, hence we assume fixed installed capacities.

Force minimum operation

We represent the forced operation of conventional power plants by setting their minimum hourly capacity utilisation *p_max_pu* (~25% in the current system).

Optimise dispatch

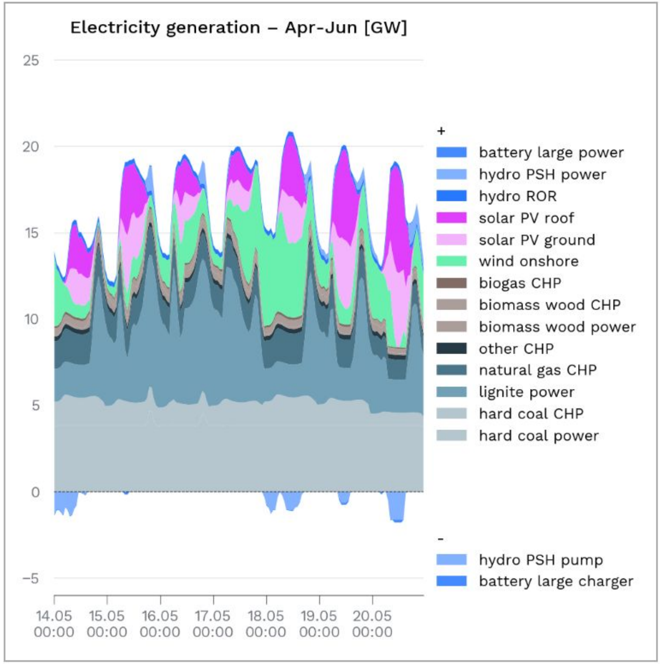
We task the model with optimising OPEX, i.e. selecting generators and dispatch times to minimise fuel expenses, CO_2 fees, and other variable cost, akin to an ideal electricity market.

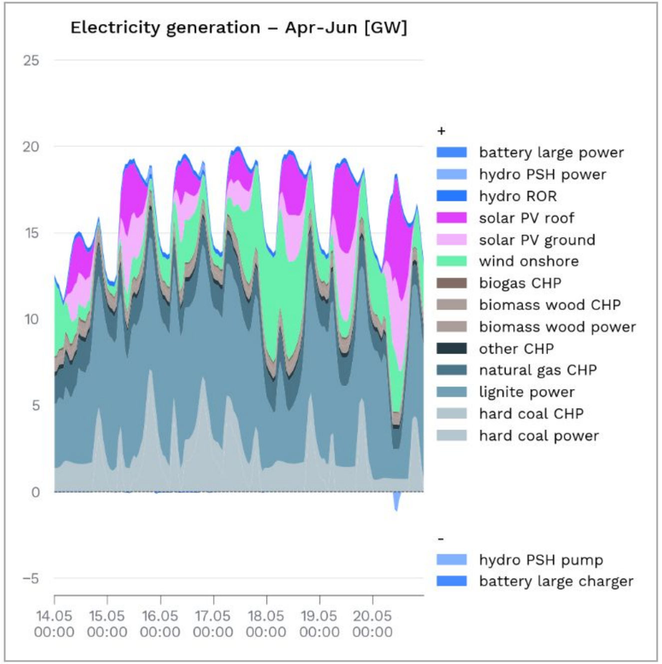
Explore consequences

For each selected *p_max_pu* optimise the system and calculate total operational cost, CO_2 emissions, marginal electricity prices, etc.

p_min_pu = 25%
(conventional baseload of around 6 GW)

p_min_pu = 0%
(no baseload)





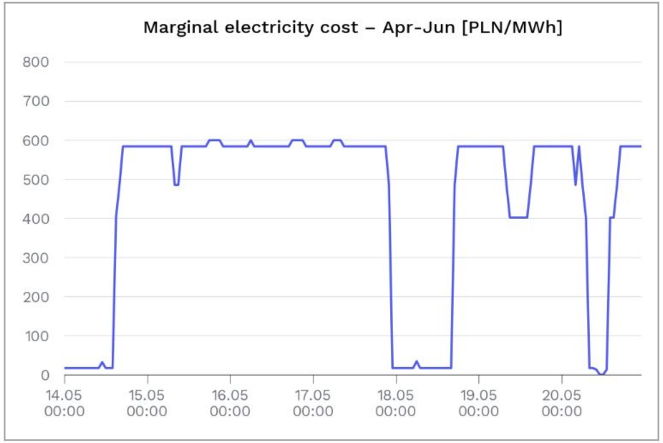
Forced operation of conventional plants leads to **curtailment** of wind and solar (vRES) energy.

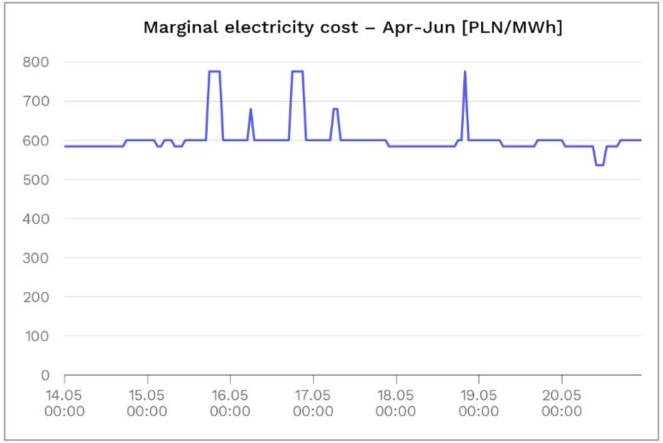
In such a case, **storage technologies** (mostly hydro PSH) are dispatched to minimise the energy losses.

Source: PyPSA-PL-mini

p_min_pu = 25%
(conventional baseload of around 6 GW)

p_min_pu = 0%
(no baseload)

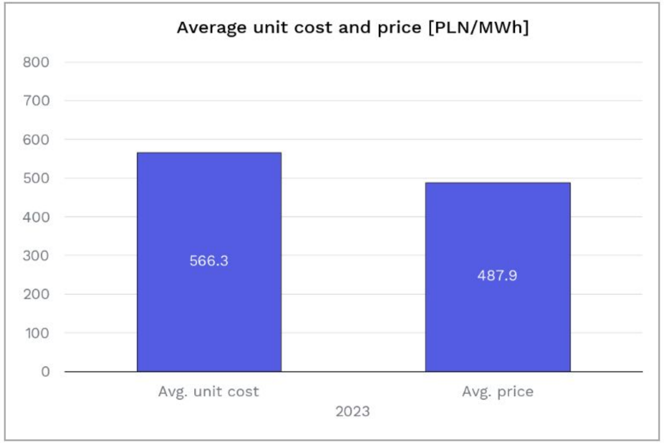




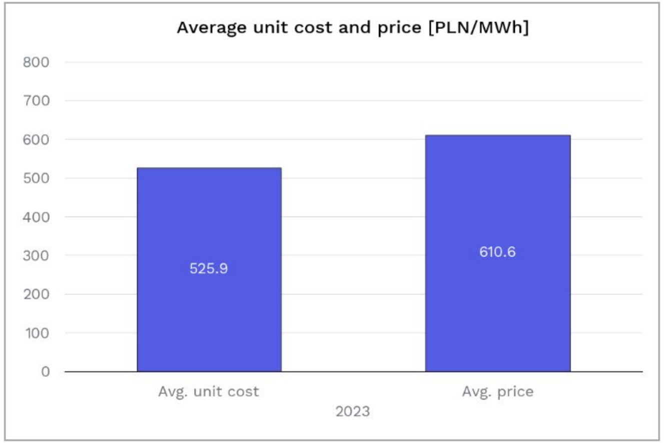
If curtailment is avoided, wind and solar PV plants rarely, if ever, become marginal electricity generators, thus maintaining **higher price levels**.

Source: PyPSA-PL-mini

p_min_pu = 25%
(conventional baseload of around 6 GW)



p_min_pu = 0%
(no baseload)



If curtailment is avoided, wind and solar PV plants rarely, if ever, become marginal electricity generators, thus maintaining **higher price levels**.

At the same time, lifting the baseload constraint allows the market to operate more efficiently, hence **unit production costs are lowered**.

Source: PyPSA-PL-mini

Model-based answers to Q1:

How does the forced operation of conventional power plants impact electricity market dynamics and systemic costs? → notebook

Higher costs

It costs more money to curtail RES and burn fossil fuels if curtailment can be avoided.

Lower market prices

Forced non-economic operation of conventional plants make it more likely for wind and solar to become marginal generators, lowering the prices.

Higher emissions

Opportunity to lower emissions by utilising more RES is missed.

Lower revenues

Conventional power plants effectively subsidise the electricity market at the expense of their diminished revenues or potential losses

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Short Q&A

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Use case 2:
optimal electricity mix in 2023

Question 2:

What could be Poland's cost-optimal electricity mix in 2023 assuming no limitation on new capacity deployment? → notebook

Optimal investments

The question focuses on long-term investment planning, hence we have to take into account both operational and investment costs.

Define which technologies to deploy and which to retire

The model operates within a defined opportunity space, deciding which technologies to deploy (e.g., wind) and which to retire (e.g., coal) to reduce maintenance costs.

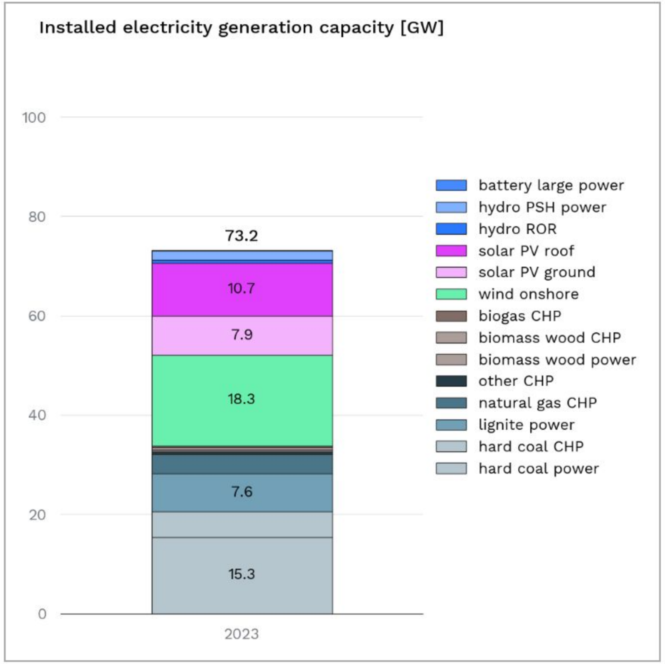
Optimise dispatch and investment jointly

Annualise the overnight investment costs and find a solution minimising the sum of CAPEX and OPEX.

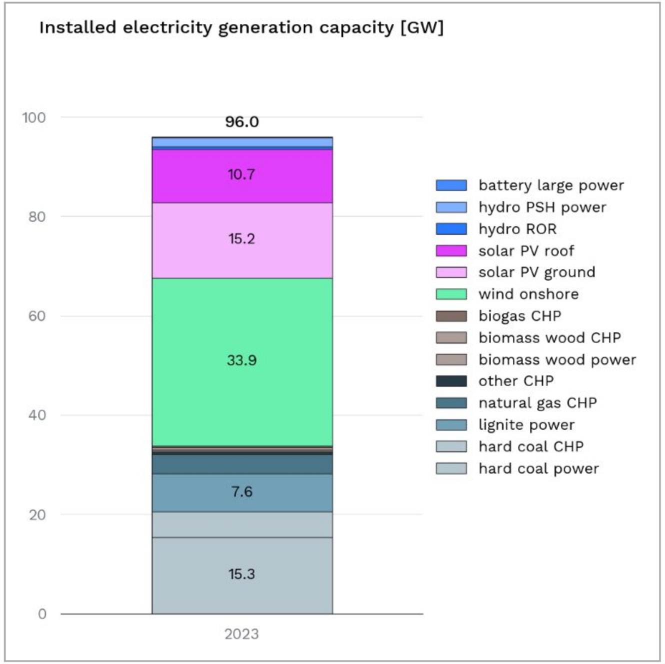
Vary cost assumptions

The result is sensitive to costs of new infrastructure and carbon pricing, which are uncertain for long-term planning. Therefore, exploring consequences of different assumptions is crucial.

p_min_pu = 25%
+ allow investment in wind, solar, batteries, natural gas



p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas



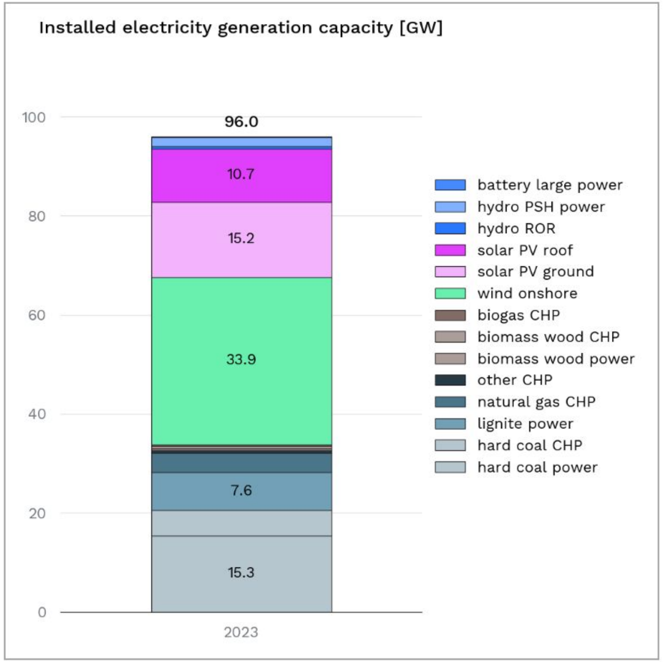
Under continued forced operation of conventional power plants, there is economic space for adding **9 GW** of onshore wind and **2 GW** of solar PV

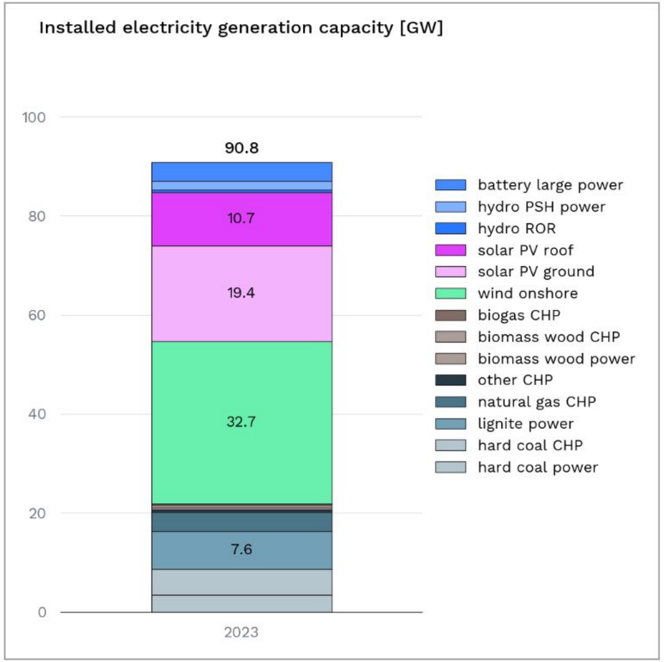
If the forced operation constraint is lifted, there is space for adding **24 GW** of onshore wind and **9 GW** of solar PV.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units



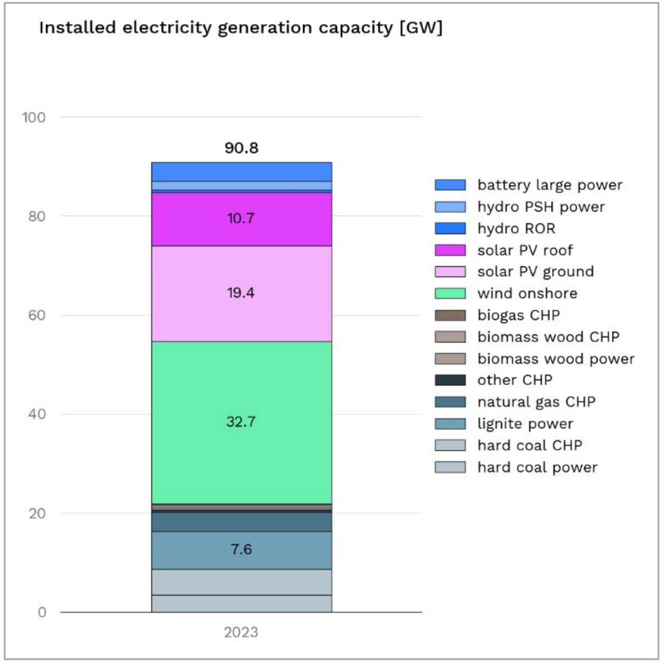


Additionally, if we permit retiring of coal-fired power plants, we create economic space for an additional **4 GW** of solar PV.

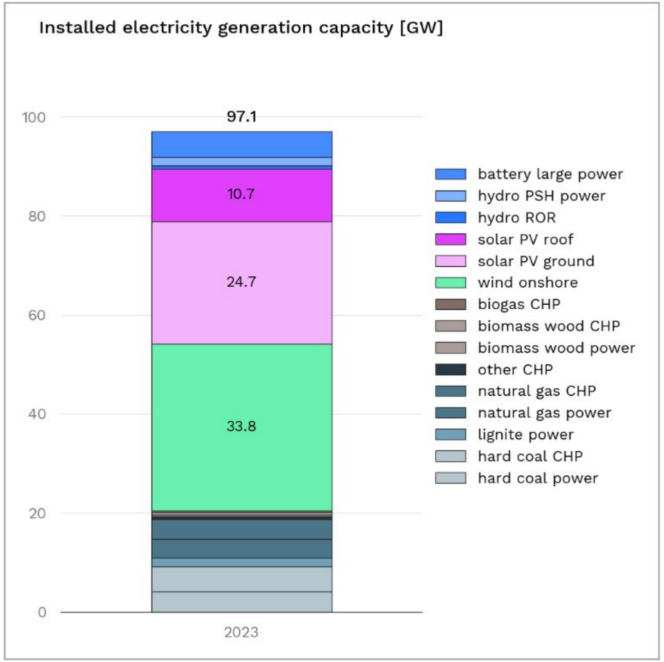
Furthermore, it's economically viable to construct around **4 GW** of new batteries.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 83 EUR/tCO2



p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2



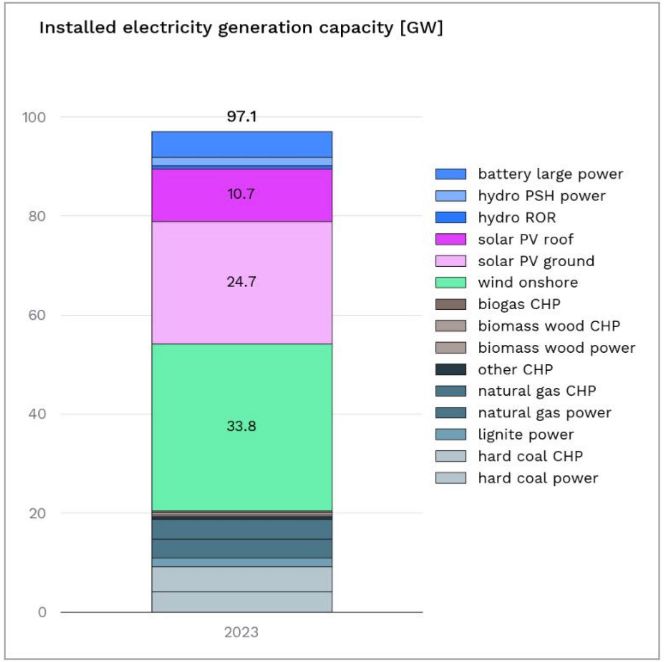
Assuming a carbon price of **140 EUR/tCO_2**, resembling realistic ETS allowance costs around 2030, the optimal solar PV capacity increases by an additional **5 GW**.

Battery capacity gains another **1 GW**, with the optimal storage-to-power ratio rising from 3h to 5h.

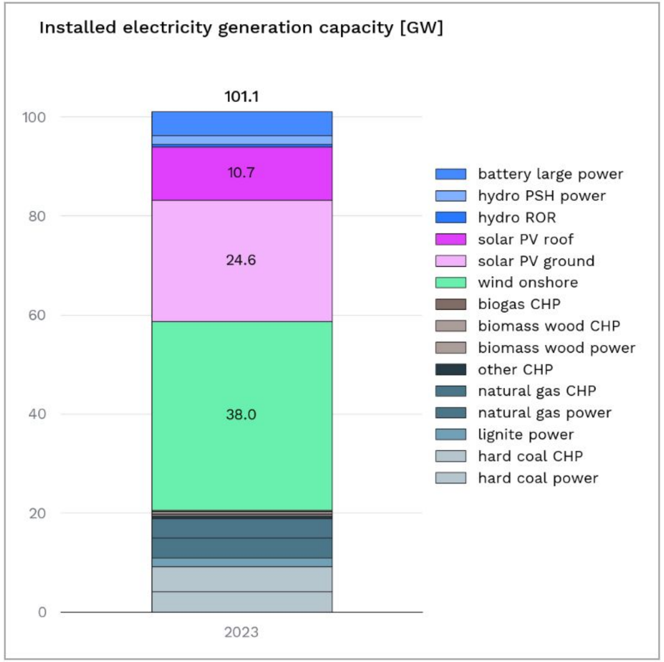
Additionally, in this higher CO_2 price setting, new gas-fired units with a capacity of **4 GW** partially displace old coal-fired plants.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2



p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%



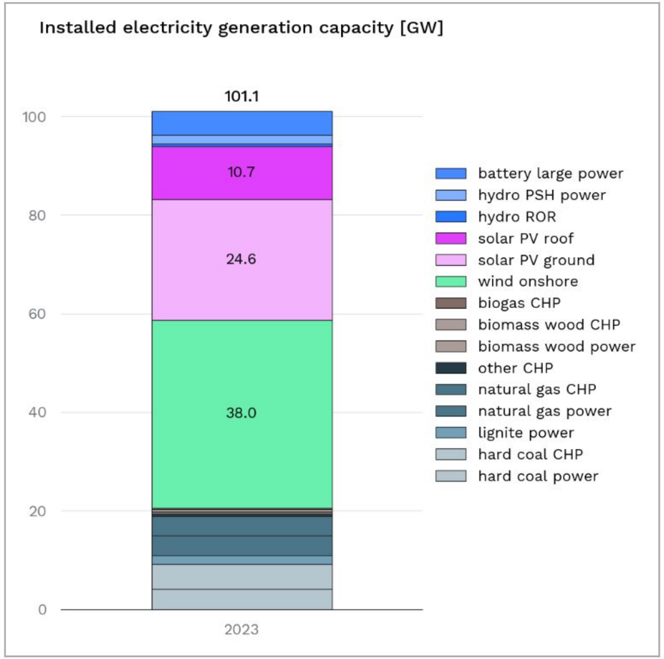
Investment costs of solar PV, wind turbines, and batteries are likely to decrease.

Interestingly, this assumed cost decrease does not significantly impact solar PV and battery capacity.

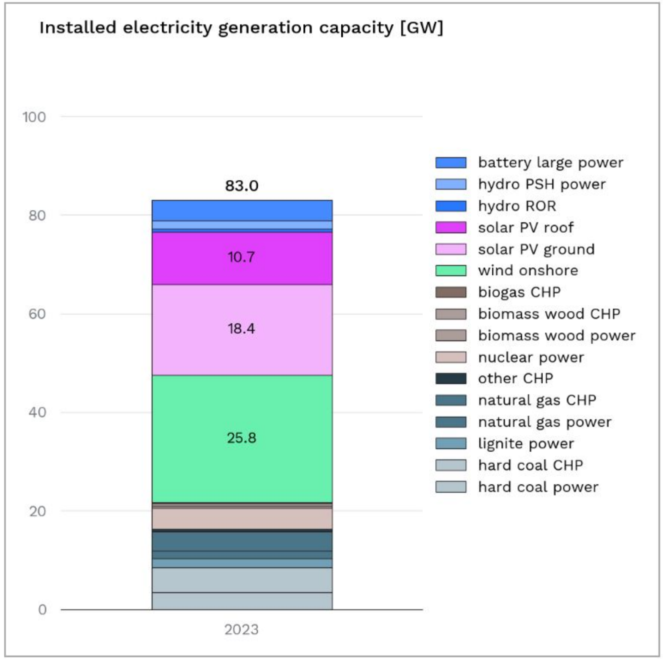
However, the optimal wind onshore capacity increases by an additional **4 GW**.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%



p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%
+ allow investment in nuclear power
nuclear_cost_factor = 150%



Nuclear power, if permitted, has the potential to further reduce systemic costs.

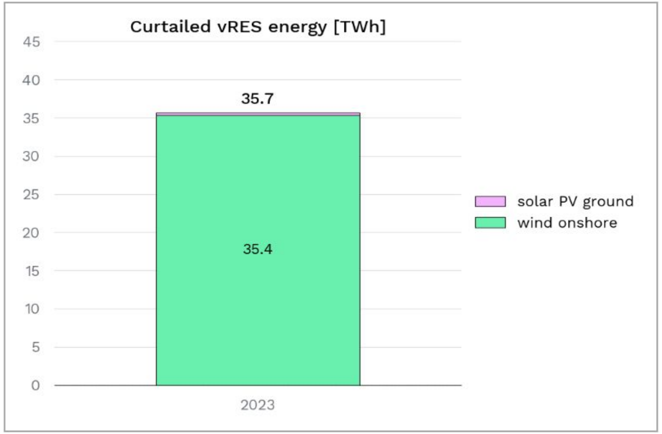
However, its investment costs will likely amount to at least **50 bln PLN/GW**, which is 150% of the typical cost assumption.

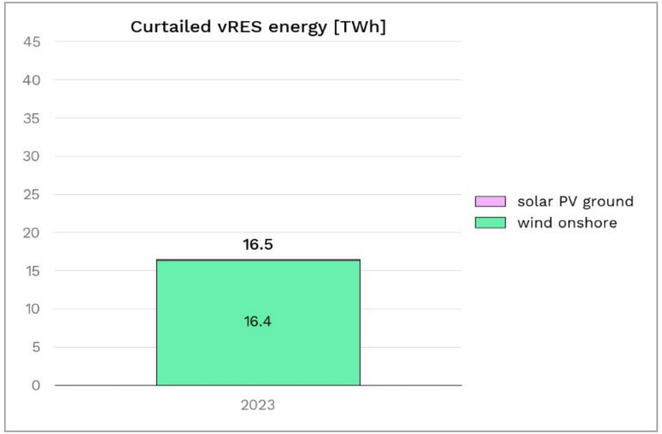
Under this scenario, an optimal capacity of around **4 GW** for nuclear power is suggested.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%
+ allow investment in nuclear power
nuclear_cost_factor = 150%

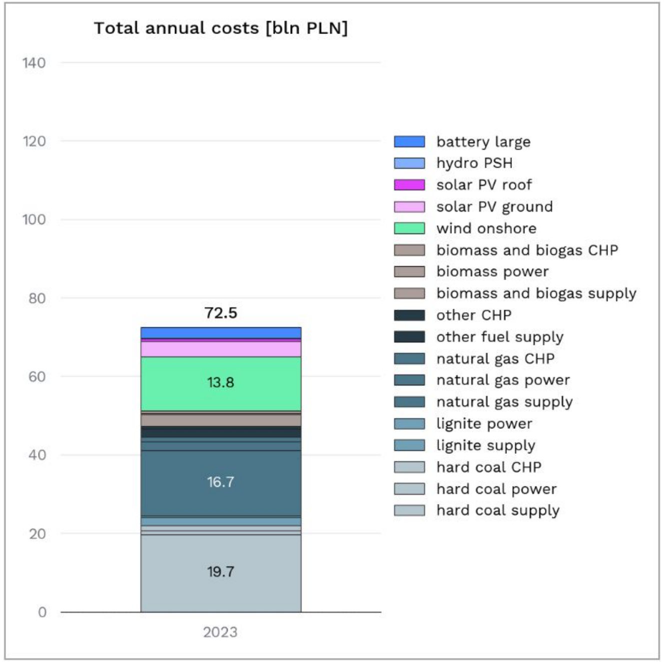




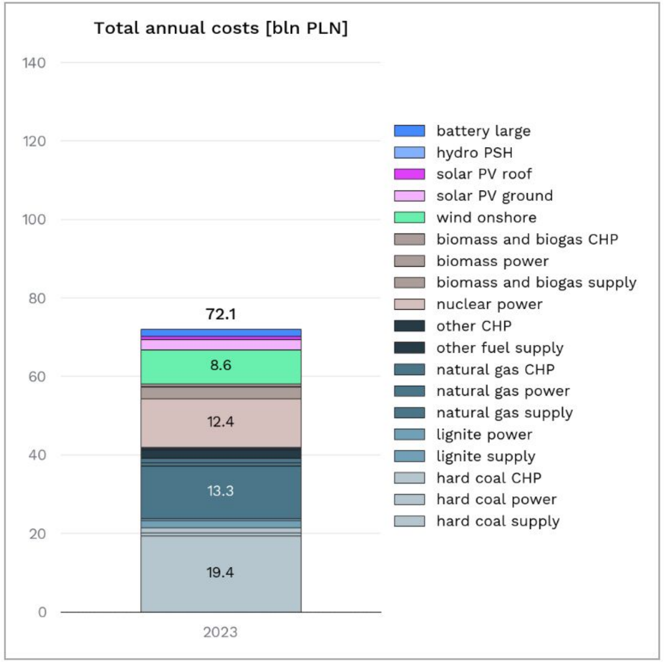
Both scenarios incorporate massive curtailment of variable solar and wind energy – **18-27%** of available vRES energy is wasted.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%



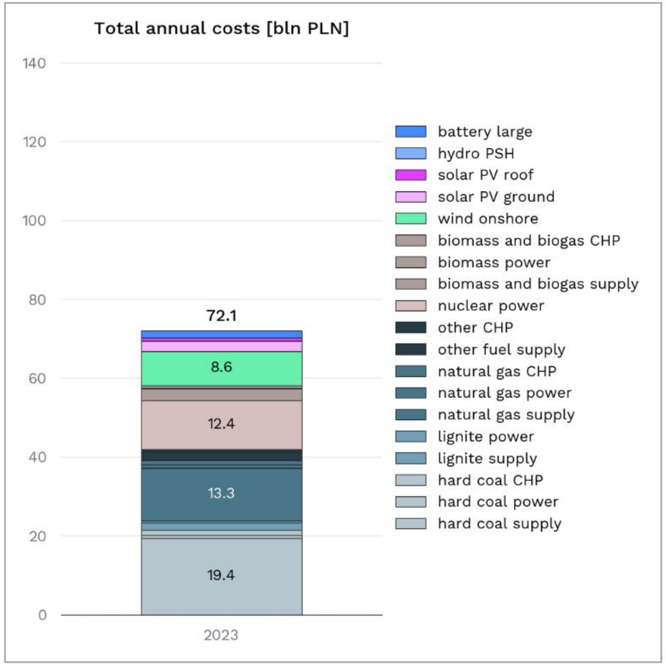
p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%
+ allow investment in nuclear power
nuclear_cost_factor = 150%



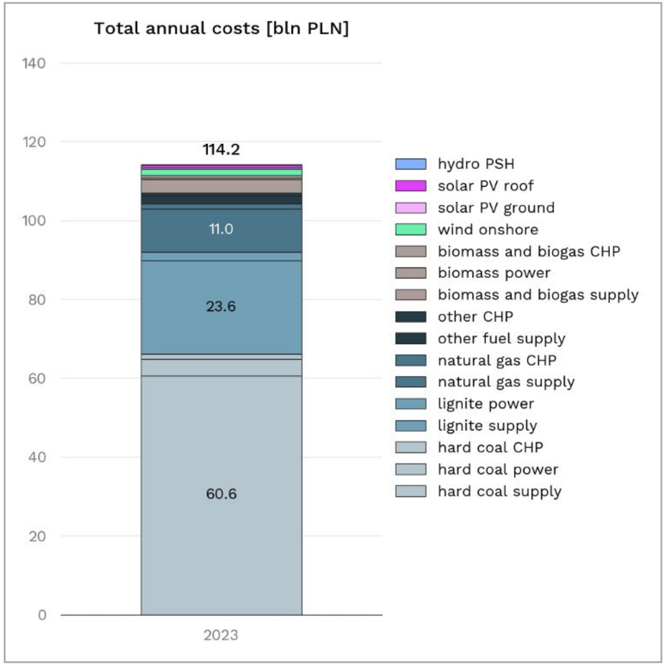
The total systemic cost (variable and fixed costs, including annualised CAPEX) between scenarios show only a slight difference: **72.1 bln PLN/year** with nuclear compared to **72.5 billion PLN/year** w/o nuclear.

Source: PyPSA-PL-mini

p_min_pu = 0%
+ allow investment in wind, solar, batteries, natural gas
+ allow retirement of coal-fired units
co2_price = 140 EUR/tCO2
wind_and_solar_cost_factor = 75%
battery_cost_factor = 50%
+ allow investment in nuclear power
nuclear_cost_factor = 150%



p_min_pu = 25%
co2_price = 140 EUR/tCO2
+ disallow all investments and retirements



If the current system had to operate under a carbon pricing of 140 EUR/tCO2, the total cost would reach as much as **114 billion PLN** annually – excluding annualised investment costs of existing infrastructure.

That is over **40 bln PLN** more than in the optimal investment scenario.

Source: PyPSA-PL-mini

Model-based answers to Q2:

What could be Poland's cost-optimal electricity mix in 2023 assuming no limitation on new capacity deployment? → notebook

Nuclear and RES

Solutions incorporating realistic cost assumptions are likely to combine nuclear power with RES.

Batteries help but firm capacities still present

Retaining some old coal-fired plants as backups may be cost-optimal rather than overinvesting in gas-fired capacities or batteries.

Massive RES curtailment may be optimal

Wind and solar energy is so cheap that optimal solutions afford to lose even as much as one quarter of its volume.

Carbon pricing influences the capacity mix

High carbon prices incentivise battery deployment and result in the displacement of coal by natural gas in the role of firm capacity.

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What do we learn?

Escaping the model land: what have we missed?

Flexible new demand

New flexible demand from electrolysers, BEVs, and P2H technologies is likely to prevent significant RES curtailment.

Grid expansion costs

Both RES and nuclear dominated systems will require significant grid reinforcements, whether at the transmission or distribution level.

Alternatives to CHP plants

CHP plants are unlikely to remain at their current capacity, creating room for other electricity generators.

Robust statistics

Four weeks of weather and demand statistics are insufficient to robustly determine the required level of firm generation capacities.

Cross-border flows

Exporting electricity surplus may increase the profitability of new investments. Imports can help avoid over-sized peak capacities.

Policy-based distortions

Policy-based financial instruments and compensations, such as capacity payments or CfD schemes, are not included in the cost calculations.

Lessons learned

Renewables make difference

Savings due to fast RES deployment within the current system are evident.

Simple models help formulate hypotheses

Plausible statements can be derived from simple model results but they need to be verified with other methods.

Systemic perspective

Lower market prices do not necessarily translate to lower costs: any compensations paid by the TSO ultimately falls on end users.

Transparency adds value

Details are important, which is why energy modelling and data should be open source and open access.

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We are looking forward to hearing from you

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Final Q&A