Plan of decarbonisation of the domestic power industry through modernisation with the use of nuclear reactors

DEsire

KM4.2 Preliminary feasibility studies for Generation IV reactors – Opole

Contractor: **Energoprojekt Katowice S.A.**

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. Basic information about the project

The aim of the project is to develop a plan for decarbonising the national energy sector through modernisation using Generation III/III+ and IV nuclear reactors.

The ongoing transformation of the Polish power system reinforces the need to develop a coherent structure that ensures stability and security. The decarbonisation plan is being developed through seven research tasks and is intended to serve as a roadmap for future investment processes in the area of Coal-to-Nuclear policy. The project plans to launch a national Energy Transformation Cluster (KTE), which will provide organisational support for activities in the process of transforming national power plants and combined heat and power plants.

The project is being implemented as part of a consortium formed by five entities: the Silesian University of Technology, the Ministry of Climate and Environment, Energoprojekt-Katowice SA, the Institute of Nuclear Chemistry and Technology, and the Sobieski Institute Foundation. Funding for the project was obtained as part of the 6th competition of the National Centre for Research and Development "Gospostrateg".

1.1. SMR technology

In order to achieve the goal of the 2015 Paris Agreement, which is to limit global temperature rise to well below 2°C above pre-industrial levels, the world will need to utilise all low-carbon energy sources. The use of renewable energy sources such as wind and solar power will continue to grow, but nuclear energy, as a low-carbon source, can provide the steady and reliable flow of electricity needed for economic development. Along with hydro and solar energy, nuclear energy is the only low-carbon energy source that can replace fossil fuels in the production of electricity and heat.

2. Market analysis of demand for investments

The main objective of this project is to investigate the possibility of replacing coal-based sources of electricity generation with nuclear energy from Generation IV reactors, which are currently only in the early stages of development. This type of investment is a forward-looking solution, in line with the pan-European decarbonisation plan and the pursuit of a zero-emission European electricity system.

This chapter presents the current situation in the electricity generation sector in Poland and its projected development over the next few decades, taking into account other projects, including planned nuclear power plants and new renewable energy sources, based on published government plans, strategic documents and analyses by the transmission system operator.

2.1. Current characteristics of the electricity market in Poland

The Polish electricity market operates on the basis of the Energy Law Act of 10 April 1997, as amended. The institution regulating the legal aspects of the market is the Energy Regulatory Office (URE), the transmission system operator is Polskie

Sieci Elektroenergetyczne (PSE SA), while electricity trading is possible through the Polish Power Exchange (TGE).

In 2024, the Polish electricity market was characterised by the following figures:

Electricity production
- 166.99 TWh

Peak demand
- 28.66 GW

Total installed capacity
- 72.8 GW

Average wholesale energy price
- PLN 418/MWh

Data source: ARE, PSE, TGE.

Figure 1: The Polish electricity market

2.1.1. Structure of electricity demand and supply

The required level of electricity production results from the demand for electricity within a given power system. Over the last dozen or so years, there has been an upward trend in electricity consumption in Poland. However, at the turn of 2019 and 2020, as a result of the outbreak of the global COVID-19 pandemic, a significant drop in electricity consumption was observed. The lockdowns announced by the government in 2020-2021 resulted in reduced electricity consumption, mainly in the industrial and construction sectors and among small consumers. It was not until 2022 that electricity consumption returned to the level seen before the outbreak of the COVID-19 pandemic.

Detailed data on electricity consumption by individual sectors over the last dozen or so years is presented in the table and graph below. Data for 2024 has not yet been published and will only be available at the end of 2025.

Table 1 Electricity consumption in 2013-2023

Sectors, TWh	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Own consumption of power plants and and professional power plants and heat and power plants[1]	14.1	13.5	13.4	14	14.3	14	13.8	12.5	14.20	13.88	12.24
Own consumption of professional heating plants	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.23	0.16	0.19
Mining and extraction	8.8	8.7	8.7	8.5	8.3	8.3	8.2	7.9	8.16	7.89	7.85
Industry and construction	47.9	48.2	50	52.1	55	57.8	57.2	55.8	58.86	57.62	54.14
Water supply; sewage and waste management waste management	2.6	2.7	2.7	2.9	3	3.1	3.1	3.1	3.32	3.28	3.27
Transport	4.1	4	4.3	4.6	5.2	5.6	5.6	5.3	5.72	5.92	6.40
Small business sector customers	68.6	70.9	71	73.9	73.1	74	72.9	72.4	73.51	74.71	71.07
Total consumption[2]	**146.4**	**148.1**	**150.3**	**156.2**	**159.0**	**162.9**	**161.0**	**157.1**	**164.0**	**163.5**	**155.2**
Consumption dynamics	100.3	101.2	101.5	103.9 %	101.8	102.5	98.8	97.6	104.4%	99.7%	94.9%
Average growth rate from period	*100.6%*										

Source: own study based on: Fuel and energy carrier consumption (Central Statistical Office)

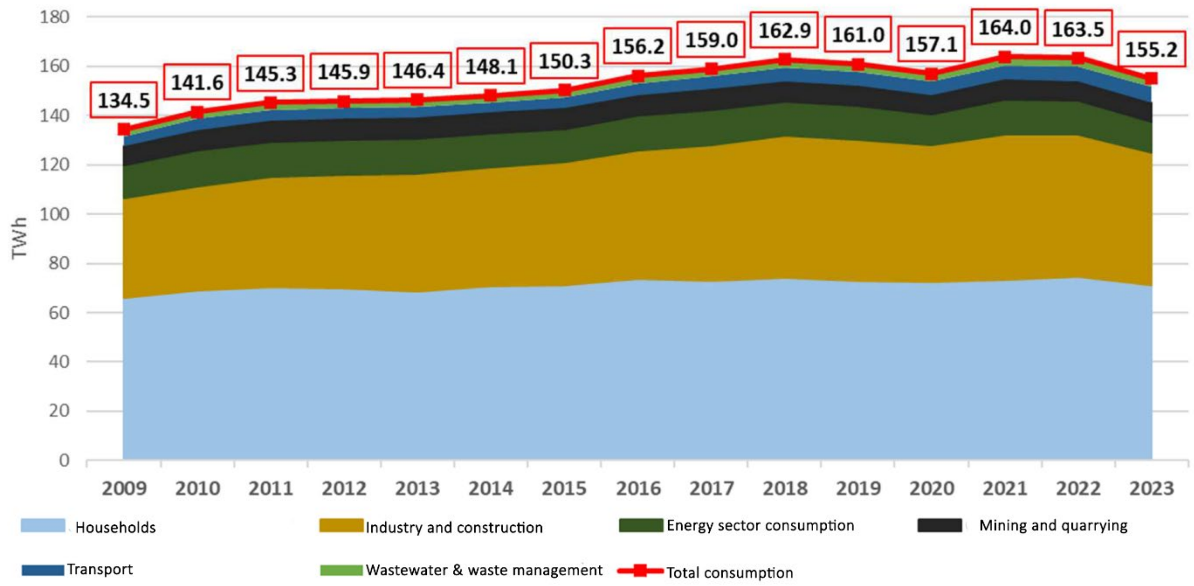

Figure 2 Electricity consumption in Poland in 2009-2023

Source: own study based on: FUEL AND ENERGY CONSUMPTION (Central Statistical Office)

The progressive increase in electricity consumption is offset by measures in the field of

[1] together with commercial heating boilers

[2] ***does not include direct consumption for heating and lighting in entities classified in section D (PKD2007)***

energy efficiency, hence the decline in consumption in 2023 and the slowdown in growth observed since 2009.

Looking at the structure of energy consumption, the small consumer sector occupies a dominant position (45.8% in 2023). Industry and construction also consume large amounts of energy (34.9% in 2023). Approximately 7.9% of total consumption is accounted for by power plants and combined heat and power plants. The mining and quarrying sector consumes slightly more than 5% of energy. The least energy is consumed by the transport and water supply sector and waste management: 4.1% and 2% respectively.

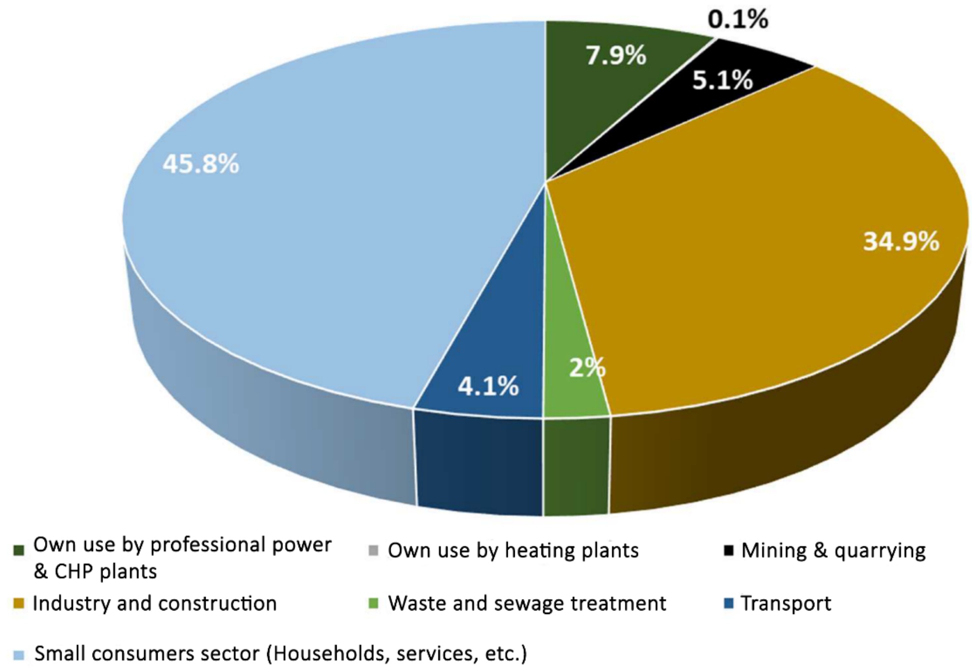

Figure 3 Structure of electricity consumption in Poland in 2023

Source: own study based on: Fuel and energy carrier consumption in 2023 (Central Statistical Office)

The decline in electricity consumption in 2019–2021 also translated into lower electricity production from domestic generation sources. Over the last dozen or so years, electricity production in Poland has shown a slight upward trend despite global events. Depending on the length of the analysed time period, it takes the following average annual values:

- 2022–2024 (last 3 years) – average increase of 2.8%
- 2019–2023 (5 years) – average increase of 0.1%
- 2014–2023 (10 years) – average growth of 0.2%

Domestic electricity production in 2024 amounted to 166.99 TWh and was over 2% higher than in 2023, while consumption increased by 0.9%. Thus, the interconnection balance amounted to approximately 2 TWh of imports. The chart below shows the changes in electricity demand and production in Poland since 2012, according to data from the transmission system operator PSE. The electricity consumption presented by PSE is higher than the consumption reported by the Central Statistical Office (GUS), which may be due, among other things, to the fact that some electricity consumers do not report their consumption to GUS.

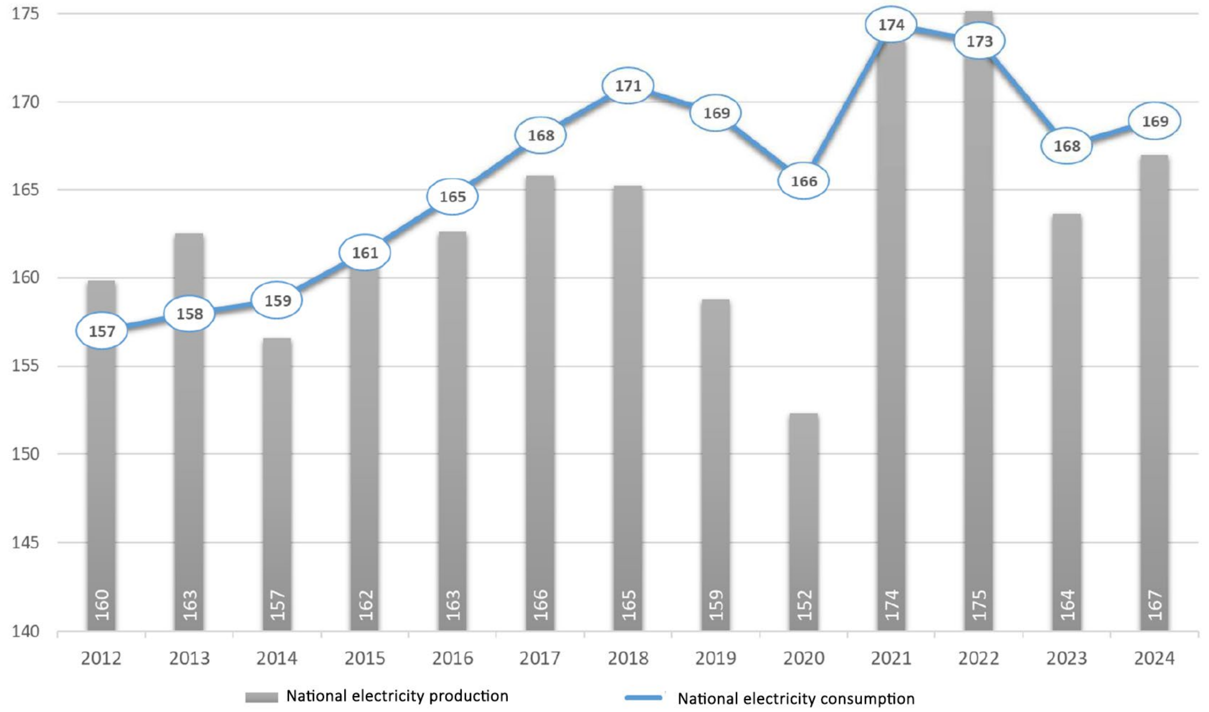

Figure 4 Electricity production and consumption in Poland since 2012

Source: own study based on PSE data

The table below presents the dynamics of changes in three time intervals, which shows that energy production in the long term has been growing with considerable fluctuation in recent years. Historical energy consumption grew until the pandemic, and after a large increase and decrease in recent years, it is now showing an upward trend again.

Table 2 Average rate of change for energy production and consumption in selected periods for the period 2012–2024

PSE data	Last 3 years	Last 5 years	10 years
Energy production	-1.2	+1.3%	+0.8%
Energy consumption	-1.0	+/-0%	+0.7%

Hard coal and lignite combustion sources account for the largest share of electricity production in Poland. However, year on year, there has been a noticeable decline in the share of these sources due to increased production from renewable energy sources. In addition, new natural gas-fired units, replacing coal-fired sources, have also increased their share in electricity production in recent years. Hydroelectric power plants have a stable share of electricity generation, similar to industrial combined heat and power plants.

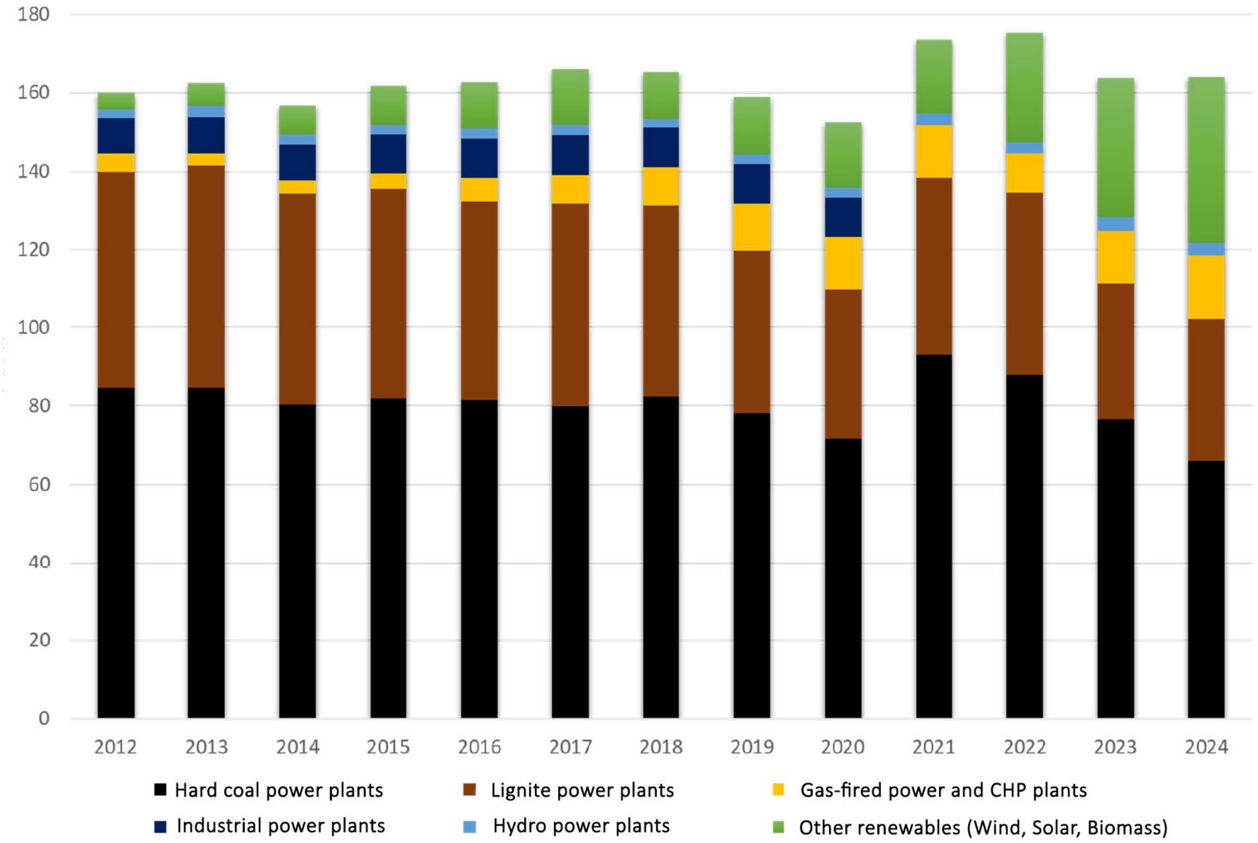

Figure 5 Structure of electricity production in Poland since 2012

Source: own study based on PSE data

2.1.2. Structure of installed capacity in the National Power System

Currently, the Polish energy mix is based predominantly on coal, both hard coal and lignite. Coal fuel is burned primarily in system condensing units, as well as in industrial and municipal combined heat and power plants (cogeneration sources). Changes in installed capacity in recent years are mainly related to the growth of Renewable Energy Sources. The chart below shows changes in installed capacity in the National Power System in recent years.

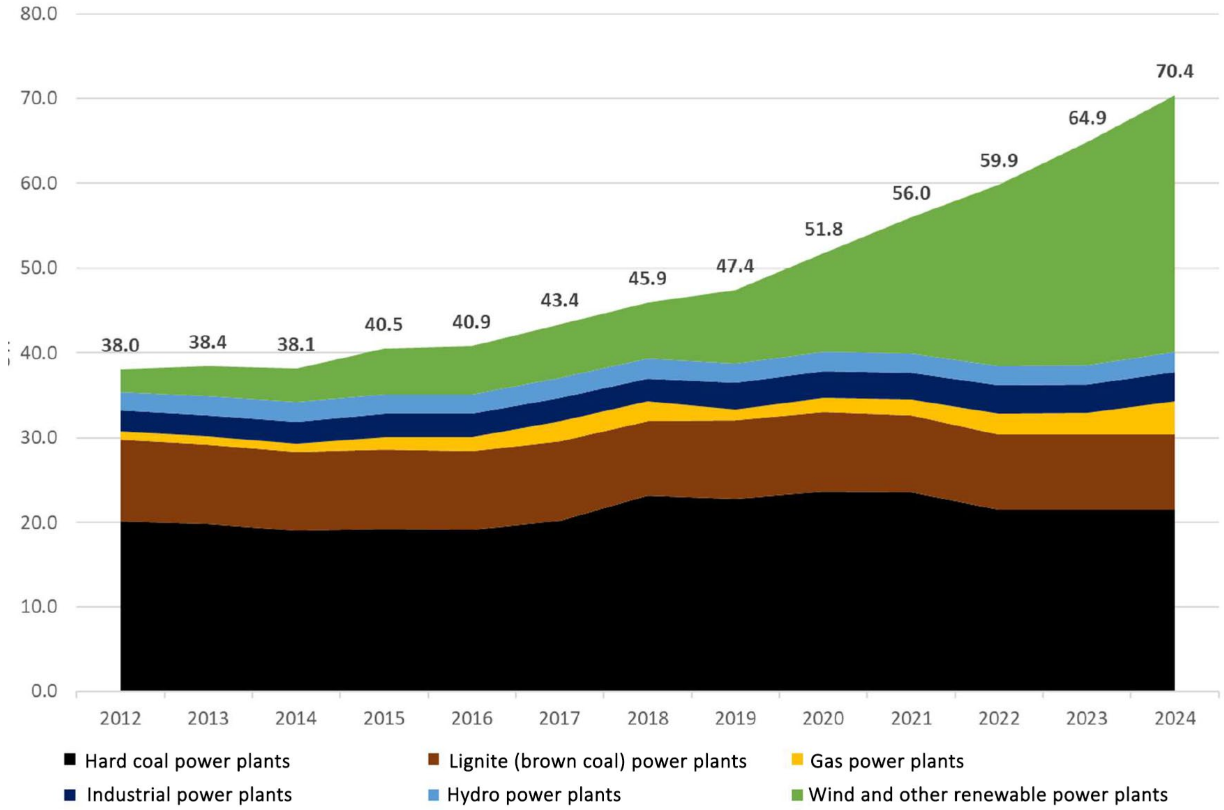

Figure 6 Installed capacity in the National Power System in recent years

Source: Own study based on data from PSE and ARE (since 2019)

In the case of new conventional generation sources, new gas-and-steam units have been connected to the system in recent years: in Włocławek – 485 MW (2017), Płock – 630 MW (2018), Stalowa Wola – 467 MW (2019) and EC Żerań – 497 MW (2021). In addition, in 2024, units in Dolna Odra with a total capacity of 1,400 MW were put into operation.

The most recent non-gas conventional investments include two units in Opole with a total capacity of 1,800 MW, commissioned in 2019, and a 900 MW unit in Jaworzno, commissioned a few years later.

Despite the appearance of the above-mentioned new units in the system, due to the age of the remaining units operating in the National Power System, the Polish power industry is not among the youngest. The majority of them are between 40 and 50 years old, and several units are already over 50 years old. The average age of generating units in Poland is over 37 years.

In terms of renewable energy sources in Poland, electricity is obtained from wind, water resources, solid biomass, biogas and liquid biofuels, as well as solar radiation. Geothermal resources are mainly used in heating installations (the heating sector).

In recent years, there has been rapid development in solar energy sources, particularly in the prosumer sector – domestic photovoltaic installations.

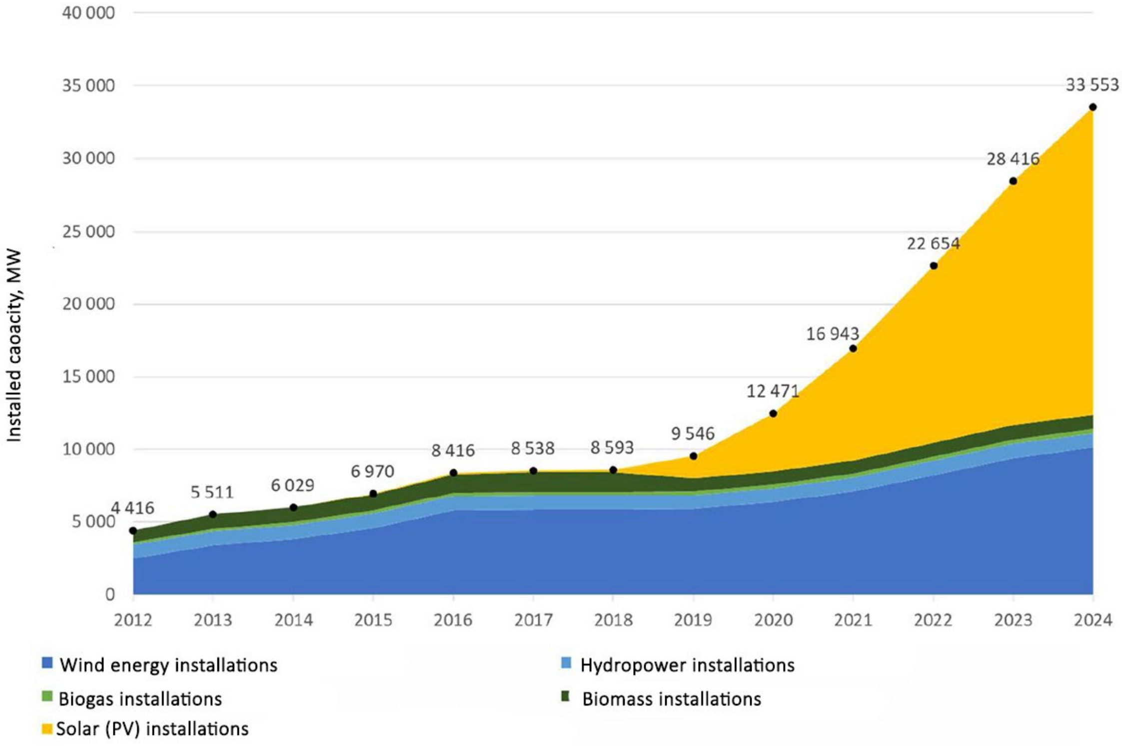

Figure 7 Installed electrical capacity in Renewable Energy Sources

Source: Own study based on data from the Energy Regulatory Office (URE) and the Energy Market Authority (ARE) (since 2019)

The installed electrical capacity of renewable energy sources in Poland at the end of 2024 exceeded 32.5 GW (according to ARE). Solar sources accounted for the largest share of installed capacity – over 19 GW. Wind installations are the next largest, with over 10 GW.

2.2. Forecast for the development of the electricity market in nd Poland

The following market development forecast has been prepared on the basis of the Development Plan for Meeting Current and Future Electricity Demand[3] by PSE and other publicly available reports on the functioning of the electricity market, as well as EPK's knowledge gained from many years of activity on the electricity market.

The forecasts presented are intended to indicate the conditions under which the project in question can be implemented and how the energy transition process in Poland may proceed.

2.2.1. Forecast of installed capacity

Over the years, Poland's energy mix will change along with the ongoing decarbonisation of the energy generation sector, accompanied by significant development of renewable energy sources. Most coal-fired power units in Poland are ageing, and their modernisation does not make economic sense given the declining use of coal in the energy mix. In addition, coal-fired power units have the highest unit carbon dioxide emissions (kgCO2/kWh), which means that they cannot be financed by, for example, the capacity market (at present, coal-fired power units could participate in capacity market auctions

3 Development plan for meeting current and future electricity demand for the years 2025–2034; PSE; December 2024.

https://www.pse.pl/-/projekt-nowego-planu-rozwoju-sieci-przesylowej-na-lata-2025-2034-uzgodniony

only until 2025), the financial market (investment loans) and, at the same time, have high CO_2 emission costs. Broadly defined taxonomy also excludes investments in this type of energy source.

The schedule of coal-fired unit decommissioning based on the PSE report[4] (broken down into hard coal and lignite) is presented below – these capacities will need to be replaced in the future in order to maintain an adequate level of available capacity in the system. The probable date of decommissioning of the 900 MW coal-fired unit in Opole considered for use in this study is 2050, which is the year when CO_2 neutrality in electricity generation in Europe is to be achieved.

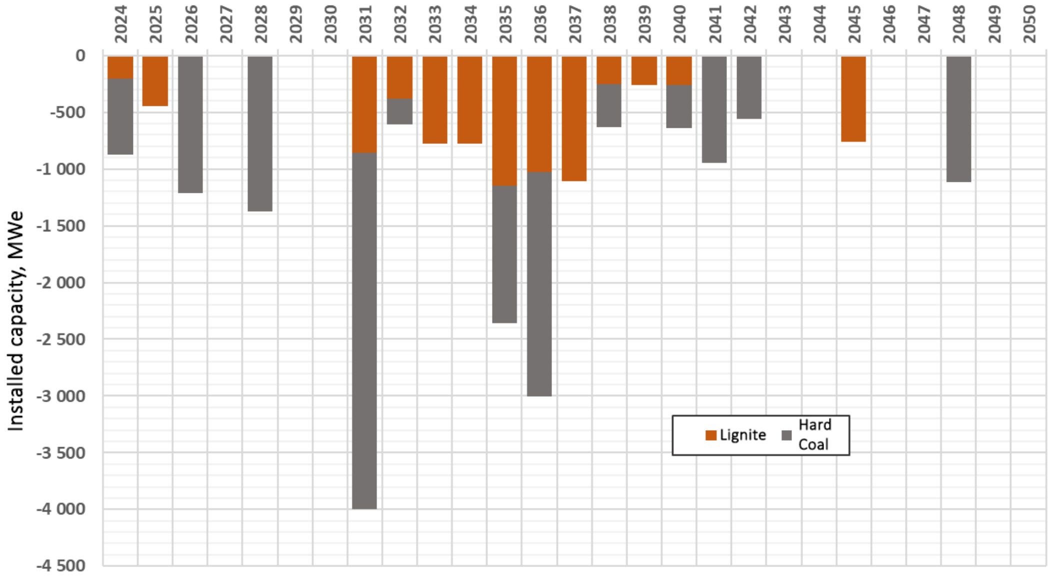

Figure 8 Schedule of shutdowns of coal-fired units participating in the central balancing mechanism.

Source: Own study based on PSE data

In terms of new capacity, it is assumed, among other things, that new combined cycle gas units will be built, which have been submitted for **auctions** on **the Capacity Market (RM)**; the last auction took place in December 2024 for the 2029 delivery year. The table below lists the new gas-steam units that won the RM auctions, some of which are currently at an advanced stage of construction.

4 Development plan for meeting current and future electricity demand for the years 2025–2034; PSE; December 2024.

https://www.pse.pl/-/projekt-nowego-planu-rozwoju-sieci-przesylowej-na-lata-2025-2034-uzgodniony

Table 3 Combined cycle gas turbines in Capacity Market auctions

No.	Name of power supplier	Location	Year of Supply	Capacity obligation [MW]	Duration of capacity obligation [years]
1	PGE Polska Grupa Energetyczna S.A.	Dolna Odra	2024	667.6	17
2	PGE Polska Grupa Energetyczna S.A.	Dolna Odra	2024	667.6	17
3	CCGT Grudziądz sp. z o.o.	Grudziądz	2026	518.4	17
4	PAK CCGT Ltd.	Adamów	2026	493.0	17
5	CCGT Ostrołęka sp. z o.o.	Ostrołęka	2026	696.0	17
6	PGE Polska Grupa Energetyczna S.A.	Rybnik	2027	794.6	17

Another source that could replace coal in the energy mix is nuclear power plants. The current strategy for the development of nuclear energy in Poland is described in **the Polish Nuclear Power Programme** published in October 2020. It envisages the construction of six nuclear units every two years, starting in 2033. In total, two nuclear power plants will be built in two locations, each with three units. Currently, it is assumed that the first power plant will be built in Lubiatowo-Kopalino on the Baltic Sea and will use Westinghouse AP-1000 reactors. The location of the second power plant is not yet known, but various locations are being considered, including Konin, Bełchatów, Połaniec and Kozienice.

The Development Plan for Meeting Current and Future Electricity Demand for 2025-2034, prepared by PSE, also provides for smaller nuclear units using SMR (small modular reactor) technology. According to the PSE report, information obtained from professional electricity producers through a survey was taken into account when determining the future generation structure. Plans for the development of offshore wind farms and nuclear energy, as specified in strategic documents, were also taken into account. Information on the results of RES auctions, as well as major national support programmes dedicated to prosumer sources and the results of concluded capacity auctions, was taken into account.

PSE has prepared a projected electricity generation structure in two scenarios, the SST (Free Transformation Scenario) and SDT (Dynamic Transformation Scenario), which differ mainly in terms of the installed capacity of renewable energy sources and energy storage facilities. The table below presents the results of PSE's analyses.

Table 4 Structure of electricity generation resources in 2034

Type of power resource	SST scenario Net capacity [MW]	SDT scenario Net capacity [MW]
Lignite	4,401	
Hard coal	6,317	
Hard coal - peak sources	2,277	
Natural gas	10,772	
Biomass and biogas	2,830	
Large nuclear power plants	1,146	2,292
SMR	560	840
Hydroelectric power	1,250	
Pumped storage power plants	2,462	
Photovoltaics	36,000	45,000
Onshore wind farms	16,940	19,362
Offshore wind farms	10,900	11,885
Energy storage facilities	3,750	15,207
Combined heat and power plants	5,217	

Source: Transmission network development plan for 2025–2034, PSE

2.2.2. Forecast of electricity demand PSE

The long-term forecast of energy demand in the National Power System presented in this section was prepared by PSE[5] taking into account:

- historical trends and the forecast for final energy consumption.
- macro factors affecting the structure of energy consumption in the household, transport, industry and services sectors,
- changes in the area of energy efficiency,
- forecasts of Gross Domestic Product growth in individual sectors,
- technological and consumer changes, as well as changes resulting from EU directives regarding Poland's achievement of the required RES target in final energy consumption,
- anticipated structural changes in final energy consumption, i.e. an increase in the number of electric vehicles, heat pumps and fuel cells, among other things.

The prepared forecast assumes two scenarios that address the adopted path of development of the KSE environment. The first is a scenario of gradual transformation, and the second is one of dynamic transformation, which assumes a significant increase in energy demand. These scenarios are illustrated in the charts below. Both scenarios assume an increase in electricity demand in the future.

5 Development plan for meeting current and future electricity demand for 2025-2034; PSE; December 2024.
https://www.pse.pl/-/projekt-nowego-planu-rozwoju-sieci-przesylowej-na-lata-2025-2034-uzgodniony

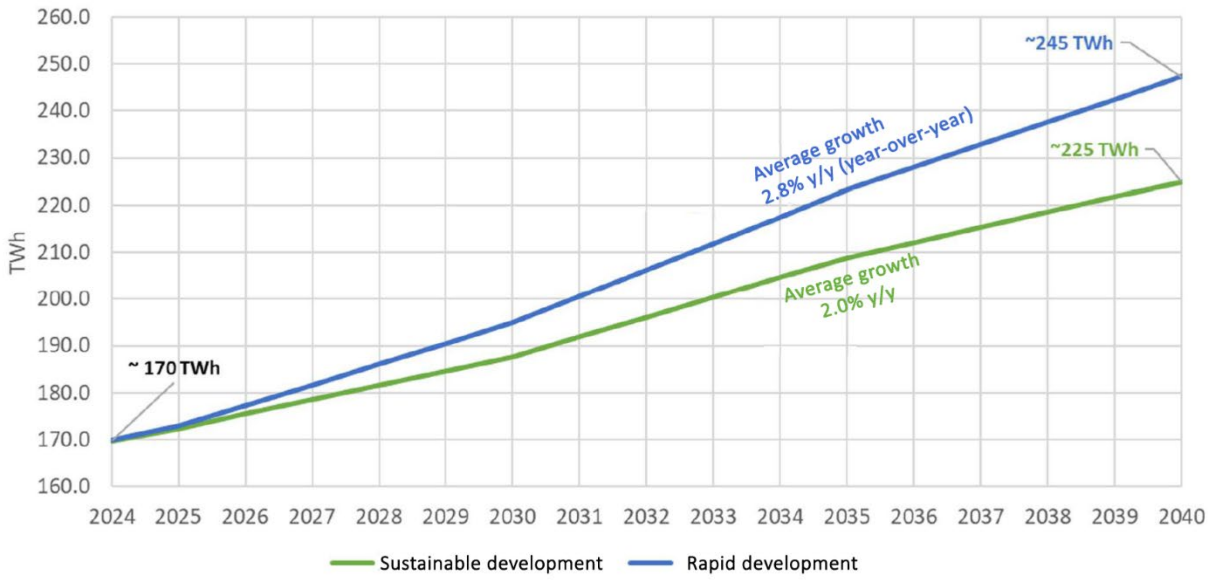

Figure 9 Forecast annual electricity demand in 2024–2040

Source: Own study based on PSE data

2.2.3. Analysis of the adequacy of generation sources

Based on the presented mix of installed capacity and projected electricity demand, the PSE Report presents the results of analyses of the sufficiency of generation sources and the security of the power system. Two power system reliability indicators, LOLE and EENS, were used for the assessment.

The first indicator, LOLE (The Loss Of Load Expectation), indicates the average number of hours per year during which the power system is likely to be unable to meet electricity demand due to a shortage of (available) power in the system. This indicator helps the transmission system operator (PSE) assess whether the national power system is sufficiently reliable. The safety standard assumes LOLE values of no more than 3 hours per year (average for the climate years 1982-2019).

At the international level, LOLE is a standard used in reports prepared by organisations such as ENTSO-E (European Network of Transmission System Operators) as part of regional and pan-European analyses, such as the Mid-term Adequacy Forecast (MAF). It enables the comparison of the reliability of power systems in different countries and the identification of potential threats in the context of energy balance. LOLE is also a key element in analyses related to the implementation of new RES sources, such as offshore wind farms, where the variability of energy production requires precise estimates of demand and capacity availability.

The second indicator, EENS (Expected Energy Not Served), indicates the amount of electricity (in GWh) that will not be delivered to consumers as a result of power shortages in the power system. This is the estimated amount of energy whose supply may be interrupted during the year due to insufficient availability of generation sources or transmission constraints.

The average LOLE and EENS values determined in the PSE Report[6] are presented below.

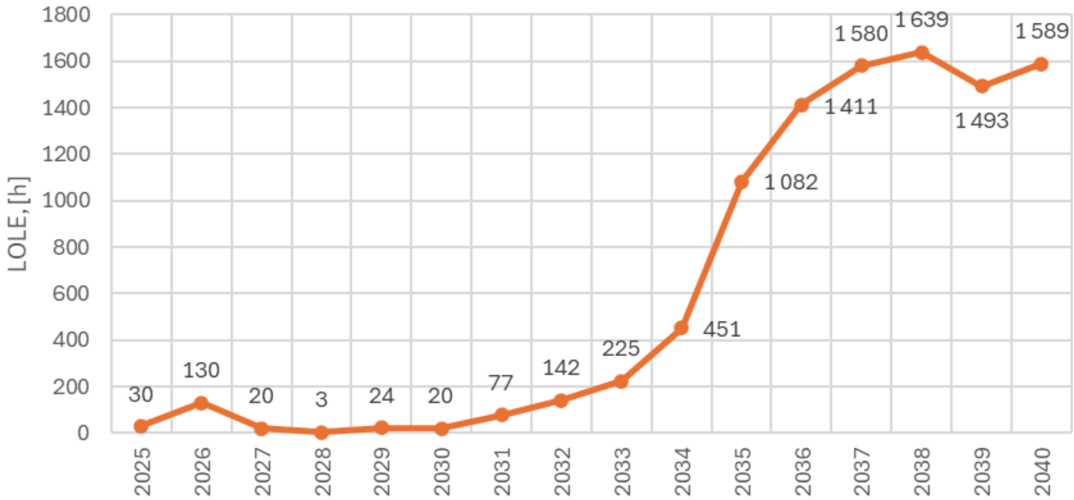

Figure 10 Average LOLE values [h/year] in 2025–2040

Source: Own study based on the PSE Report

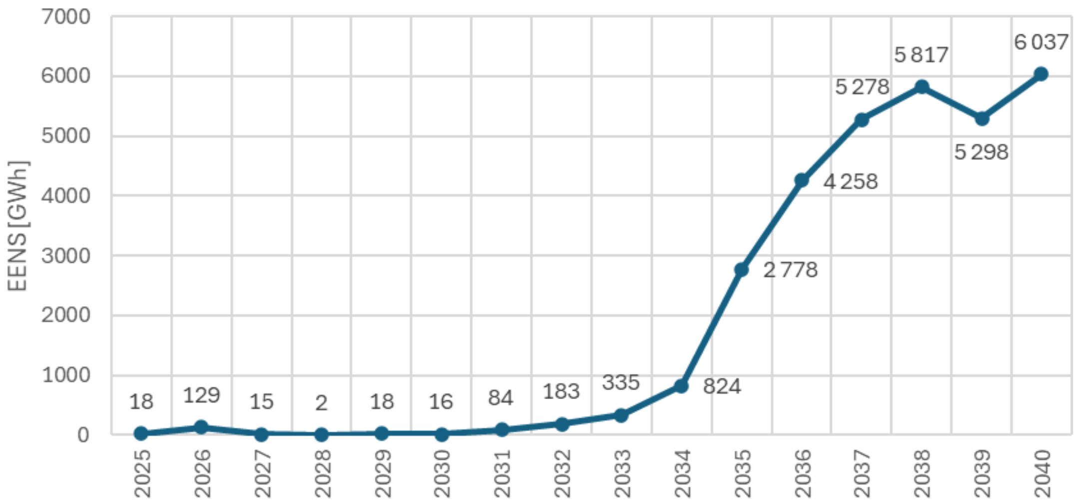

Figure 11 Average values of the EENS indicator [GWh/year] in 2025–2040

Source: Own study based on the PSE Report

Both indicators show a noticeable increase as early as 2026, followed by a decline and another increase after 2030. Between 2035 and 2040, the indicators are already several dozen times higher than the initial values. Over the period under review, only in one year does the LOLE indicator not exceed the assumed 3 hours per year.

2.2.4. Additional available capacity required

The PSE Report presents a solution aimed at keeping the presented indicators as low as possible (including LOLE<3h). The amount of additional available capacity that would need to be added in a given year to ensure the security of the energy system has been estimated.

6 *Development plan for meeting current and future electricity demand for the years 2025-2034; PSE; December 2024.*

https://www.pse.pl/-/projekt-nowego-planu-rozwoju-sieci-przesylowej-na-lata-2025-2034-uzgodniony

Table 5 Required additional net available capacity in the National Power System [MW]

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
1,400	3,400	1,600	200	1,600	1,600	3,200	4,200	5,200	6,800	9,600	11,200	12,200	12,800	12,800	13,600

Source: Own study based on the PSE Report

As early as 2026, an additional 3.4 GWe of net available capacity will be required, and after 2030 this figure will continue to rise. By 2040, it will be four times higher (13.6 GW). As the authors of the Report mention, it should be borne in mind that the assumed additional capacity may be higher depending on:

- the pace of energy transition in the country – faster growth in electricity demand,
- climatic conditions in future years – harsher winters, less sunny summers,
- changes to the dates for decommissioning conventional units – earlier than assumed in the report,
- changes to the dates for commissioning new capacity – later than assumed in the report.

In addition, the authors of the report presented potential sources of additional available capacity, which may include:

- new gas-fired power plants (in addition to those contracted on the capacity market),
- extension of the operation of existing coal-fired units (including extension of the capacity market for them after 2025),
- new energy storage facilities (using various technologies) with accompanying new RES sources,
- new biomass and biogas power plants,
- new hydrogen and alternative fuel technologies,
- additional energy import opportunities and growth in demand response (DR) services.

Most of the solutions presented, apart from conventional units, are unlikely to ensure stable coverage of demand, especially in terms of high volume and continuity of supply.

2.3. Selection of optimal system structures

Based on the presented PSE forecast of demand growth and the energy mix, a team of scientists from the Silesian University of Technology in Gliwice performed a model optimisation of the power system structure in Poland.

First, for both PSE electricity demand growth scenarios, an estimate of hourly demand changes for 2035 and 2040 was made. The figure below shows a comparison of the curves for different years, broken down into both scenarios.

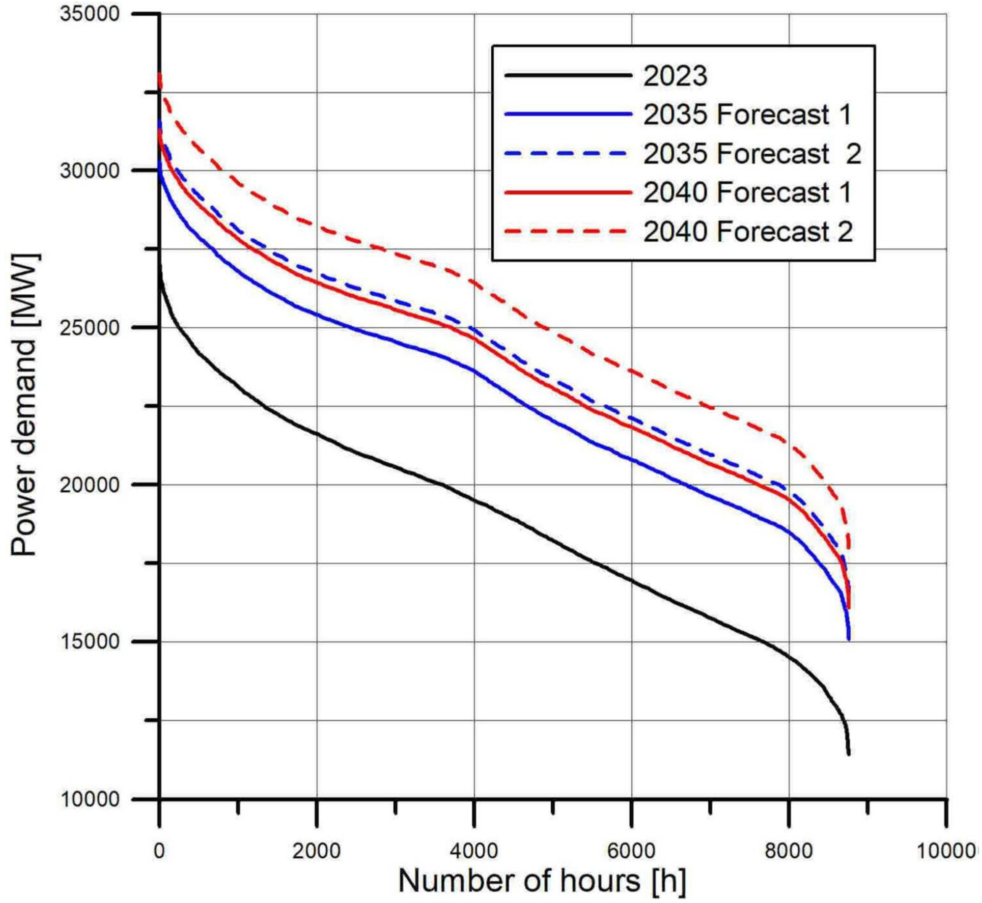

Figure 12 Power demand in 2023 and power demand forecasts for 2035 and 2040

Source: Presentation Nuclear investments and national energy security; A. Rusin, A. Wojaczek, PŚ

In the second step, the projected energy mix was determined in two cases, with greater and lesser development of nuclear energy (understood as large-scale units and SMRs). It was also assumed that the RES capacity projected for 2034 from the dynamic transformation scenario would be achieved in 2040. Furthermore, no coal-fired units were assumed in the mix after 2040, and it was assumed that no new gas-fired units would be added. The energy mix does not take into account energy storage facilities at this stage, as the required power and capacity of energy storage facilities was the result of this optimisation.

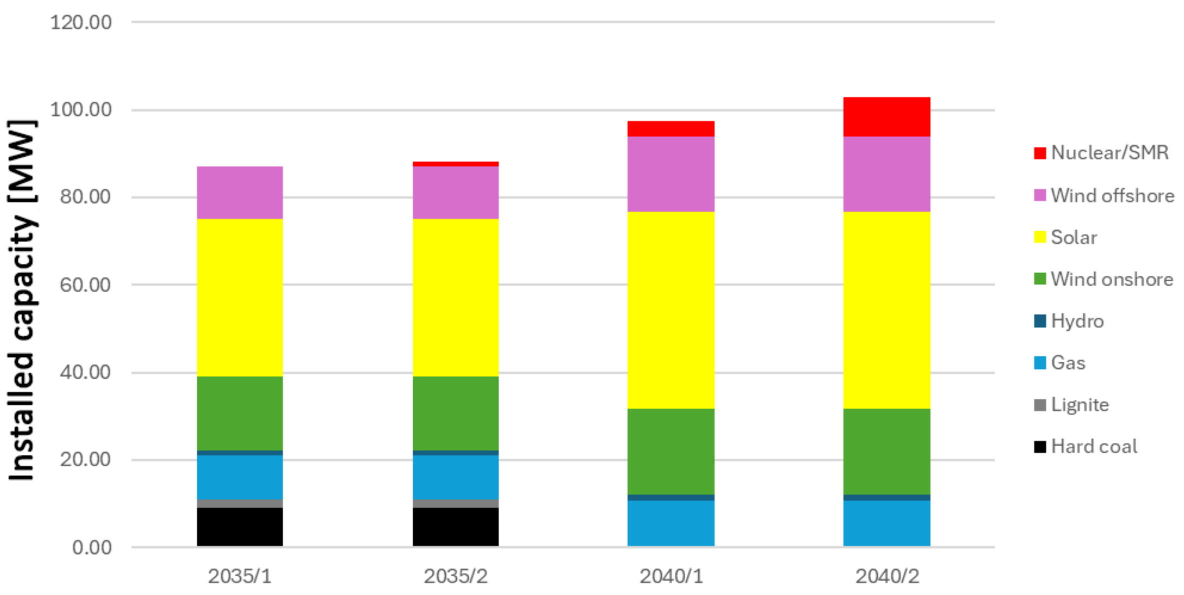

Figure 13 Forecast of generation source structures in 2035 and 2040

Source: Own study based on the presentation: Nuclear investments and national energy security; A. Rusin, A. Wojaczek, PŚ

For the preliminary structure of power sources in the system and the characteristics of power demand in a given year, the optimal capacity and power of energy storage facilities were selected so that the energy system supported by these storage facilities would ensure the required reliability of energy supply. This required level of reliability was adopted as the limit value of the LOLE indicator, amounting to 3 hours/year.

Table 6 Results of the optimisation of energy storage parameters cooperating with energy systems with the adopted structures

Year/system	Demand forecast	LOLE initial [h]	Storage capacity [MWh]	Warehouse capacity [MW]	Number of hours of empty storage [h]	Number of hours of full storage [h]	Final LOLE [h]
2035/1	Forecast 1	30.5	7,300	1400	65	7791	3.00
2035/2	Forecast 2	156.1	16,400	2900	104	7,199	2.99
2035/2	Forecast 1	42.4	8700	1600	72	7696	2.99
2040/1	Forecast 2	811.6	220,000	5600	5	4822	3.22
2040/2	Forecast 1	3.7	Unnecessary storage				
2040/2	Forecast 2	90.5	11,100	2000	72	7607	3.03

Source: Own study based on the presentation: Nuclear investments and national energy security; A. Rusin, A. Wojaczek, PŚ

In conclusion, maintaining the reliability of the National Power System at an appropriate level requires the presence of a sufficient number of stable energy sources in the system to meet demand, which in the current situation cannot be fully replaced by wind and solar sources. Nuclear power plants supplemented by gas-fired units could fulfil this role. Energy storage facilities with adequate capacity and power must play an important role in stabilising a system with a high share of renewable energy sources.

Until the aforementioned new energy sources and a sufficient number of energy storage facilities are built and commissioned, only existing coal-fired units and new gas-fired units can ensure the reliable operation of the energy system.

2.4. Summary of the energy market analysis

- When analysing the current situation on the market for electricity, it should be assumed that demand for electricity will grow over the next few decades. Consequently, electricity production should also grow or remain at a level that allows the system to be balanced in conjunction with, for example, energy imports or demand reduction.
- The presented schedule for decommissioning coal-fired units indicates that after 2040, only 1000 MW units will remain in the system, and all others will be taken out of service. The planned new gas units are unlikely to replace coal-fired sources on a 1:1 basis, and even if gas is a transitional fuel in Europe on the way to zero-emission electricity production, which will also be enforced by the EU (e.g. through investment financing mechanisms – exclusion of fossil fuels, taxonomy, carbon footprint, sustainability reporting requirements, in particular the CSRD directive, etc.).
- In turn, the projected significant growth of renewable energy sources (over 30 GW in PV by 2034 according to PSE forecasts) and their "priority" in electricity sales may hinder the operation of large conventional units by limiting their use on the market. Even despite the assumed development of electricity storage in the system, controllable units may be required to ensure energy security on the generation side. The use of modular generation reactors can increase the flexibility of the systems, making them more attractive to transmission system operators.
- According to the SE optimisation carried out by the Silesian University of Technology, without stable generation sources (such as nuclear power), the power system in Poland will need very high-capacity storage facilities (even over 220 GWh) with a large number of cycles (which affects the service life of the storage facilities).
- In turn, according to PSE analyses, without additional available capacity, it may not be possible to ensure an adequate level of security for the power system, or other mechanisms (DSR, emergency energy imports) may be activated, which could lead to an increase in electricity costs or, in a critical situation, to a blackout.
- Therefore, once Generation IV reactor technology is commercialised, which is expected to happen around 2040, Generation IV reactors could be used to extend the operation of, for example, 1000 MW units necessary for the proper functioning of the power system. This would result in a change in the fuel used for steam production, which currently, due to, among other things, the provisions of the Taxonomy, would limit the further operation of coal-fired power plants.

3. Detailed diagnosis of the technical condition of the existing infrastructure of the facility in terms of its potential use for the nuclear power plant, including the infrastructure necessary for the operation of the power plant, i.e. transmission networks, road and rail infrastructure, external and internal water sources

3.1. Existing power generation units

The Opole Power Plant is a condensing thermal power plant located in the northern part of the city of Opole, below the mouth of the Mała Panew River to the Odra River.

Currently, the Opole power plant operates six power units with a total achievable capacity of approximately 3,340 MW generated by:

- 4 units - with an achievable capacity of units 1 - 4 of 386, 383, 383 and 380 MW, respectively, commissioned in 1993 - 1997;
- 2 units - with an achievable capacity of 2 x 905 MW, commissioned in 2019.

The Opole Power Plant has a block system in which each of the power units is fired with hard coal and has a closed cooling water system.

3.2. Mechanical and technological section

3.2.1. Description of existing power units 1 - 4 and their auxiliary installations

The existing basic technological line of the Opole Power Plant consists of four power units with installations ensuring their operation. Power units 1 - 4 consist of the following main equipment:

- BP-1150 subcritical steam, pulverised coal and tower boilers
  - Maximum Continuous Rating (MCR) 1150Mg/h
  - thermal capacity 3143 GJ/h (873MW)
  - boiler efficiency for MCR 91.7%
- Condensing turbines: 18K376 (block no. 1), 18K373 (blocks no. 2 and 3) and 18K370 (block no. 4)
- GHTW360 hydrogen-cooled generators
- Cooling towers: one cooling tower for two power units
- Electrostatic precipitators: two-section, three-zone with 99.5% dust removal efficiency
- DeNOx installation: Non-catalytic nitrogen oxide reduction system (SNCR) using an aqueous urea solution as a reagent (concentration 15 - 20%)
- IOS: wet flue gas desulphurisation installation with 92% efficiency

3.2.1.1. BP-1150 boiler

The BP-1150 boiler is a flow boiler designed to work in a block system with a slip pressure turbine. The BP-1150 boiler is a single-pass boiler with a height of approximately 100 m, fired with hard coal. The boilers are equipped with mill units (6 mill units for boiler No. 2; 5 units each for boilers No. 1, 3 and 4) for grinding hard coal, drying it (with hot air) and feeding it as a dust-air mixture through dust burners into the boiler combustion chamber. Low-emission dust burners are used to reduce nitrogen oxide emissions. The boiler combustion chambers have been configured as tangential furnaces (with jet burners positioned in the corners of the chamber).

The advantages of this solution, which affects the proper course of the combustion process, include: flame self-stabilisation, tolerance to fuel changes, optimal mixing of the dust-air mixture and secondary air. The chambers are also equipped with systems enabling gradual feeding of combustion air. In the boiler section of each block, there is one coal hopper for each mill.

Each boiler is equipped with 12 oil burners with ignition burners. Combustion air is supplied by one primary air fan and two secondary air fans. Primary and secondary air is heated in rotary air heaters. Exhaust gases are discharged into the chimney after being cleaned in dust removal, desulphurisation and denitrification systems.

3.2.1.2. Dust removal system

Exhaust gases from all boilers are dedusted in dry electrostatic precipitators with horizontal exhaust gas flow. These are two-section, four-zone electrostatic precipitators with a uniform exhaust gas flow system with high inter-electrode voltage (70kV) and high-frequency units.

3.2.1.3. Flue gas desulphurisation system

Flue gases from all boilers in power units 1 to 4 are treated for sulphur dioxide in the flue gas desulphurisation system (I0S) by binding it with calcium carbonate contained in limestone powder.

3.2.1.4. Flue gas denitrification system

All boilers in units 1 to 4 are equipped with flue gas denitrification systems. The flue gas denitrification systems in the boilers combine two methods of nitrogen oxide reduction: primary ROFA and secondary Rotamix.

3.2.1.5. Boiler coal feeding system

Coal is delivered to the power plant by rail in open wagons (so-called coal wagons) and unloaded on two WWb-130 wagon tippers, each with a nominal capacity of 1,500 Mg/h.

Coal unloaded into the tipper hopper is collected by WWh 2000 scrapers and transferred to belt conveyors connected to the main transfer station located in transfer building No. 10. Here, magnetic and non-metallic impurities in the transported coal are separated and the transport is directed:

a) to storage yards,

b) directly to the boiler feed hoppers of individual units, using a system of belt conveyors with a capacity of 1,500 Mg/h and a belt width of 1,400 mm.

The coal storage areas are divided into four depots:

- equalisation coal storage areas No. 1 and 2 – maximum storage height 19 m,
- reserve coal storage areas No. 1 and 2 – maximum storage height 30 m.

The total capacity of the coal yards is 800,000 Mg, including: reserve coal yard no. 1 with a capacity of 300,000 Mg, compensatory coal yard no. 1 with a capacity of 110,000 Mg, coal yard
Reserve No. 2 with a capacity of 285,000 Mg, compensatory coal storage No. 2 with a capacity of 105,000 Mg.

The storage facilities can hold approximately 30 days' worth of coal.

Two independent coal feeding galleries are in operation: for boilers in units 1 and 2, and units 3 and 4. Each coal feeding gallery has coal storage bins and two reversible mobile conveyors.

Biomass, which, in addition to coal, is burned in power plant boilers, is delivered to the Opole Power Plant Branch by road and unloaded in a specially designated area of the coal storage yard. Biomass from the coal yard is picked up by a wheel loader and fed into the biomass feeding line, equipped with devices that prevent biomass larger than 40 mm from being fed (oversized biomass is shredded by an external company). From the conveyor system, the biomass is fed onto one of three selected B1500 coal belt conveyors, which transport coal dust from the wagon tipper unloading area - this applies to boilers in blocks 1, 3 and 4.

In the event of a lack of coal supplies for unloading from the tipper, coal dust is collected from the coal yard using wheel-rail loaders and fed via a reversible belt conveyor onto a belt conveyor where biomass has already been fed.

From the belt conveyors, the biomass and coal dust are fed through chutes to the boiler hopper and then on to the mills.

The area around the coal yards is equipped with retaining walls, drainage channels and settling wells to drain rainwater from the sides of the coal piles into the combined sewer system. They also serve as separators (settling tanks) for solid particles carried by rainwater.

Boiler No. 2 is equipped with a system for direct feeding of biomass into the boiler. It is used to receive, unload, store and blow ground agricultural biomass into boiler No. 2 for simultaneous combustion with coal dust.

The biomass feeding system enables continuous combustion of a 100 MW stream of energy supplied in fuel, i.e. approximately 23 t/h of pellets with a calorific value of approximately 15.5 MJ/kg.

Biomass (so-called ‘Agro’) in the form of pellets is delivered to the power plant by road transport between 6:00 a.m. and 10:00 p.m., Monday to Friday. After being accepted and weighed on a weighbridge, the biomass is cleaned of ferromagnetic impurities and unloaded into two storage tanks, each with a capacity of 3,200 m^3.

From the storage tanks, biomass is fed into a series of devices where it is weighed, ground and pneumatically transported to biomass burners located in the walls of boiler No. 2.

3.2.1.6. Boiler ash removal system

The ash removal system includes installations and equipment from the flange of the electrostatic precipitator hopper to the flange of the expansion fitting located on the ceiling of the ash retention tank and in the ceiling of the storage tank, together with the associated technological installations.

The installation comprises: installations and equipment for pneumatic transport of ash from electrostatic precipitator hoppers to the equalising tank, installations and equipment of the block ash dispatch station from the electrostatic precipitator, ash pipelines between the electrostatic precipitator and the ash retention tank, ash pipelines between the electrostatic precipitator and the ash storage tank, installations and equipment for aerating the aeration troughs and the equalisation tank, installations and equipment for preparing compressed air for ash transport, installations for venting the ash removal system, installations for washing the floors under the electrostatic precipitator.

In the electrostatic precipitators of the power units, ash is separated from the flue gas. Ash from the electrodes is shaken off into 18 hoppers, which constitute three ash removal zones. From the electrostatic precipitator hoppers, the ash flows into aeration gutters, from where it is transported to an equalisation tank with bottom aeration. From the equalisation tank, the ash flows into horizontal tank pumps. From the tank pumps, the ash in the form of a dust-air mixture can be transported through pipelines located on the L trestle to the storage tanks of the Central Ash Loading Station (CALS), where there are 3 tanks with a capacity of 2000 m^3 each, or to the storage tank silos (*zbiornika magazynowego* - ZM), from where it can be transported via Turbuflow pipelines to any selected storage tank located in the CALS. Ash from the storage tanks is loaded onto tank wagons or tankers and sent to its destination. The ash storage and retention tanks are equipped with a dust extraction system (fabric filters).

3.2.1.7. Boiler deslagging system

The slag removal system is designed to continuously remove slag from BP1150 boilers. The slag produced during combustion falls into a scraper slag remover filled with water. After extinguishing and cooling, the slag is transported to an impact ring crusher, where it is crushed.

After crushing, the slag is rinsed with water in the deslagging channels through a set of rinse nozzles into the pulp tank in the dredging pumping station. One dredging pumping station collects slag from two boilers.

From the pumping station, the slag in the form of pulp is transported by dredging pumps through slag pipelines to the settling chamber of the slag settling tank. After the slag has precipitated in the settling chamber, the water flows into the pre-treated water chamber and then through the suction chamber and return water pumps, it is transported through return water pipelines to the flushing system in the gravity slag removal channel, thus completing the technological cycle.

After being drained of water in the settling chamber, the slag is transported by a gantry crane with a grab to a storage area or wagons and lorries, which transport it away from the power plant. The wagons are placed on the track behind the storage area wall. The lorries are loaded in the storage area.

The slag removal system consists of: a boiler slag removal system, a dredging pump station, a slag settling tank with a capacity of 23,000 m^3 (two settling chambers), a return water pumping station, and pipelines on trestles.

3.2.1.8. Auxiliary boiler room

An auxiliary boiler house producing heat used to heat domestic water, supply central heating, air conditioning and to obtain steam for technological needs and external heating networks.

The boilers of the auxiliary boiler room are a source of backup process steam for the Opole Power Plant.

The boilers of the auxiliary boiler house are started up in cases of increased heat demand, i.e. during unit start-ups and in winter when temperatures are lower.

The auxiliary boiler room is equipped with two oil-fired boilers to enable rapid production of process steam through quick start-up of the oil-fired boilers from the boiler control panel.

Two oil boilers with a total capacity of 50 Mg/h of steam are located in the north-western part of the auxiliary boiler room building at a level of +4.50 m, in a room designated for this purpose.

The auxiliary boiler room consists of:

- 2 LOOS ZFR-X 28000 oil-fired steam boilers with a thermal output of 17.862 MW (nominal steam output of 25 Mg/h per boiler) and a thermal efficiency of 94%, fired with light fuel oil. The boilers are located in the auxiliary boiler room at a level of +4.50 m, in a separate room designated for this purpose, with a water degassing station, 4 feed water pumps, 2 reduction and cooling stations, a sludge expansion tank, a desalination expansion tank, a drainage and condensate expansion tank, two chimneys 26 m high and 1.1 m in diameter, boiler feed water, two underground light fuel oil storage tanks with a capacity of 100 m³ each, located on the south-western façade of the building. The boiler room building houses a 102 MWt heating plant powered by steam from power units 1 to 4.

3.2.1.9. Diesel generator system

Diesel power plants, designed as an emergency power source for safety loads of turbo units of power units 1-4 and fire water pumping stations, consist of:

- the power system of Diesel Power Plant No. 1, with a generator installed in building 140, used to provide emergency power to selected loads of units 1 and 2 and the fire water pumping station,
- the power system of Diesel Power Plant No. 2, with a generator installed in building 141, used for emergency power supply to selected consumers in units 3 and 4 and the fire water pumping station.

Each power generator set is driven by a H. Cegielski-Sulzer diesel engine with direct fuel injection (diesel oil).

The thermal power of each engine is 2602 kWt with a thermal efficiency of 41.5%.

Diesel power stations are kept in constant readiness for start-up (once a week, control start-ups and tests are performed for a period of 30 minutes).

The diesel power plant, designed to supply power to the circuits of the Opole Power Plant Control Room, consists of a GEP-165 power generator set driven by a 0.35 MWt diesel engine (fuel: diesel oil).

3.2.1.10. Oil management systems

Oil management facilities are located in the south-eastern part of the power plant site. Fuel oil, transformer oil, turbine oil and contaminated oil tanks are placed in concrete basins, which allow the entire volume of oil to be retained in the event of any damage. Transformers are secured in the same way. The oil retained in the above-mentioned devices is collected in contaminated oil tanks and transferred to authorised external companies.

Heavy fuel oil (mazut) is used during start-ups and shutdowns of power units 1 to 4 to stabilise the combustion process in transient states and power shortages. The primary task of the mazut plant is to supply mazut to the boiler mazut installations in units 1 and 2 according to system I and in units 3 and 4 according to system II.

The separation of the fuel oil plant's technological system into two systems results from the different methods of oil atomisation in the combustion chamber.

And so:

- system I (boilers No. 1 and 2) – pressure atomisation (replacement of the installation with one similar to that in blocks 3 and 4, i.e. with steam atomisation, is planned),

- system II (boilers No. 3 and 4) – steam atomisation.

The fuel oil storage facility consists of the following systems:

- unloading ramp for receiving and unloading 32 tankers with mazut,
- unloading pumps for transferring fuel oil from the unloading ramp to any selected fuel oil storage tank,
- 2 storage tanks with a capacity of 2,000 m³ each, - feeding fuel oil to boilers,
- process steam at 1.8 MPa and 0.45 MPa.

Turbine oil - TU-32 turbine oil is used in circulating turbine lubrication systems and high-speed gearboxes. Corvus oil 32 is currently used in electric pump gearboxes.

Oil is delivered to the power plant by rail or road. Turbine oil is unloaded at the unloading station, from where it is fed into three storage tanks (each with a capacity of 50 m³) intended for clean oil for replacement and replenishment. For handling oil, i.e. oil from emergency drains or drains for repair purposes, a single 50 m^3 tank is provided. Used or partially used oil is stored in a separate 50 m^3 tank. All turbine oil storage tanks are steel, above-ground tanks, positioned horizontally, each separately in a concrete basin, and the entire tank farm is enclosed by an oil basin in the form of a slope. The tanks are thermally insulated and equipped with a steam heating system for heating the oil in winter, as well as a system of oil pipelines connecting the individual tanks to the turbine oil pumping station.

Transformer oil

Transformer oil is delivered to the power plant for the initial filling of transformers by railway tankers, while for stockpiling in three storage tanks (each with a capacity of 50 m³) it is delivered by road tankers. A single 50 m³ tank is used to store used oil. Transformer oil is intended exclusively for filling transformers, circuit breakers, transformers, i.e., electrical equipment. For the ongoing replenishment of oil in electrical equipment, oil is taken from two dispensing tanks located in the oil management building.

In order to improve the quality of the oils used and minimise waste production, they are treated using centrifuges that remove solids and water from contaminated oils. The capacity of the equipment ranges from 70 to 180 litres per minute.

3.2.1.11. Water management installations

The Mała Panew river intake is used to ensure water supply. The water collected is used for:

- closed cooling system for steam turbine condensers
- replenishing the steam-water system of the units
- flue gas desulphurisation installations
- the heating system of the auxiliary boiler house
- slag transport system
- firefighting and domestic water systems (emergency)

After preliminary treatment, the water is sent directly from the intake to the power plant via pipelines, where it undergoes further treatment at the Water Treatment Plant (WTP) serving units 1-6, which consists of two basic technological systems:

- pre-treatment water treatment plant (*stacja wstępnego uzdatniania wody* - WUW)
- water demineralisation station (*stacja demineralizacji wody* - SDW)

The new water treatment plant serves all six power plant units. A detailed description of the installation is provided in the section on units 5 and 6.

In addition to the operating "new WTP" water demineralisation station, a third water demineralisation line of the "old WTP", which was intended for the needs of units 1-4, may be periodically started up and operated to cover additional needs.

The water demineralisation process in the third demineralisation line is carried out in the following devices:

- strongly acidic cation exchanger;
- CO_2 desorber with air fan and aerated water pumps;
- weakly alkaline anion exchanger;
- strongly alkaline anion exchanger;
- dual ion exchanger;
- auxiliary equipment such as a regeneration exchanger, heat exchanger, ionite traps, acid tank, lye tank and pumps.

3.2.1.12. Storage tanks for fuels, oils and raw materials

- Fuel oil (mazut) storage tanks – 2x2000 m^3
- Turbine oil storage tanks – 5x50 m^3
- Transformer oil storage tanks – 4x50 m^3, 2x5 m^3
- Industrial oil storage tanks – 8x5 m^3, 4 (five-part)x1 m^3
- Oil waste tank – 1x2.5 m^3
- Concentrated HCl storage tanks (35%) – 1x48 m^3, 4x50 m^3, 1x25 m^3
- NaOH storage tank (diluted) – 1x5 m^3
- Concentrated NaOH (48%) storage tanks – 3x48 m^3
- Concentrated NaOH (50%) storage tank – 1x25 m^3
- Diluted HCl (10%) storage tank – 1x5 m^3

- Limestone powder storage tanks – 3x2300 m^3
- Ash retention tanks 1,2,3 – 3x2000 m^3
- Ash storage tanks No. 1, 2, 3 – 33x~16,800 m^3
- Hydrogen storage tanks – 4x60 m^3
- Ammonia water storage tank (24%) – 1x30 m^3
- Ammonia solution tanks (1%) – 4x1.2 m^3, 1x11 m^3
- Silenal solution tanks (3%) – 4x1.2 m^3
- Formic acid storage tank – 1x25 m^3
- TM T-15 storage tank – 1x3 m^3
- Diesel fuel distribution tanks for diesel engine room – 2x~4m m^3
- Urea solution storage tanks (40%) – 3x140 m^3
- Light fuel oil storage tanks – 2x100 m^3
- PPR tank (by-product or post-reaction waste with code 10 01 05) – 1x600 m^3

3.2.2. Description of existing power units No. 5 and 6 and their auxiliary installations

The existing technological line of the Opole Power Plant consists of two power units with installations ensuring their operation. Power units 5 and 6 consist of the following main equipment:

- BP-2455 pulverised fuel, tower and flow boilers with a thermal capacity of 1898 MWt and an efficiency of approximately 94.8%.
- Condensing turbines divided into 1xWP, 1xSP, 3xNP sections
- Hydrogen-cooled generators
- Cooling towers: one cooling tower per power unit
- Electrostatic precipitators: two-section, four-zone with 99.8% dust removal efficiency
- DeNOx installation: Selective catalytic reduction (SCR) system using ammonia water as a reagent (concentration 24%)
- IOS: wet flue gas desulphurisation installation (*instalacja odsiarczania spalin*) with 92% efficiency.

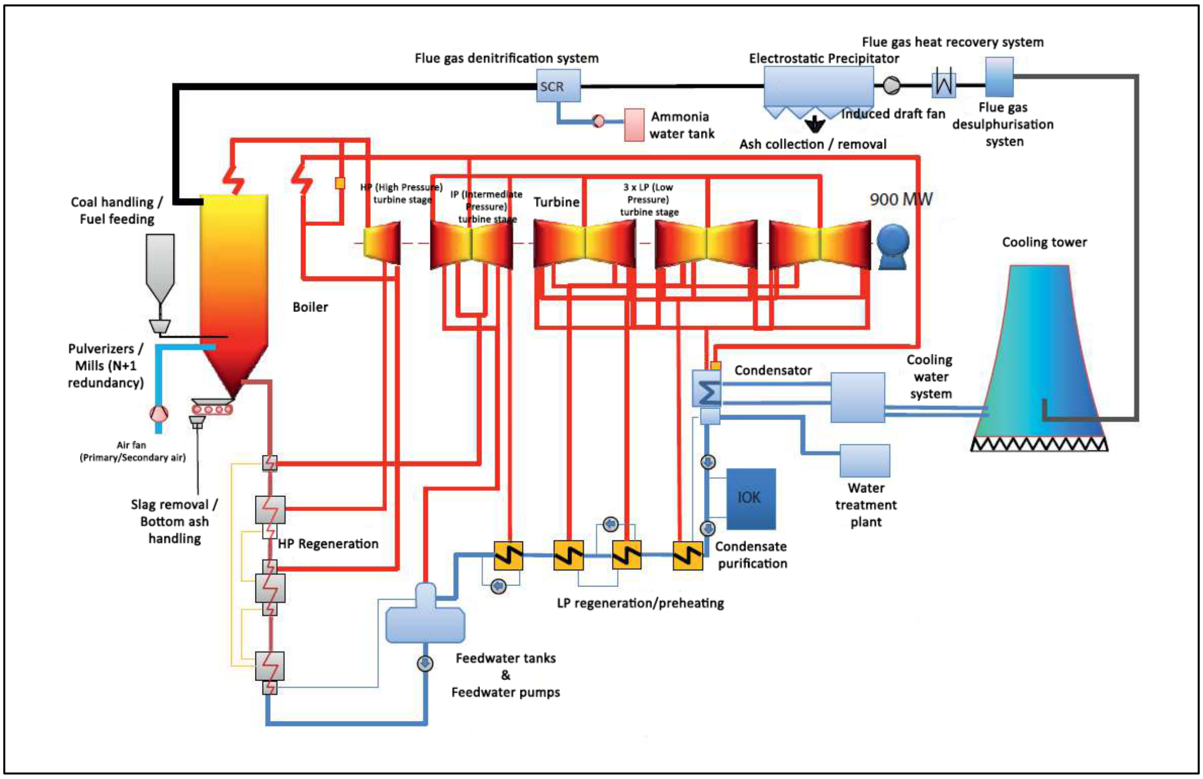

Figure 14 Layout of the 900 MW unit at the Opole Power Plant

The coal-fired boilers installed in units 5 and 6 are once-through, single-pass supercritical boilers with single secondary steam superheating, operating at slip pressure.

3.2.2.1. Steam-water circuit

Each boiler is equipped with a water heater (ECO), an evaporator (located in the lower walls of the combustion chamber), four stages of fresh steam superheating and two stages of secondary steam superheating. Two fresh steam cooling stages and one secondary steam cooling stage are used to regulate the steam temperature. In order to compensate for uneven flue gas temperatures throughout the furnace chamber, the primary and secondary steam superheaters are arranged in four parallel streams connected transversely.

The walls of the evaporator furnace chamber are formed by inclined pipes. The walls of the upper part of the furnace chamber consist of vertical pipes of the fresh steam superheater.

The start-up system, also used for water circulation during low boiler loads, is designed to ensure the required flow of medium through the evaporator. This system includes steam separators, an expansion tank, a circulation pump, drainage pipes to the expansion tank, and a condensate drainage system to the condenser or cooling water, depending on the quality of the condensate.

To ensure the cleanliness of heating surfaces due to fly ash settling during boiler operation, steam blowers and water cannons are used. Steam blowers are used to clean the heating surfaces of steam superheaters, SCR catalytic surfaces and the heating surfaces of the rotary air (pre)heater (RAH). Water cannons are used to clean the walls of the boiler combustion chamber.

3.2.2.2. Combustion system

The combustion chamber is equipped with four levels of coal burners arranged tangentially, forming a single rotating ball of fire during combustion. Burners are installed in each of the 4 corners of the combustion chamber on all levels. During normal operation of the unit, 3 of the 4 mills and the corresponding 3 of the 4 levels of coal burners are in operation. The boiler is equipped with a wet slag remover.

The combustion chamber is equipped with four levels of oil burners with steam atomisation (four burners on each level) operating during start-up and shutdown of the unit. The total thermal power of the oil burners corresponds to 35% of the boiler's thermal power at MCR-NC (maximum continuous rating - nominal conditions).

Each of the four coal mills supplies a dust-air mixture to the corresponding coal burners at the appropriate level in the combustion chamber. Roller mills with a dynamic separator are used.

Primary air, which is partially heated in a rotary air heater (RAH), is supplied to the boiler by two primary air fans (PAF). Primary air is used to dry and transport the dust-air mixture to the dust (coal) burners in the combustion chamber.

Secondary air is supplied to the combustion chamber by two combustion air fans (CAF). The air is distributed to the burners based on the total combustion parameters, including information about the level of operating burners.

In order to meet exhaust gas quality requirements, part of the secondary air is fed into the combustion chamber through afterburner air nozzles (AAN).

3.2.2.3. Exhaust gas-air system

The flue gas-air system consists of two flue gas ducts and two air ducts. Combustion air is supplied by two combustion air fans (CAF) and two primary air fans (PAF). Secondary air is heated in two steam air heaters, while primary and secondary air is heated in two rotary air heaters (RAH). The flue gases leaving the boiler are cooled in rotary air heaters (RAH) by the flow of combustion air, which is heated at the same time. The flue gases are cleaned of most solid particles in electrostatic precipitators, sucked in by two flue gas fans (GF), flow through flue gas desulphurisation systems (IOS) and are discharged into the atmosphere through a cooling tower.

In order to prevent the exhaust gases from cooling below the dew point at the outlet of the combustion air fans (CAF), steam air preheaters (SAP) have been installed to preheat the secondary air before it enters the rotary air preheaters (RAH). The steam air heater mainly uses the heat of steam condensation to heat the flowing secondary air.

Net electrical efficiency of units 5 and 6: 45.5%.

3.2.2.4. Installation of catalytic exhaust gas denitrification (SCR) in boilers

In order to reduce the amount of nitrogen oxides (NO, NO_2) produced as a result of fuel combustion, a dusty exhaust gas denitrification system is installed in the boiler exhaust duct. The system operates in accordance with selective catalytic reduction (SCR) in the exhaust gas duct. The system consists of ducts and components for exhaust gas purification. After the exhaust gas outlet, in the upper part of the boiler, the exhaust gases are fed to the DeNOx system. After passing through the ammonia injection system (obtained from ammonia water as a result of evaporation), the exhaust gases are directed to the reactor (through catalysts) and further to the air preheaters and electrostatic precipitators, and then to the flue gas desulphurisation system and the cooling tower.

The exhaust gas denitrification (SCR) system consists of the following subsystems:

- Ammonia preparation system upstream of the injection grid
- DeNOx system in the exhaust duct
- DeNOx reactor
- Monitoring devices (operational measurements).

3.2.2.5. Boiler exhaust gas dust removal system

After the denitrification process in the SCR system, the exhaust gases are subjected to dust removal. Two electrostatic precipitators are used for each boiler in a 2x50% system (60% when one exhaust gas stream is in operation), installed outside the boiler room building, between the rotary air heaters (RAH) and the exhaust gas fans (GF).

Each electrostatic precipitator consists of 4 zones and 10 sections. The first zone of each electrostatic precipitator consists of 4 sections (arranged in parallel), and the last three zones have 2 parallel sections each.

Dust is precipitated in an electrostatic precipitator by transferring and collecting dust under the influence of an electric field. The collected dust is then shaken off the electrodes. The electric field for transferring and collecting dust is created by a high-voltage source. The collected dust is directed to the boiler ash removal system and constitutes waste or a by-product.

3.2.2.6. Flue gas desulphurisation system (IOS)

After undergoing processes in the flue gas denitrification system and electrostatic precipitator, the flue gases are subjected to desulphurisation. Each unit is equipped with two flue gas fans (GF) and one dedicated absorber.

The exhaust ducts leading to the absorber boiler room located outside the building start with shut-off dampers installed at the outlet of each exhaust fan. The flue gases from the boiler are fed into the absorber at its lower part through an inlet pipe made of high-alloy steel resistant to corrosion, which may occur when dry flue gases and the wet atmosphere inside the absorber come into contact.

The exhaust gases flowing through the absorber are immediately cooled by the absorption slurry for SO_2 removal; sprayed by injection nozzles, it falls downwards, in the opposite direction to the exhaust gas flow. Limestone was used as a sorbent for the flue gas desulphurisation system, where the end product is gypsum. Due to the direct contact between the exhaust gases and the slurry, the exhaust gases leaving the absorber are cooled to saturation temperature. Therefore, the exhaust duct of each absorber is made of GRP (glass fibre reinforced plastic) material, which is resistant to wet exhaust gases with an acidic pH.

The limestone powder slurry is transported from the slurry tank to the absorber using a suitable pump. The limestone-gypsum slurry is circulated by circulation pumps, and its velocity is kept constant, while the amount of limestone powder slurry is controlled by control valves.

Each absorbers is fitted with a gypsum discharge system. Gypsum slurry collection pumps feed the slurry to hydrocyclones, where the gypsum is pre-dewatered and then pumped to a gypsum slurry tank common to both blocks, from where the slurry is transported to a system of centrifuges operating in an automatic reservation system.

The gypsum dewatering system using centrifuges will enable gypsum to be dewatered to a minimum moisture content of 8%. Ten centrifuges are used, six of which operate at the base and four are in reserve. Raw wastewater from both flue gas desulphurisation (IOS) installations is continuously discharged to a wastewater treatment plant common to both blocks from the flue gas treatment (IOS) installation, which is part of the IPPC installation in question.

3.2.2.7. Flue gas ducts

Raw exhaust duct – the exhaust duct leading to the absorber begins at the exhaust fan outlet dampers. The dampers were installed at the outlet of each exhaust fan. Two exhaust fans were installed for each power unit. Behind the damper, the two ducts merge into one. The ducts are made of alloy steel. The dampers are double-bladed.

Purified exhaust gas duct – used to transport exhaust gases from the absorber to the cooling tower. Due to the close contact between the suspension and the exhaust gases in the absorber, the exhaust gases leaving the absorber are cooled to their adiabatic saturation temperature. The channel from the absorber is made of acid-resistant fibre-reinforced plastic (GFK).

3.2.2.8. Water management

As mentioned earlier, the Opole Power Plant has a shared water intake system with preliminary treatment, after which the water is transported through pipelines to the power plant, where it undergoes further treatment at the Water Treatment Plant (WTP). The WTP consists of two main technological lines, such as:

- pre-treatment water treatment plant (*stacja wstępnego uzdatniania wody* - WUW)
- water demineralisation station (*stacja demineralizacji wody* - SDW).

The WUW preliminary water treatment installation consists of four identical technological lines, each of which includes:

- preliminary filtration,
- water oxidation with chlorine dioxide,
- coagulation, flocculation,
- pressure flotation
- rapid filtration on an anthracite-sand bed.

Each of the lines can independently carry out the treatment process, consisting of the above-described components.

The SDW water demineralisation process line includes:

- preliminary filtration,
- ultrafiltration,
- two-stage reverse osmosis
- dual ion exchange.

The raw material for water treatment in SDW is water pre-treated in the WUW installation. Water prepared in WUW and SDW is directed to individual power plant circuits.

3.2.2.9. Cooling water circuit

In units 5 and 6, independent closed cooling circuits using cooling towers have been installed for each unit. Waste heat generated during unit operation is transferred to the main cooling water system via a condenser and cooling water coolers. The cooling water pumping station for a single 905 MW unit consists of two identical systems, each with a capacity of 50%, equipped with valves, a grate with a cleaner, a rotary screen, a cooling water pump with adjustable impeller blade angle, and a shut-off and check valve on the pump discharge pipe.

3.2.2.10. Chimney cooling towers

The cooling towers of units 5 and 6 are supplied with make-up water from the preliminary water treatment plant. The purpose of the cooling towers is to transfer the waste heat absorbed by the water flowing in the condenser to the atmosphere in a heat exchange process. In addition, the cooling tower chimney is used to discharge purified flue gases from the desulphurisation system (cooling towers are the main emitters of gases and dust from units 5 and 6 of the Opole Power Plant).

The water heated in the condenser is pumped to the cooling tower, where it is evenly distributed by a water distributor across the sprinkler zones inside the cooling tower. The water cools down through direct contact with the air flowing countercurrently from the base of the cooling tower. The force causing the air to flow through the cooling tower is the difference in air density inside and outside the cooling tower, creating a chimney draft. The heat transfer process takes place through convection and evaporation.

A natural draft cooling tower ensures proper operation under all heat load conditions, both in winter and summer, minimising operational problems and water consumption compared to open cooling circuits. In addition, special drift eliminators are installed in the cooling tower to reduce water consumption by recapturing water droplets carried away by the air.

From an ecological point of view, the use of cooling towers does not contribute to the heating of river water through the discharge of cooling water, which in turn has a positive impact on the preservation of aquatic ecosystems.

3.2.2.11. Coal feeding system

Coal is delivered to the Opole Power Plant by rail. Coal from the unloading point is transported and with the help of belt conveyors trough conveyors in the following manner:

- to the coal storage yard;
- directly to the boiler hoppers of blocks 5 and 6.

Two new stacker-reclaimers have been installed at the storage yard, enabling coal to be loaded from belt conveyors onto the yard, and collected from the yard and dumped onto a selected conveyor for further transport to the units (new or existing).

Coal is delivered to the boiler hoppers by means of conveyor transport. Coal is discharged into individual boiler bunkers by means of discharge ploughs.

The coal feeding system consists of the following main devices:

- wagon tippers;
- mobile wheeled scrapers; — belt conveyor system;
- yard machines;
- additional equipment: scales, coal sampling devices, electromagnetic separators, metal detectors.

The existing railway infrastructure has been adapted to also cover additional coal transport (approximately 4 million Mg/year) for the needs of the new units. The existing development plan for the Opole Power Plant site provides for the necessary areas - the paved coal yards have been increased to an area of 92,500 m^2.

3.2.2.12. Ash removal system

Ash collected from electrostatic precipitators is transported pneumatically to ash storage tanks ZMP1, ZMP2 and ZMP3, dedicated to units 5 & 6, with a capacity of 27,000 m^3 each, or to ash retention tanks No. 4 and No. 5 with a capacity of 2,000 m^3 each, located at the Central Ash Loading Station. Here, it is loaded onto railway tankers, road tankers and self-unloading trucks and transported outside the Opole Power Plant.

The ash removal system for the new units 5 and 6 is connected by technological trestles for ash transport to the existing ash removal system for units 1 - 4, which will enable separate collection of ash that does not meet the quality standards for commercial ash.

Under the electrostatic precipitators of units 5 and 6, there are ash dispatch stations SWI and SW2, equipped with a tank pump system, enabling the collection of ash from the electrostatic precipitator hoppers and its pneumatic transport to:

- ash storage tanks ZMPI, ZMP2 and ZMP3;
- ash retention tanks No. 4 and No. 5;
- the existing ash retention tank No. 2 (in the event of non-compliance with the quality standards specified in PN-EN 450-1:2009 and PN-EN 197-1:2002).

Each of the ZMPI, ZMP2 and ZMP3 tanks ensures a minimum of two weeks of ash storage retention in the case of new boilers operating at nominal power, when burning coal with the worst parameters.

The ZMP 1, ZMP2 and ZMP3 tanks are equipped with a complete loading system.

- loading;
- dust extraction;
- unloading;
- recycling of stored ash.

The unloading system for ash storage tanks No. 4 and No. 5 allows for the simultaneous loading of two railway tankers (four-pod), one road tanker and one self-unloading truck from each tank. Ash can be loaded onto lorries using the "dry" method (tankers) and the "wet" method for open dump trucks.

3.2.2.13. Deslagging system

Slag is one of the main wastes generated in the coal combustion process. Slag produced as a result of coal combustion is directed from the slag remover through a two-way chute to the crushing system or, in an emergency, to a wheeled means of transport. Two crushing systems are installed for each boiler, one operational and one backup. Each system consists of a primary crusher and a main crusher. The capacity of the crushing systems and conveyors receiving slag from them is 50 t/h. This is 20% more than the capacity of the slag remover. The crushed slag is then transported by a scraper conveyor to a system of belt conveyors (reserved). The belt conveyor system is shared by two units, 5 and 6.

The slag is transported by belt conveyors to a storage facility with a 30-day retention capacity. The slag is unloaded by a portal scraper operating along the entire length of the storage facility and working in conjunction with a single belt conveyor. From the storage facility, the slag is transported by a belt conveyor to the lorry loading station.

The control system for the slag transport and storage system is located in a shared control room near the fly ash unloading station. The loading of lorries is controlled from a separate control room located in the slag loading building.

3.2.2.14. Gypsum transport and storage system

Gypsum produced in the wet flue gas desulphurisation plant is collected from the centrifuges by a system of belt conveyors, which transport the gypsum to the existing shared gypsum storage building. Dehydrated gypsum from each centrifuge line is collected by a special belt conveyor. Two belt conveyors are installed under the centrifuges, one for each line. The conveyors described above direct the gypsum through chutes to two transfer conveyors. The transfer conveyors then direct the dewatered gypsum via chutes to two existing GIA and GIB conveyors (depending on their availability), which transport the gypsum to the storage facility. All gypsum conveyors are designed for twice the flow rate from a given block, i.e. 100% gypsum production in both blocks. This gives the transport system a 100% reserve capacity.

3.2.2.15. Diesel power stations

Each of units 5 and 6 has a diesel power plant, each with a generator capacity of 1.6 MVA, fuelled by diesel oil. In addition, four fire pumps powered by diesel engines with a thermal power (in fuel) of 0.295 MWt each are installed in the cooling water and fire water pumping stations. Both the diesel power plants and the pumps are sources of low emissions of gases and dust into the air.

3.2.2.16. Oil management

The oil management facilities located in the south-eastern part of the Opole Power Plant site are shared by units 1-6.

The fuel oil storage and distribution system shared by units 5 and 6 consists of screw transfer pumps (3 x 100%) that supply oil from storage tanks (2 x 1,000 m^3). The oil distribution system supplies oil at the appropriate pressure to the boiler for the second stage of oil pumps, from where the oil is distributed to the oil burners. Excess oil is returned to the storage tanks. The storage tanks 2 x 1000 m^3 can be filled with oil from both railway tankers and road tankers using screw unloading pumps (3 x 100%).

3.3. General scope of dismantling works for the technological section

The project assumes that for the retrofit of a coal-fired boiler with fourth-generation reactors, the turbine island of the currently operating system will be retained along with all accompanying infrastructure.

Generation IV reactors are planned to be located on the site of the existing coal-fired boiler. All boiler systems, coal feeding systems, primary and secondary air supply systems, as well as flue gas cleaning and discharge systems may also be classified as demolition works (due to the need to clear the site for reactor construction). The classification of the boiler systems of unit 6 for demolition will strongly depend on their interconnections with unit 5. The sketch below shows the area of the infrastructure of coal-fired unit 6, which can be divided into two groups of facilities. Facilities classified for demolition and facilities that will be used or developed for integration with the KP-FHR Generation IV nuclear reactor system.

The facilities and installations that can be used in the decarbonisation investment of the Opole Power Plant include all equipment and infrastructure not directly related to coal combustion. This group includes:

- Steam turbine with generator
- Electrical equipment, transformers, switchgear
- Condenser cooling system and cooling tower
- Access road and rail transport infrastructure
- Car parks
- Main and auxiliary buildings.

Facilities of unit No. 6 with a capacity of 905 MW to be demolished and/or cleared for construction:

- Boiler room of unit 6
- SCR installation for NOx reduction
- Wet flue gas desulphurisation system consisting of:
    - Flue gas duct system with booster fan.
    - A lime slurry production system.
    - Absorber.
    - Gypsum dewatering system.
    - A wastewater treatment system in the flue gas cleaning process.
- Flue gas discharge system (electrostatic precipitators, flue gas ducts).
- Coal feeding system belonging to unit No. 6 (coal feeding gallery connecting the coal feeding galleries above the engine room of units No. 5 and 6 with the boiler room of unit No. 6 – belt conveyor with ploughs feeding unit No. 6).

Figure 15 Location of the main facilities of the Opole Power Plant

Technological systems/facilities common to units 5 and 6 that should be retained:

- Coal feeding system
  - Coal yard with coal unloading systems (wagon tippers).
  - Main coal feeding gallery supplying units 5 and 6 from the coal yard.
  - Coal feeding gallery above the engine room (reversible conveyors supplying units 5 and 6).
- Ash removal system
  - Joint routes/flyovers pipelines transport pneumatic ash from electrostatic precipitators of units 5 and 6 to ash storage tanks 2, 4 and 5 and to storage tanks ZMP1, ZMP2 and ZMP3.
  - Retention tanks No. 2, 4, 5.
  - Storage tanks ZMP1, ZMP2 and ZMP3.
- Deslagging system
  - Common slag belt conveyor trestles for units 5 and 6 to the slag portal warehouse.
  - Slag portal warehouse with a loading system for lorries.
- Gypsum transport and storage system
  - Shared flyovers for gypsum conveyors from centrifuges to the gypsum storage facility.
  - Gypsum storage facility (shared by blocks 1-6) with a loading system for lorries or wagons.
- Oil system
  - The oil management facilities located in the south-eastern part of the Opole Power Plant site are shared by units 1-6.
  - 2 x 1000 m^3 oil storage tanks with an oil unloading system.

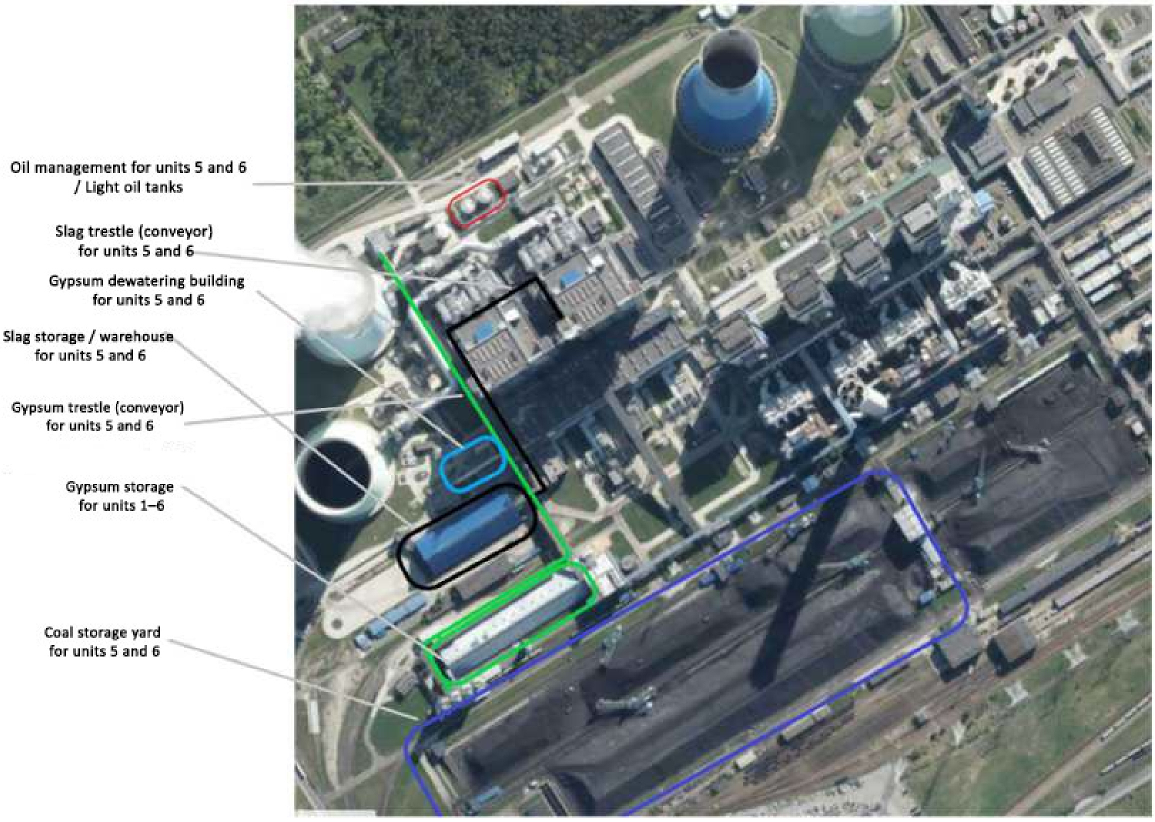

Figure 16 Technological systems/facilities common to units 5 and 6, which should be retained

The main facility of the existing unit scheduled for demolition (or adaptation) will be the boiler house of boiler No. 6, which results from the original design assumptions, i.e., an investment involving the retrofit of the coal-fired unit, consisting in replacing the boiler island with a reactor or a system of fourth-generation nuclear reactors.

3.4. Electrical layout of the Opole power plant

3.4.1. Structural section

The Opole Power Plant was built between 1993 and 1997, comprising four (4) power units with a capacity of <400 MW each (units 1-4), and then in 2019 it was expanded with two units (5-6) with a total capacity of 2x900MW.

Table 7 General characteristics of the Opole Power Plant units

No	Unit 1	Unit 2	Unit 3	Unit 4	Block 5	Block 6
Completed [year]:	1993	1994	1996	1996	2019	2019
Power [MW]	386	383	383	380	900	900
Voltage level [kV]	110	110	400	400	400	400

The electrical power systems of units 1-4 are already approximately thirty (30) years old, and in the time frame of the Coal-to-Nuclear project, it is assumed that they cannot be used for several decades of future operation in the new formula.

Due to their relatively young age (they will be 21 years old in 2040), the technical infrastructure of units 5-6 could potentially serve as a basis for the implementation of power output and power supply systems for the specific and general needs of the Coal-to-Nuclear project.

The main electrical system of blocks 5-6 consists of:

- Two (2) generators with a capacity of ~1230 MVA, ~27 kV, each protected by a generator circuit breaker,
- Two (2) sets of single-phase block transformers (three (3) units per block) with a capacity of ~450 MVA each, and one reserve unit,
- Two (2) 400 kV block circuit breakers, implemented in GIS technology, located in dedicated buildings in front of the block transformers,
- Two (2) overhead 400 kV block lines connecting the power plant to the 400 kV Dobrzeń substation,
- Four (4) tap transformers – two (2) per block – three-winding, with a capacity of ~90/45/45 MVA,
- 10 kV switchgear for own and general needs,
- Two (2) transformers (2) power supply reserve – three-winding, o power ~90/45/45 MVA, and voltages of 110/10/6 kV, constituting the backup power supply for units 5-6 and units 1-4 at a voltage of 6 kV,

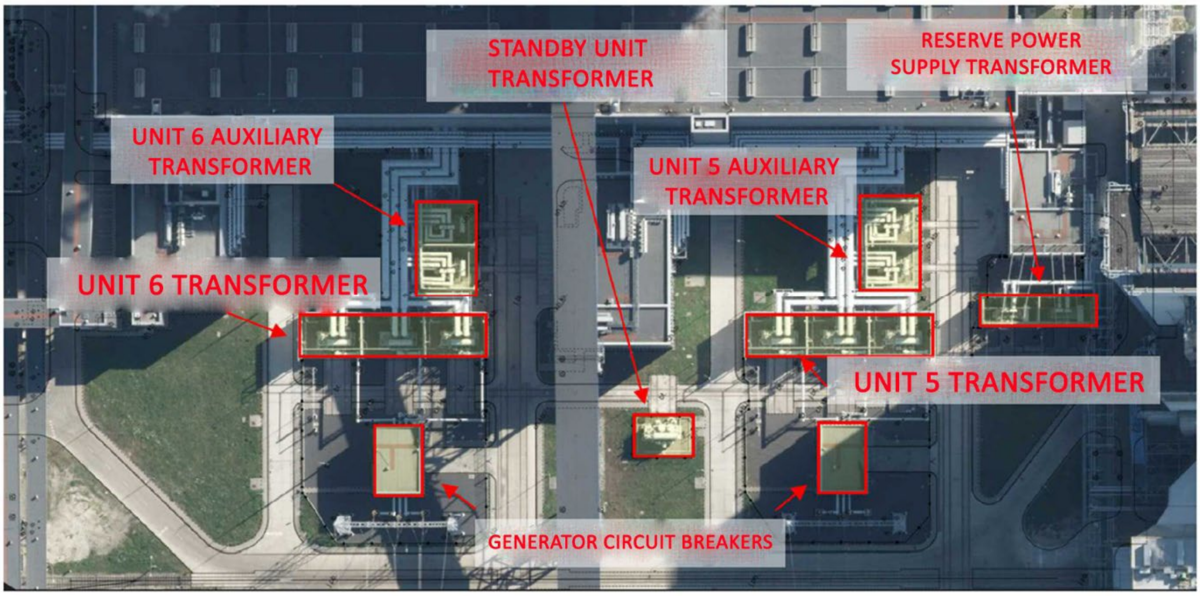

Figure 16 Aerial photograph of the power transmission system from units 5 and 6 of the Opole power plant. (source: geoportal.gov.pl)

3.4.2. Power line section

Power lines, in particular high and extra-high voltage lines, have a long service life of over 50 years, which can be significantly extended with proper operation. In view of the above, there is a potential opportunity to use all the available high and extra-high voltage line infrastructure of the Opole power plant in the Coal-to-Nuclear project.

After the existing power plant units are decommissioned, the availability of the following lines is identified:

- 110 kV overhead line of unit No. 1,
- 110 kV overhead line of unit No. 2,
- 400 kV overhead line of unit No. 3,
- 400 kV overhead line of unit No. 4,
- 400 kV overhead line of unit No. 5,
- 400 kV overhead line of unit No. 6,
- 110 kV overhead backup power line for units 1 and 2,
- 110 kV overhead reserve power line for units 3 and 4,
- Overhead cable backup power supply line 110 kV for blocks 5 and 6.

Due to the technological layout of the Opole Power Plant, the power outlets from units 1-4 are located on the opposite side to the Dobrzeń substation. This makes it necessary to bypass/cross the power plant buildings. The block lines run along the right side of the boiler room (with the Dobrzeń substation behind them), where they enter the gate and then, above the electrostatic precipitator system of the blocks, they enter the pylon in front of the coal yard. Then the lines enter the poles behind the coal yard (behind the track) and proceed further on to the poles in front of SE Dobrzeń and to the dedicated 110 and 400 kV switchgear fields.

Due to the time when they were built, the power lines of units 1 - 4 may not comply with the current regulatory requirements for the design of overhead lines.

Power is supplied from units 5 and 6 from the Dobrzeń substation, which did not require the line to be routed over the power plant's boiler room/engine room. The lines run over the coal yard and then to dedicated 400 kV switchgear fields at the Dobrzeń substation.

The 110 kV backup power supply is provided via a 110 kV switchgear located in the south-eastern part of the power plant, where the 110 kV overhead lines towards the 110 kV SE Dobrzeń switchgear end.

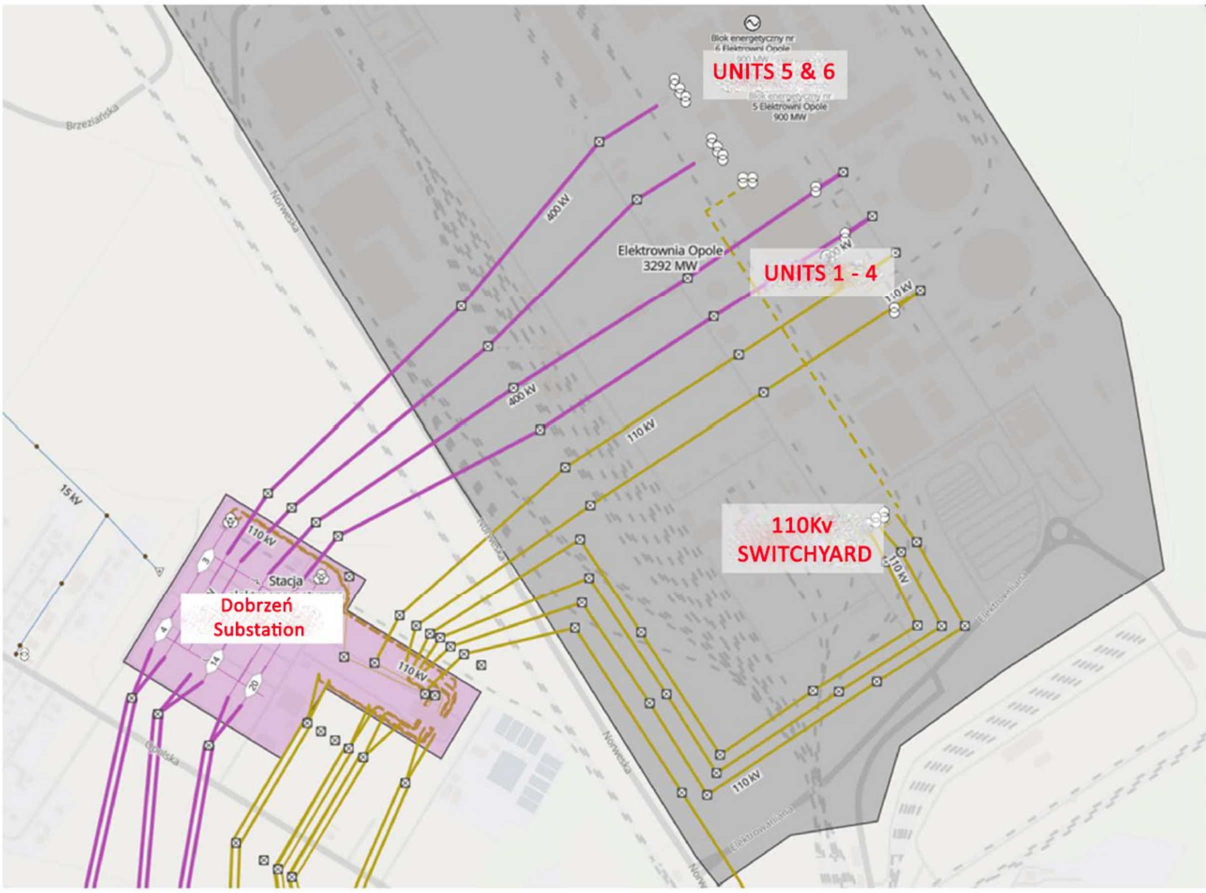

Figure 17 Power lines for power output and backup power supply of the Opole Power Plant.
(source: Open Infrastructure Map)

3.4.3. Connection point of the Opole Power Plant to the National Power System – SE Dobrzeń

The SE Dobrzeń power station is located in the vicinity of the Opole Power Plant in Dobrzeń, north of the city of Opole, in the Opole Province, and is one of the most important elements of the National Power System (KSE).

The station consists of a 400 kV switchyard and a 110 kV switchyard and is owned by PSE S.A. (Transmission System Operator). The 400 kV switchyard is an overhead 3/2 circuit breaker system. The 110 kV switchyard is an indoor GIS switchyard.

The 400 kV switchyard at the Dobrzeń substation (as of 2034, in accordance with the Development Plan for meeting current and future electricity demand for 2025–2034 – PSE) will be connected to the National Power System via eight 400 kV lines, including two southbound lines to the new Wrzoski substation, two south-eastbound lines to the Blachownia substation (Kędzierzyn Koźle), two westwards to the Lewin substation, and two northwards to the Pasikurowice and Ostrów Wielkopolski substations.

The station's strong connection to the power system, on the one hand, provides good potential for the transmission of significant volumes of power through the node, while on the other hand, the station's ability to introduce additional generation capacity into the system is limited by "macro" north-south flows resulting from the planned significant generation in the north of the country (related to the decommissioning of conventional sources in the south).

Figure 18 Dobrzeń Power Station

The 110 kV switchgear has been modernised and rebuilt in recent years from an overhead AIS insulation system to an indoor GIS switchgear and adapted to the operator's current standards.

The 400 kV switchgear was modernised and adapted to the current operator standards when blocks 5 and 6 of the Opole Power Plant were connected to it. This involved replacing the worn-out primary equipment of the 400 kV switchgear and installing new secondary and auxiliary circuits.

In the coming years, there are plans to connect a photovoltaic farm with a total capacity of 350 MW to the Dobrzeń substation and to install a new 400/110 kV autotransformer, which will involve the modernisation/expansion of the substation with additional 400 kV fields.

3.4.4. Other power systems

The Opole Power Plant has telecommunications links with the systems of PSE, the operator of the National Power System. These systems can be used in the modernised generating unit as part of the "Coal-to-Nuclear" project.

3.5. Water and sewage infrastructure (outside the technical)

The water and wastewater infrastructure (excluding process technology) at the Opole Power Station consists, in particular, of the following on-site networks and systems:

- drinking water and firefighting water
- rainwater and industrial sewage systems, including a mechanical and chemical sewage treatment plant and a single common outlet (water facility) for all sewage into the Odra River;
- domestic sewage system with a mechanical-biological sewage treatment plant and a single common outlet (water device) for all sewage into the Odra River.

3.6. Construction infrastructure

3.6.1. Description of the existing road system

There are two entrance gates leading to the Opole Power Plant. Their schematic location is shown in the figure below.

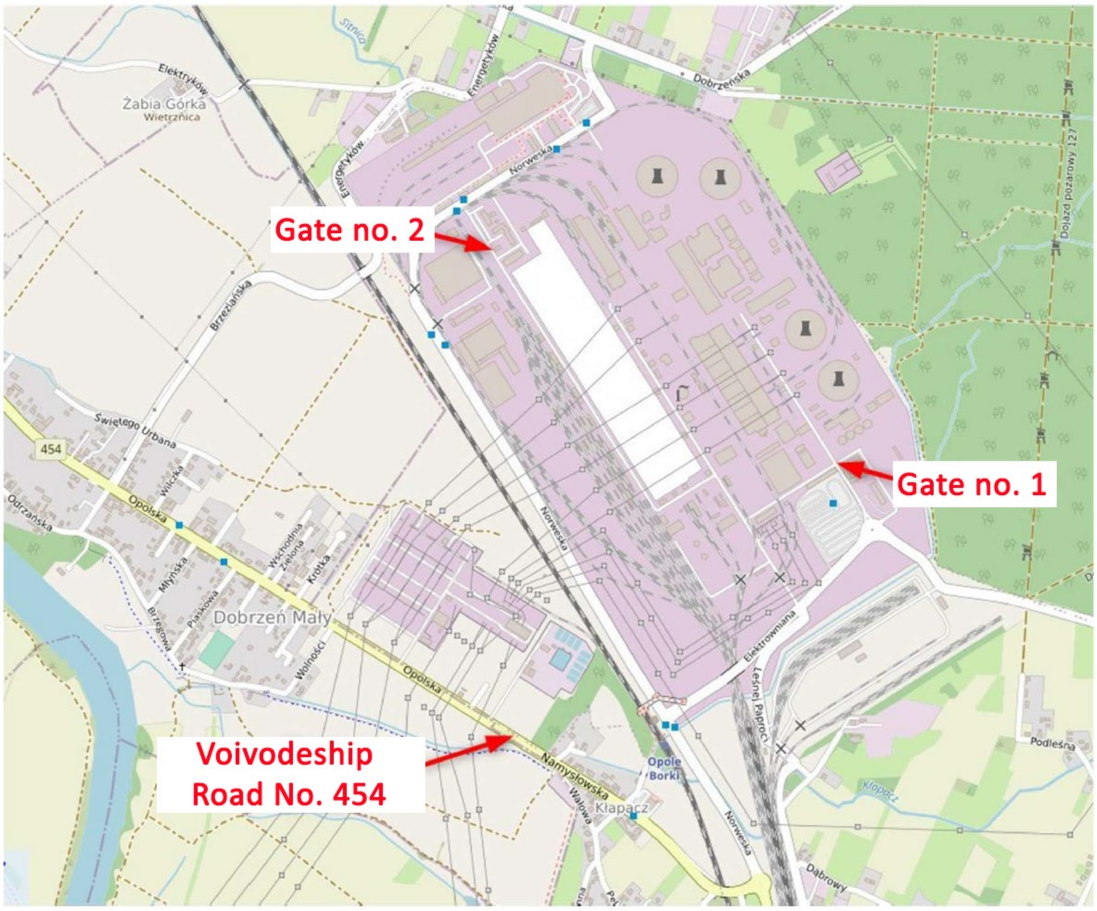

Figure 19 Layout of entrances to the Opole Power Plant7

7 https://www.geoportal.gov.pl/

The power plant has a system of internal roads with pavements, car parks and storage areas. [8]

The Opole Power Plant is surrounded by a network of public roads, including national and provincial roads:

- Provincial road No. 454
- National road No. 45
- National road No. 46
- National road No. 94
- A4 motorway

The road network is shown in the figure below.

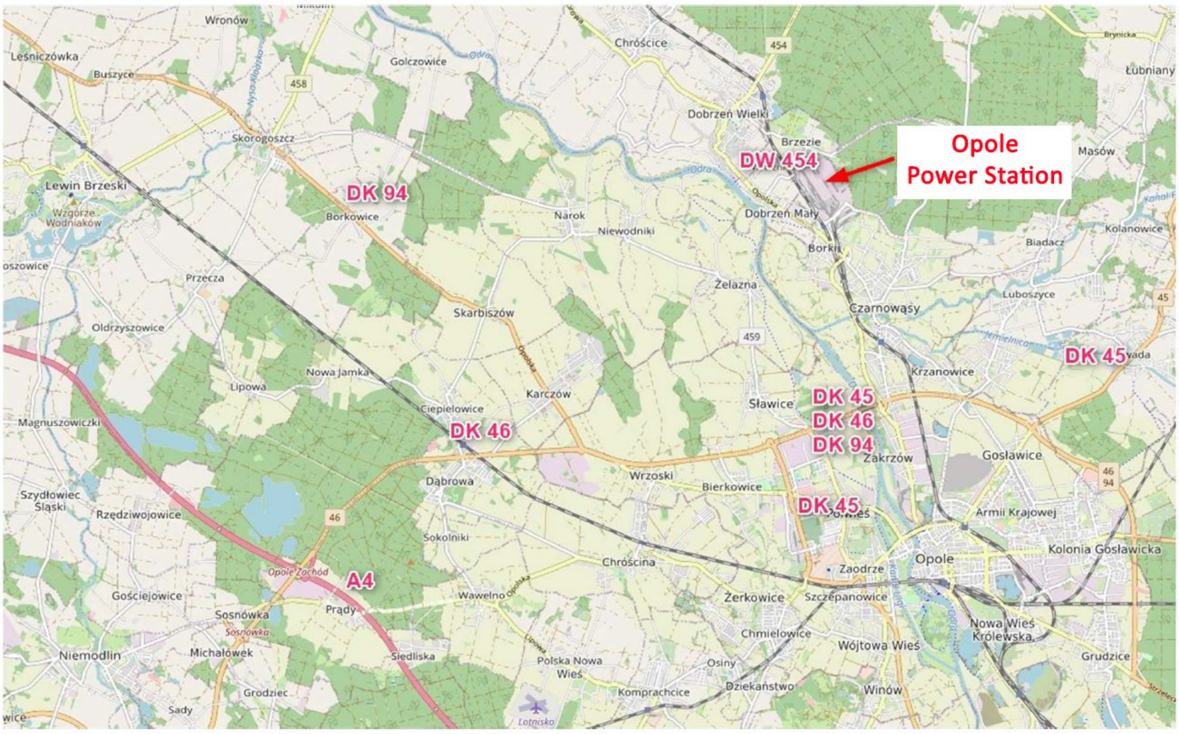

Figure 20 Road layout in the area of the Dolna Opole Power Plant

3.6.2. Description of the existing railway network

Public railway lines

Railway line No. 277 – electrified, single and double track, primary railway line connecting Opole Groszowice with the Wrocław Brochów station. It runs through the Lower Silesian and Opole provinces and through the districts of Wrocław, Oława, Brzeg and Opole. The line is used by freight and passenger trains. Classified as a line of national importance[9]

8 https://www.geoportal.gov.pl/

9 https://pl.wikipedia.org/wiki/Linia_kolejowa_nr_277

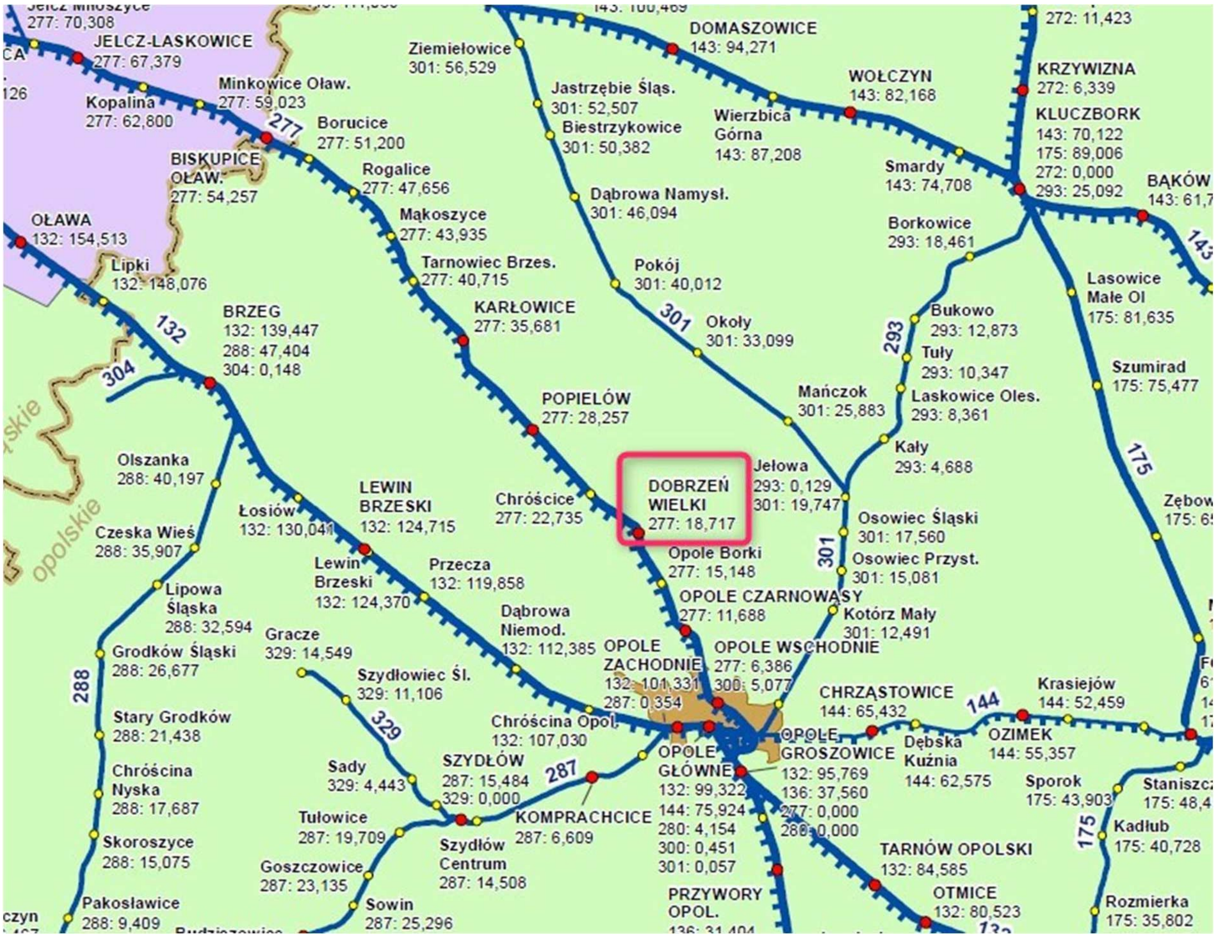

Figure 21 Diagram of state railway lines in the Opole Power Plant area[10]

Internal railway lines

The Power Plant has a railway track system connected to the Polish Railway Lines system via line no. 277

10 http://mapa.plk-sa.pl/

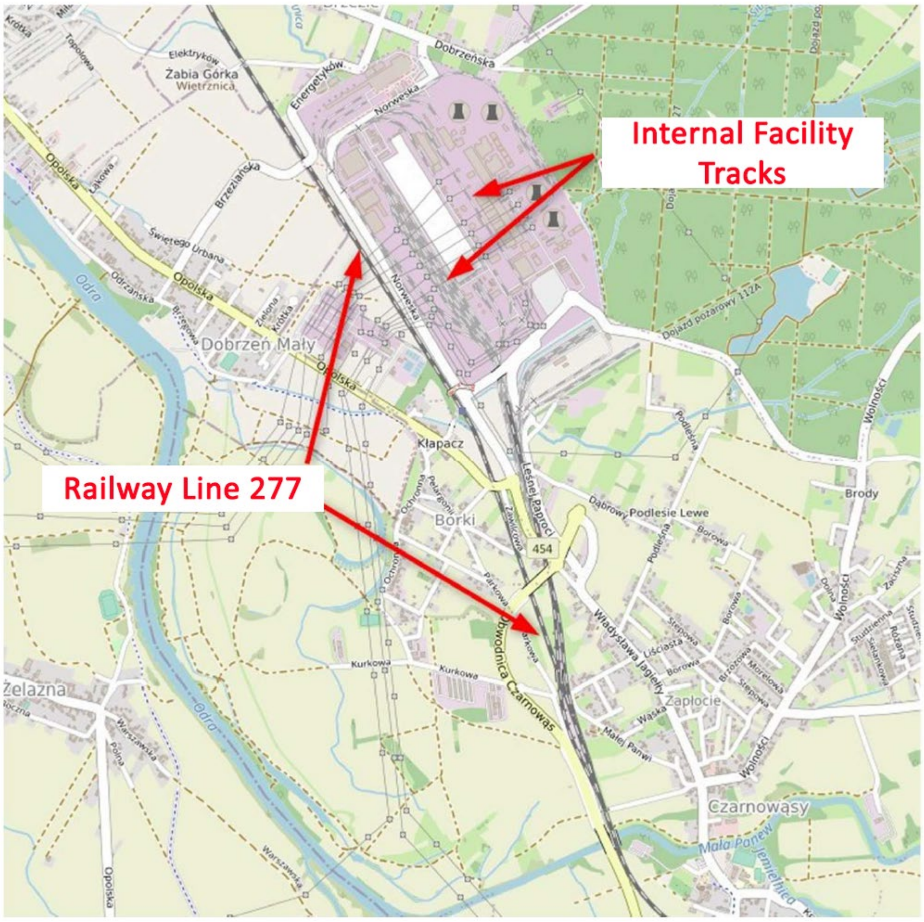

Figure 22 Diagram of railway lines on the premises of the Opole Power Plant[11]

3.6.3. Description of geological and water conditions

Geological conditions

The geological conditions were characterised on the basis of publicly available sources. [12]

The area lies on the Pre-Sudetic monocline and in the north-eastern part of the Opole Basin. The pre-Cenozoic bedrock consists of Triassic and Upper Cretaceous formations, with Permian sandstones, Lower Carboniferous greywackes and shales, and Vendian-Cambrian gneisses at greater depths.

In terms of stratigraphy, rocks from the Proterozoic to the Quaternary are found here:

- Proterozoic–Cambrian: deeply buried gneisses (e.g. Wrzoski),
- Carboniferous: shales and sandstones with flora imprints (e.g. Asterocalamites),
- Permian: sandstones, conglomerates, tuffs and tuffites (rhyolite tuffs),
- Triassic: variegated sandstone, dolomites, limestones and anhydrites (ret), shell limestones (Middle Triassic), and kajpru mudstones (Upper Triassic),
- Upper Cretaceous: marls and limestones with rich fauna (Cenomanian–Coniacian),

11 https://www.geoportal.gov.pl/

12 https://geologia.pgi.gov.pl

- Neogene: mainly clays, sands, gravels with lignite inserts,
- Quaternary: mainly river, glacial and aeolian deposits, with terraces of the Odra River valley and its tributaries.

The area was intensively shaped by glaciation and river activity. There are troughs, dunes, terraces and remnants of human activity (quarries, clay pits, embankments).

Water conditions

The area has a well-developed hydrographic network. The main watercourse is the Odra (Oder) River, whose valley dominates the north-western part of the area. Numerous tributaries flow into the Odra, including the Mała Panew, Brynica, Prószkowski Potok and Malina. In the past, the Odra formed an extensive inland delta with several branches flowing around chalk outcrops. Currently, only the main branch is functional, while the others have taken the form of oxbow lakes, partially filled with water or converted into breeding ponds. The area also includes artificially dug canals (e.g. the Ulga Canal), built for flood protection and navigation. River terraces, especially floodplains and post-floodplains, act as natural filtration corridors. Groundwater occurs mainly in Quaternary sandy and gravel deposits. Deeper aquifers are found in Triassic formations (dolomites and limestones) as well as in Permian and Carboniferous sandstones. Their thickness and quality depend on the lithology and tectonics of the bedrock. In some areas, the water is confined or artesian. In river valleys, the groundwater level is shallow, and swamps are common. Areas of loam and clay uplands are characterised by poorer hydration. High fluctuations in groundwater levels are observed in sandy areas. The area is hydrologically important – there are several water intakes here. The diversity of water conditions results from the geological structure and the activity of glaciers and rivers. Hydrogeological studies have revealed the presence of trough structures filled with aquifer sediments.

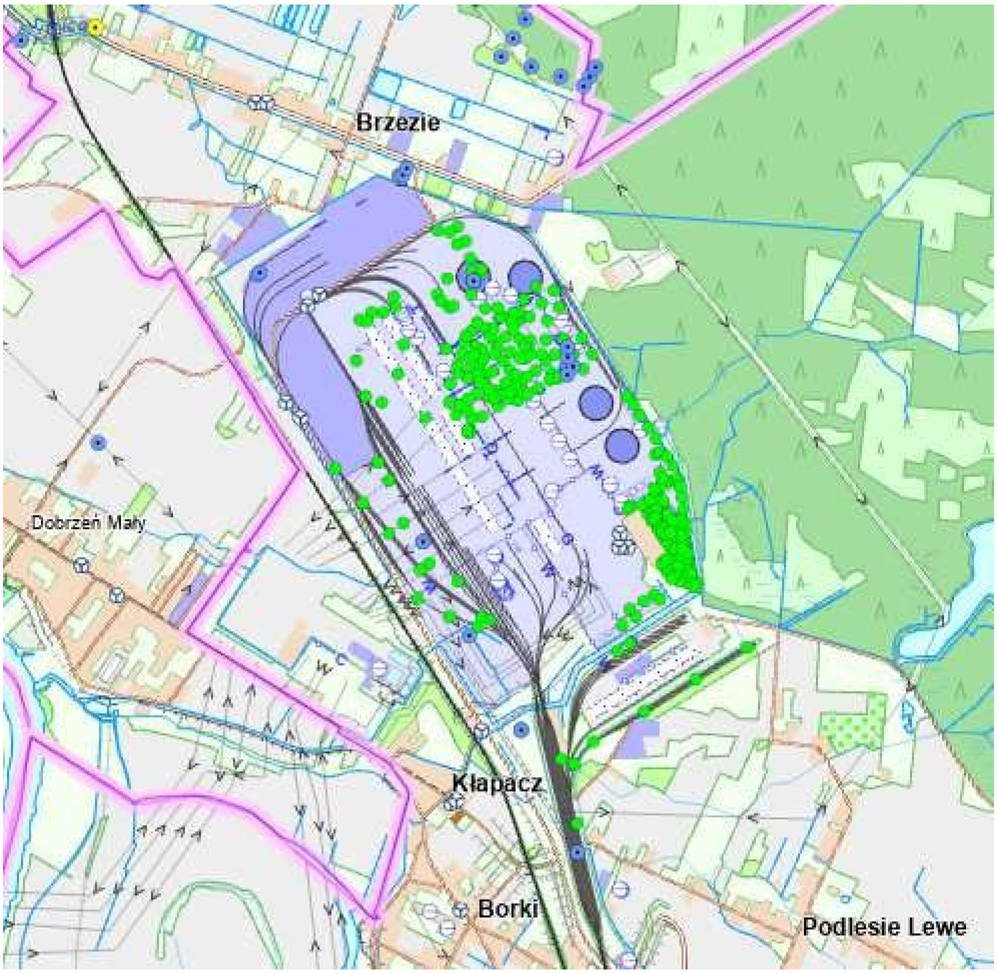

Figure 23 Location of soil testing points[13]

The ground has a layered structure, varying in composition. It consists of compacted sand, hard-plastic and plastic clay, loam and soft rock in the form of marl.

13 https://geologia.pgi.gov.pl

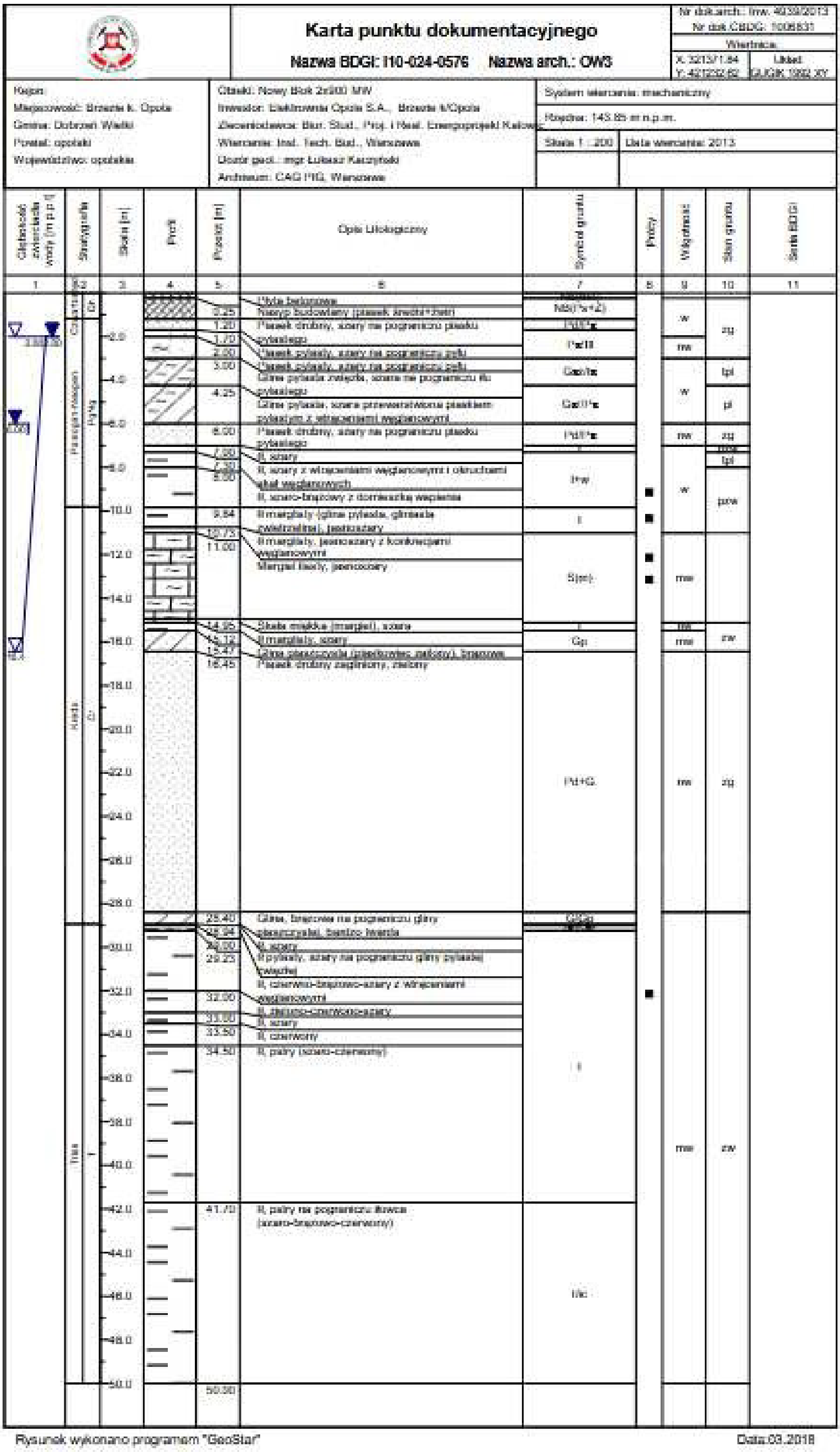

Figure 24 Sample ground test card in the area of existing buildings of the Opole Power Plant[14]

14 https://geologia.pgi.gov.pl

3.6.4. Identification of flood risk

The area of the Opole Power Plant is located outside the flood risk area (Q1%, i.e. once every 100 years).

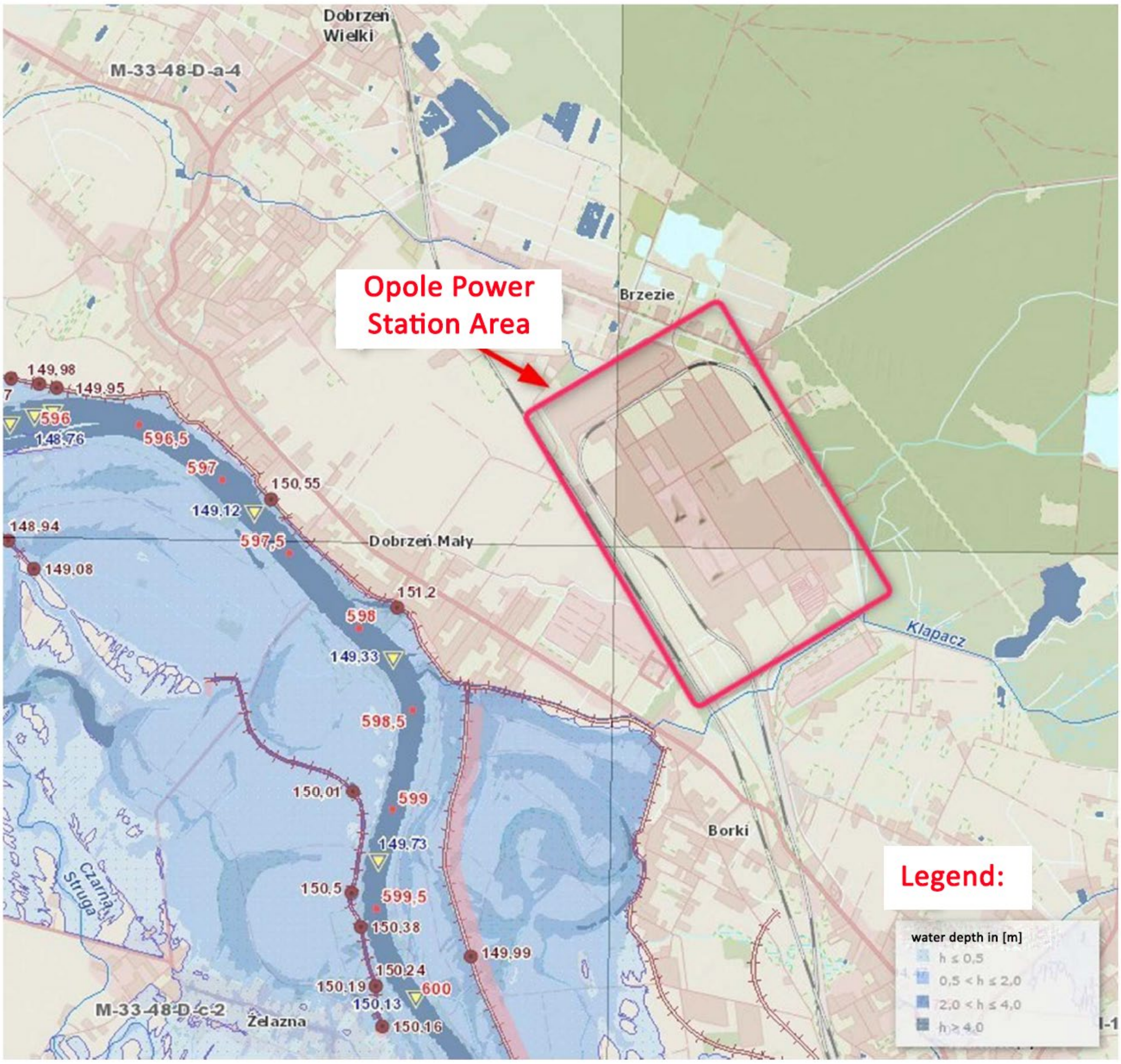

Figure 25 Flood risk area [15]

15 https://wody.isok.gov.pl/

3.7. Assessment of the possibility of using the existing infrastructure of the Facility – summary

Construction industry

The possibility of using existing buildings should be assessed after a detailed expert analysis has been carried out to determine their technical condition and suitability for new functions. At present, it is assumed that if the function and technical condition allow it, they could be used for the purposes of accompanying infrastructure for the SMR.

The Opole Power Plant site has a complete road and rail infrastructure serving the existing buildings and structures of the operating coal-fired power plant. Depending on the final configuration of new or rebuilt structures, the road and rail layout will have to be adapted to meet new functional requirements. It is assumed that the existing infrastructure will largely be usable and that any changes will be kept to a minimum.

The ground conditions allow for the planning of construction projects related to nuclear infrastructure. In the case of heavy buildings that are sensitive to subsidence, such as reactor buildings, ground reinforcement should be considered.

The Opole Power Plant area is located outside the flood risk area.

Technology industry

An analysis of the technical condition of the existing infrastructure of Unit 6 of the Opole Power Plant in terms of technology has shown that it is possible to use part of the unit's infrastructure to retrofit the heat source with small, modular KP-FHR nuclear reactors. The main equipment qualified for adaptation to the new heat source is the turbine with all related installations (start-up, discharge, etc.). In addition, no restrictions were found in the use of the closed cooling system, consisting of a cooling tower, pumping station, condenser and cooling water pipelines. The use of a water treatment plant is also assumed, as there will be no additional, stricter requirements resulting from the operation of nuclear reactors in this system. The selected reactors will operate on the basis of a reactor cooling circuit using molten fluoride salt rather than water, as in Generation III nuclear reactors.

The possibility of using the above installations will strongly depend on their operating time. The later the planned investment begins, the worse the technical condition of the equipment considered for further use will be. The qualification of equipment for further use must be preceded by thorough diagnostic tests (resulting, for example, from material fatigue, reduced strength, reduced efficiency, etc.) and further modernisation work aimed at improving key system operating parameters.

The use of the infrastructure of the other units of the Opole Power Plant was not covered by this Feasibility Study.

Electricity industry

Due to the varying age and quality characteristics of the existing infrastructure, the diagnosis of its use for the implementation of nuclear projects was divided according to the generating units.

Units 1-4 – it is not possible to use the existing electrical infrastructure of the facility. Existing power distribution systems, including: unit and tap-off transformer stations, as well as the power supply systems for the units' auxiliary equipment, will be dismantled and demolished.

There is also no potential for the use of existing unit lines, including tall structures, pylons and gates, due to the fact that the lines were built to standards that are now obsolete and are located in an unfavourable position above the existing power plant.

Units 5 and 6 – there is a potential possibility (depending on the generator power and internal power demand) of using (for Generation IV reactors):

- A generator with a capacity of ~1230 MVA,
- generator switch,
- rail bridge system from the generator to the block transformer/tap changers
- single-phase block transformers,
- three-winding tap transformers,
- overhead power output system,
- 110 kV backup power supply system, including backup power supply lines for units 1 - 4,
- telecommunications connections between units 5 and 6 and PSE.

The potential for utilising the existing electrical infrastructure of units 5 and 6 depends on the possibility of adapting the nuclear technology used and its power to the parameters of the existing unit. It should be noted, however, that units 5 and 6 are one of the newer domestic coal-fired power sources, and shutting them down for modernisation using nuclear reactors may be impossible for reasons related to the National Power System balance, as well as economically unjustified due to the failure to utilise the available and fully functional coal-fired generation infrastructure.

<u>Installation industry</u>

Considering the planned solutions related only to the replacement of equipment within the boiler section, it is anticipated that the existing networks and installations for domestic water, firefighting water and sewage may continue to be used. It is anticipated that water consumption for the above purposes should not increase compared to the current situation.

At later stages of design, when all the exact quantitative and qualitative parameters regarding water demand and sewage disposal are known, it will be possible to consider optimising the use of existing water intake systems, water treatment plants, existing sewage treatment plants and sewage discharge into the environment. This should be done with particular regard to the long-term operation of these facilities to date and the possible need for their modernisation in the coming years.

Additionally, it cannot be ruled out that at a later stage of design, when the exact scope of the possible need to clear the site is known, it will also be necessary to adjust the layout of the above-mentioned existing underground infrastructure and internal installations. It is anticipated that it may be necessary to remove certain sections, install connectors or new sections of the network and installations in order to maintain their continuity of operation and further use for existing and newly designed elements of the Power Plant's land development.

4. Analysis of selected Generation IV reactor technologies required for the investment process

4.1. Analysis of selected SMR reactor technologies

The commercial implementation of Generation IV nuclear reactors creates an opportunity for more advantageous adaptation of the steam turbines currently in use in coal-fired power units, and thus their decarbonisation. From the point of view of upgrading coal-fired power plants to supercritical parameters, the best fit is provided by the SMR reactors currently under development, in which the main coolant is gas, liquid metal or molten salt. In the case of thermal reactors, the working medium of the steam turbine can be heated to temperatures as high as 600°C. Due to the different technologies, heat can be extracted from the reactor in different reactor systems. The steam cycle of the steam turbine can receive heat directly from the primary coolant of the reactor or from the secondary coolant in an indirect heat transport system. Given the wide range of thermal powers of the planned reactors, the development of SMR technology may also contribute to the retrofitting of heating systems and the development of the chemical industry.

Many countries are currently working on the development of high-temperature SMR reactors. SMR technologies are are mainly based on low-power reactors, typically not exceeding $300MW_e$, and a modular design concept, which means that most of the reactor installation will be built at the manufacturer's factory. Currently, most SMR designs are in the concept or preliminary basic design phase.

SMR reactors are being developed in both Generation III and Generation IV reactor groups in all available reactor technologies:

- high-temperature reactors cooled by gas, e.g. HTR-PM, Xe-100
- molten salt-cooled reactors: IMSR400, KP-FHR
- water-cooled reactors: BWRX-300, VOYGR^{TM} , CANDU SMR^{TM}
- liquid metal-cooled breeder reactors: ARC-100, SEALER-55
- microreactors: Energy Well, MoveluX, Xe-Mobile, etc.

4.2. Characteristics of gas-cooled SMR reactors (GCR) based on the commercially operating HTR-PM reactor

HTR-PM is a small, modular Chinese nuclear reactor. It is a Generation IV high-temperature reactor cooled by gas with a gravel bed, which evolved from the HTR-10 prototype. The first power plant of this type has a capacity of 210 MW; it began producing energy in December 2021 and will commence commercial operation at the end of 2023.

HTR-PM is the first project to use a modular design, which means that two reactors called NSSS (nuclear steam supply system) with a thermal power of $250MW_t$ each are connected to a single steam turbine to generate $210MW_e$ of electricity.

The main cooling agent for the reactor is helium at a pressure of 7.0 MPa with a nominal mass flow rate of 96 kg/s. The helium coolant enters the reactor at the bottom of the reactor vessel with an inlet temperature of 250^{o}C. The helium is then heated in the active core of the reactor and mixed to an average outlet temperature of 750^{o}C, after which it flows to the steam generator. Each reactor is connected to a single steam generator, which supplies steam at a temperature of 560^{o}C and a pressure of 13 MPa to the turbine. The helium from the primary circuit is not used in any industrial processes.

The main feature of high-temperature gas-cooled reactors is their inherent safety, which allows them to be located near industrial plants and population centres. HTGR reactors are characterised by self-regulating reactor power, guaranteed by strong negative feedback between core temperature and reactivity. This regulation means that even a slight increase in core temperature causes an immediate decrease in reactivity, which in turn leads to immediate stabilisation or reduction of reactor power. Even a slight decrease in core temperature causes an immediate slight increase in reactivity, resulting in an increase in reactor power, allowing it to return to a stable operating state. Therefore, an unlimited increase in power that could lead to the destruction or melting of the core cannot occur in an HTGR.

Another characteristic safety feature of HTGRs is their ability to automatically remove post-shutdown heat from the reactor core after a loss of coolant (LOCA failure), which in this case is helium. This is based on the natural processes of heat conduction in the graphite block surrounding the heated fuel rods (characterised by high heat capacity). The heat stored in the graphite elements is transferred to the environment through the reactor shielding by means of thermal radiation. The third important safety feature of the HTGR reactor is the TRISO (tri-structural-isotropic) fuel, which contains several protective coatings, known as cladding. The jacket surrounding the fuel consists of pyrolytic carbon and silicon carbide, materials resistant to high temperatures that prevent radioactive substances from escaping outside the fuel balls. The core is in the form of a bed of TRISO spherical fuel elements, with uranium enclosed inside multilayer grains. ..\Opole\SMR_Book_2022.pdf

5. Market analysis of the of technology required in the investment process

Approximately twelve SMR reactor projects based on advanced molten salt reactor (MSR) technology are currently under development worldwide. MSR reactors promise many benefits, including increased safety due to the properties of salt, a low-pressure single-phase cooling system that eliminates the need for a large containment building, and a high-temperature system that ensures high efficiency and a flexible fuel cycle.

The basic design concept of the MSR reactor, i.e. KP-FHR, is to combine three-structured isotropic molecular fuel (TRISO) with molten fluoride salt as a coolant. This combination results in a high-temperature, low-pressure reactor with robust passive safety systems. In addition to inherent safety, the design also reduces dependence on expensive nuclear-grade components and structures and utilises conventional technologies to lower capital costs.

Molten salt reactors contain solid fuel, mainly based on coated fuel particles, embedded or surrounded by a graphite moderator cooled with fluoride salt. As in the case of gas-cooled high-temperature reactors, fuel particles can be dispersed in a graphite gravel bed, concentrated in sealed plates or surrounded by graphite blocks. The technology of coated fuel particles was proposed as early as 1957 for high-temperature reactors. Early designs for fluoride-cooled high-temperature reactors (FHR) were based on prismatic blocks containing TRISO fuel. This solution was quickly rejected because the average density of the fuel blocks would be lower than the density of the salt, causing the blocks to float and making certain operations, such as fuel transfer, very difficult. Instead, designs using pebble (sphericall) fuel gained popularity.

The Kairos Power reactor uses molten fluoride salt "FLIBE" as a coolant. Molten fluoride salts have excellent chemical stability and a high heat transfer capacity at high temperatures, and the ability to retain fission products. Various American reactor studies confirm the compatibility of molten fluoride salts with conventional high-temperature construction materials (e.g. stainless steel), thus providing a commercially attractive technology due to its reliability and longevity.

The Kairos Power reactor also uses TRISO fuel, which retains its structural integrity even at extremely high temperatures. This fuel will not be damaged at temperatures well above the melting points of conventional reactor fuels. By using loose (pebble) fuel, Kairos Power reactors can refuel during operation, providing exceptional reliability and availability.

5.1. Technology description

In the case of modernisation aimed at replacing a coal-fired boiler with a KP-FHR reactor system, it is necessary to use a steam generator in which the medium mediating heat transfer to the working medium of the steam turbine is a salt solution consisting of a mixture of $NaNO_3/KNO_3$. This technology involves the use of two closed heat exchange loops from the reactors to the steam turbine circuit:

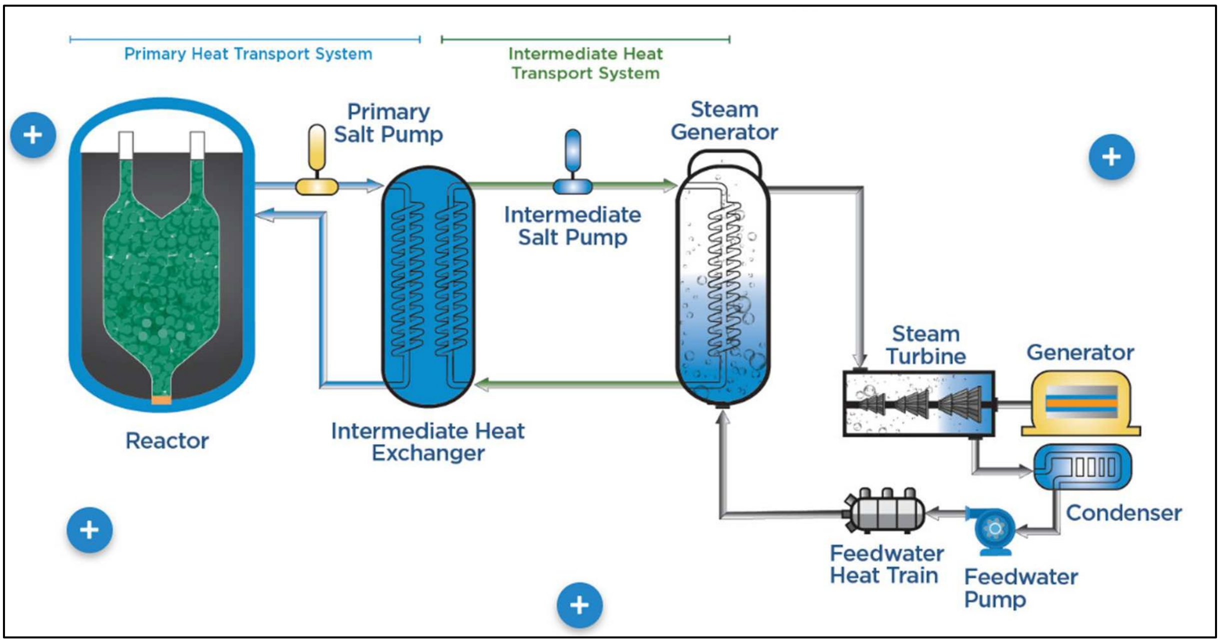

Figure 26 Schematic diagram of the KP-FHR reactor system and medium flow

In the primary heat transport system, LiF/BeF2 "FLiBe" fluoride salt pumped by circulation pumps collects the heat generated in the reactor. The heat is then transferred in an indirect heat exchanger to the salt in the second circulation loop, which is also pumped in a closed circuit by pumps and directed to the steam generator. The salt in the second circulation loop, $NaNO_3/KNO_3$ transfers the heat to the working medium of the steam turbine in the steam generator.

The conceptual diagram below shows that the reactor manufacturer assumes the cooperation of two heat exchangers that collect heat from the reactor cooling salt in the first loop and transfer heat to the second, intermediate cooling loop.

The available data also indicates that the steam generator will not be part of the reactor module; it will be a component that needs to be designed to work with a specific steam turbine set.

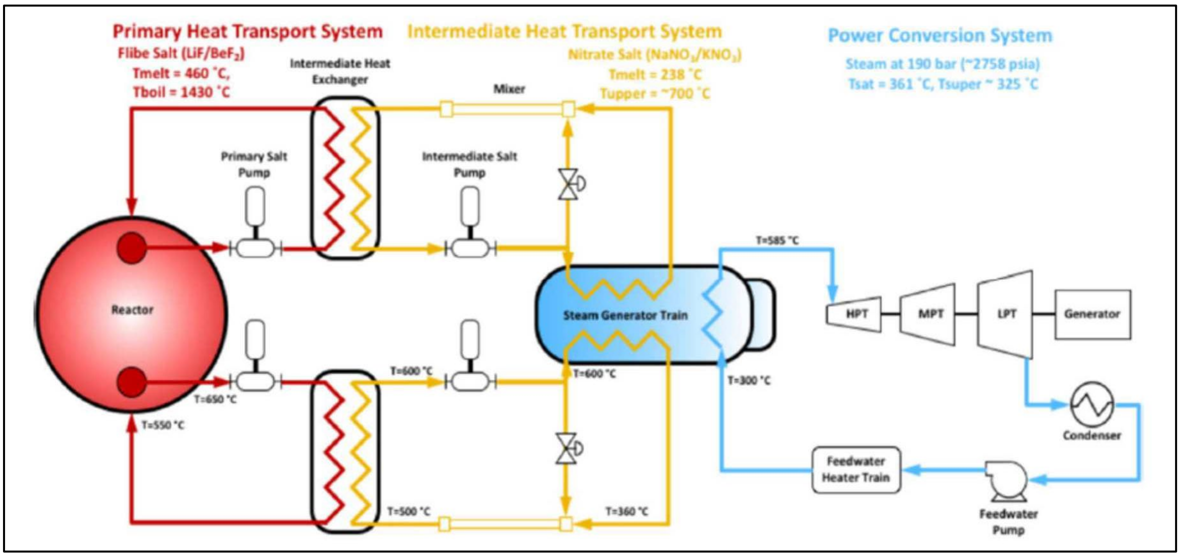

Figure 27 Schematic diagram – basic parameters of working media

Basic assumed parameters of the KP-FHR nuclear reactor:

Table 8 Basic assumed parameters of the KP-FHR nuclear reactor

Parameter	Reference value
Reactor type	High-temperature fluoride-cooled reactor (FHR)
Basic reactor configuration	Loose/gravel bed core, graphite moderator/reflector Low-enriched high-quality HALEU fuel Flibe molten fluoride salt cooling
Thermal power	320 MW_t
Operating pressure in reactor	<2 barg
Salt inlet temperature FLIBE to core	550°C
Salt outlet temperature FLIBE from core	650°C
Net thermal efficiency	45%
Refrigerant flow rate of reactor coolant	1200-1400 kg/s (~0.11-0.15 m/s)
Loading intervals fuel	None, continuous reloading of burnt-out elements during normal operation
Reactor vessel size	Diameter – 3.9 m, height – 6.1 m, thin-walled construction made of 316H stainless steel

5.2. Safety features of the KP- FHR reactor

The main principle behind the safety of the KP-FHR reactor is the use of passive protection. This means that Kairos Power reactors do not require electricity to remove post-shutdown heat from the core.

KP-FHR reactors have exceptionally high safety margins based on the selected combination of fuel and coolant, allowing emergency cooling to be powered solely by natural forces such as gravity and convection, rather than mechanical or electrical systems. There is no need to replenish the coolant in the Kairos Power reactor (as the coolant cannot boil away), and the fuel's tolerance to extremely high temperatures allows for greater cooling capabilities in emergency scenarios compared to water-cooled reactors. High-temperature fuel and coolant greatly simplify emergency cooling for all possible failures.

For reactivity control purposes, the reactor will be designed to have negative feedback loops for fuel reactivity, moderator and coolant temperature. Reactivity control during reactor operation and non-accidental events is provided by control elements placed in a graphite reflector surrounding the gravel bed core. Reactivity control during accidental events is provided by shutdown elements placed directly in the gravel bed. The shutdown elements are gravity-driven and released by the reactor protection system. Both the shutdown and control elements consist of a composite structure of neutron-absorbing material made of natural boron carbide (B_4C) in an inert gas with a stainless steel SS316H cladding. The shutdown and control elements are fail-safe in the event of a power loss. The number and location of the shutdown elements will be selected to ensure a sufficient margin of safety for shutdown at zero power and with sufficient reactivity to shut down the core at full reactor power.

- Reactor vessel design – the natural and fundamental protection system is the reactor vessel design, which ensures tightness and protection against leaks. The reactor system comprises a core with a gravel bed, surrounded by a graphite reflector, housed in a cylindrical stainless steel reactor vessel.
- Decay heat removal system – decay heat removal during normal operations and non-accidental events is provided by the normal shutdown cooling system, which connects directly to the main heat transport system, i.e. the primary heat removal loop from the reactor using molten Flibe salt.
- Emergency core cooling system – the fuel design and appropriate selection of coolant, as well as their mutual compatibility, enable emergency cooling of the reactor based solely on natural physical processes, e.g. convection, without the use of active systems such as pumps.
- Safety casings – the KP-FHR reactor uses a specific type of encapsulation for radioactive products, which is ensured by the properties of TRISO fuel and Flibe fluoride salt – it is the fuel structure that is responsible for retaining fission products in the fuel layers. The silicon carbide (SiC) coating on TRISO particles is the primary barrier for fission products, while the pyrolytic carbon layers and matrix act as secondary barriers, retaining or hindering the transport of fission products and protecting the integrity of the SiC layer – this ensures the health and safety of the population and workers. Additional reactor containments provide defence-in-depth protection.
- The coolant chemistry control system (CCS) monitors the salt coolant for contaminants, ensuring that it remains in a stable operating state within specified operating parameters.
- Spent nuclear fuel cooling safety system – KP-FHR fuel is fully ceramic, which simplifies the requirements for spent fuel cooling and storage in canisters/tanks.

The combination of fuel resistant to extremely high temperatures and low-pressure, single-phase, chemically stable reactor coolant eliminates most potential fuel damage scenarios, greatly simplifying the design and reducing the number of safety systems. The low pressure in the reactor and associated piping, together with the functional safety provided by TRISO fuel, increases safety and eliminates the need for high-pressure containment structures.

5.3. TRISO fuel characteristics

TRISO fuel is a tri-structural isotropic molecular fuel in the form of a sphere containing uranium. The fuel sphere is coated with special ceramic layers designed as small pressure vessels. These layers contain fission products inside and ensure mechanical and chemical stability during irradiation and temperature changes.

This fuel has been designed to withstand high temperatures without melting, enhancing safety features for advanced nuclear reactors. Its ability to withstand high temperatures without melting provides safety benefits and contributes to the overall efficiency, economy and operation of the reactor. This fuel is extremely durable.

The basic fuel element consists of a grain of fissile material (e.g. uranium dioxide UO_2) with a diameter of 500-700µm covered with four layers. The first layer of material is a porous buffer made of pyrolytic carbon, whose task is to collect gaseous fission products. The second layer consists of a dense, high-temperature-resistant material with high mechanical strength. A similar protective function is performed by the next layer of silicon carbide. It ensures high fuel tightness by retaining all fission products, regardless of their form. The outer layer of high-density pyrolytic carbon mechanically protects the entire TRISO fuel element, creating a "deep defence mechanism". TRISO balls are sintered with a graphite matrix and formed into larger elements with a shape appropriate for the adopted core concept. These can be larger balls with a diameter of about 6 cm. [1] *GOSPOSTRATEG-HTR PROJECT: PROJECT RESULTS*

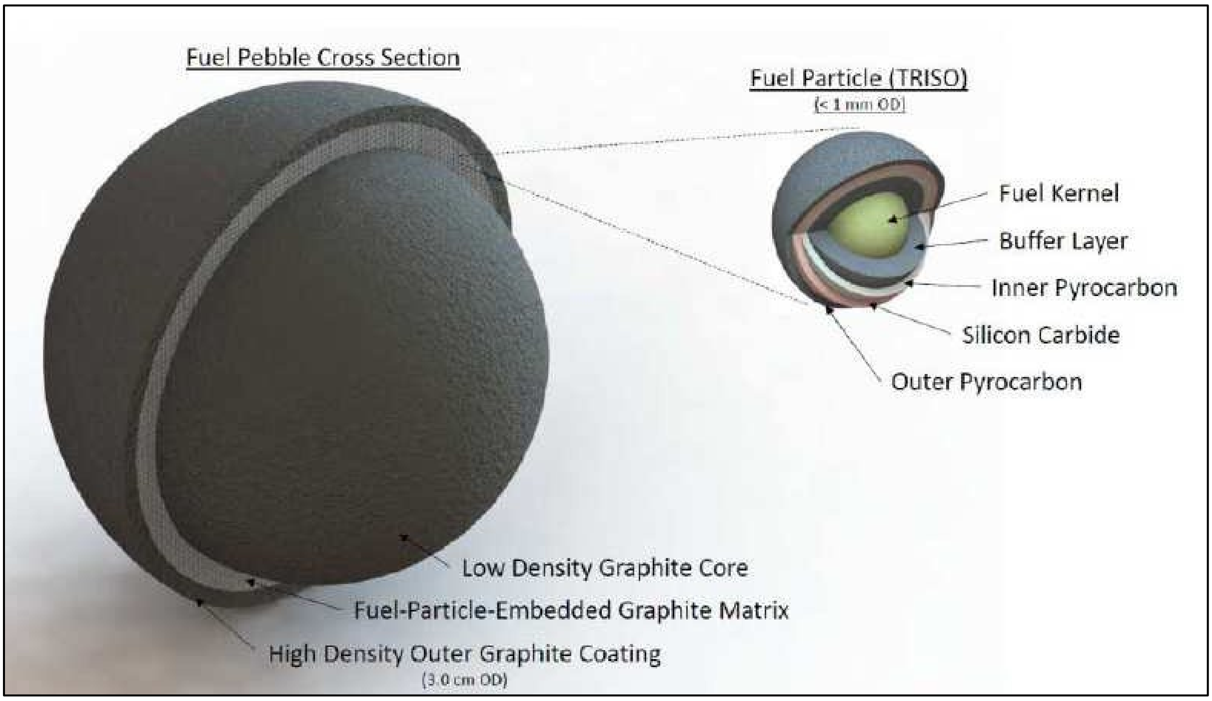

Figure 28 Structure of TRISO fuel

TRISO particulate fuel differs fundamentally from conventional fuels, which are centimetre-sized pellets of uranium dioxide enclosed in 4-metre-long zirconium alloy tubes. The main idea behind TRISO particulate fuel is to provide each millimetre-sized piece of nuclear fuel with its own container and pressure vessel, which greatly increases the fuel's ability to retain fission products even at very high temperatures and under neutron bombardment, where conventional fuel would melt.

The main disadvantage of TRISO fuel is its disposal due to its complex structure, which ensures complete tightness during operation. Another disadvantage is the problem of spent fuel management due to the significant volume of irradiated graphite. The structure of the fuel also poses a serious challenge when it comes to processing it for the recycling of fissile components for reuse.

Compared to conventional fuel elements, a TRISO particle contains 5 million times less fissile mass. Dividing nuclear fuel into small, self-contained packets eliminates the risk of single failures in the pressure vessel or fuel cladding. Typically, a single failure of the reactor's main steel pressure vessel would lead to a nuclear accident.

Even a single failure of conventional fuel cladding results in the leakage of fission products into the coolant and the tank, which can lead to unplanned downtime or a serious accident. With TRISO, single failures are unlikely, and when they do occur, they lead to a small release of radiation into the fuel matrix, where it is likely to be retained.

6. Description of the adopted solution

6.1. Assumptions

The main assumption of the preliminary feasibility study is an investment involving the retrofitting of a coal-fired unit, consisting in replacing the boiler island (the existing coal-fired boiler of unit 6) with a Generation IV nuclear reactor or reactor system. The concept of adding Generation IV reactors to the existing turbine island requires, first and foremost, the adjustment of the parameters of fresh and secondary steam produced in the steam generator to the parameters of the unit. All changes required to adjust the reactor to the parameters of the steam turbine are to be made on the turbine circuit side.

6.2. Building area

The available knowledge about KP-FHR Generation IV reactors suggests that the area occupied by boiler No. 6 will be sufficient for the construction of six complete reactors with the required installations. Below is a proposal for the construction of six KP-FHR reactors on the site of coal-fired boiler No. 6 at the Opole Power Plant.

The graphic below and the green outline show the replacement of the coal-fired boiler with a KP-FHR reactor complex.

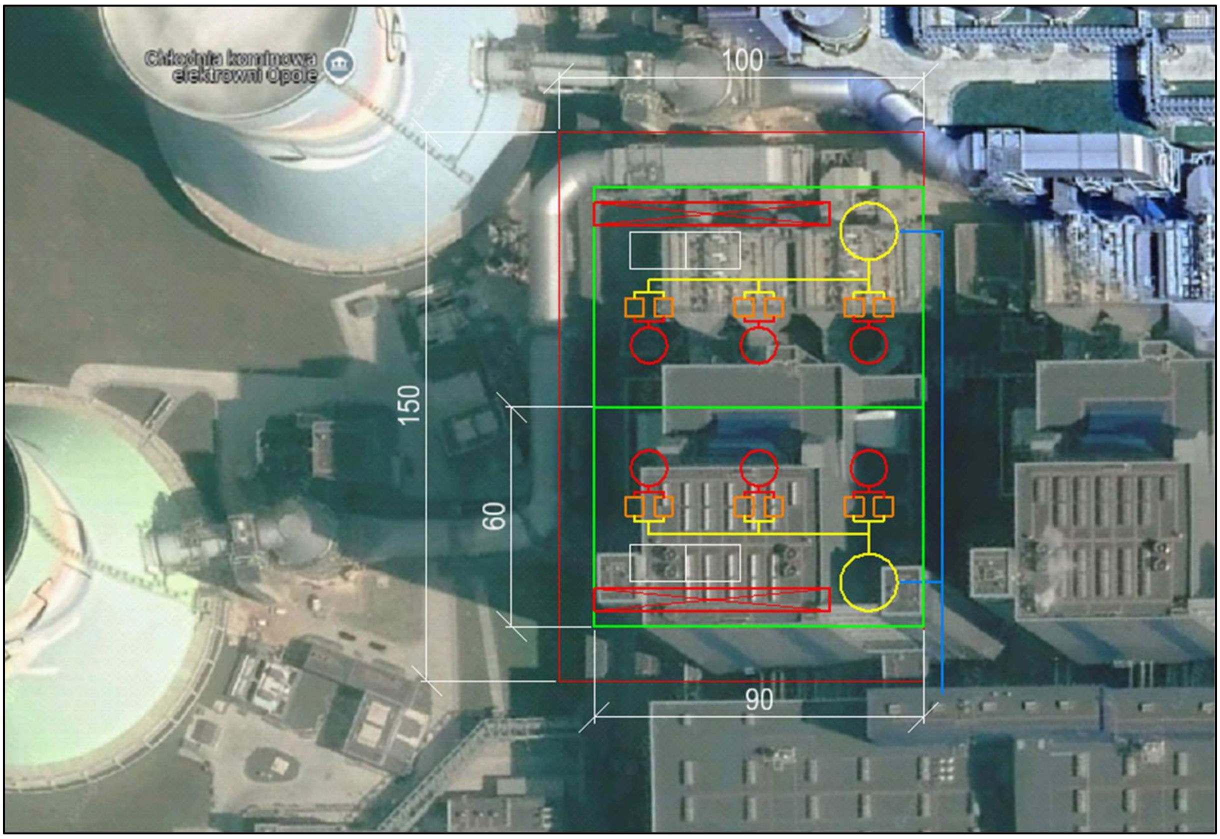

Figure 29 Preliminary location of the Kairos Power KP-FHR reactor system at the Opole power plant (unit 6)

In the coming years, rapid development of KP-FHR reactor technology and updates and availability of data are expected, which may necessitate changes to the above assumptions. In the event of a significant increase in the space required for the installation of KP-FHR reactors, the investment could be considered, for example, on the site currently used by the 360 MW units.

6.3. Integration of KP-FHR modular nuclear reactors into a single source of heat

Due to the lack of basic data on the KP-FHR prototype reference reactor regarding the combination of reactors into modules containing a larger number of reactors, it is assumed that such a combination will be possible in order to achieve sufficient thermal power of the source, meeting the requirements of the existing steam turbine.

The available materials indicate that in the case of parallel connection of reactors and steam production for a single turbine set, one larger steam generator can be used for three KP-FHR reactors. To replace coal-fired boiler No. 6 at the Opole Power Plant, six units will need to be integrated.
6 KP-FHR reactors to obtain a thermal power of approximately 1920 MW_t. It is assumed that the reactors will be divided into two modules, each containing three reactors. Each module will be connected to one steam generator through the integration of the secondary $NANO_3/KNO_3$ cooling salt circuits of individual reactors.

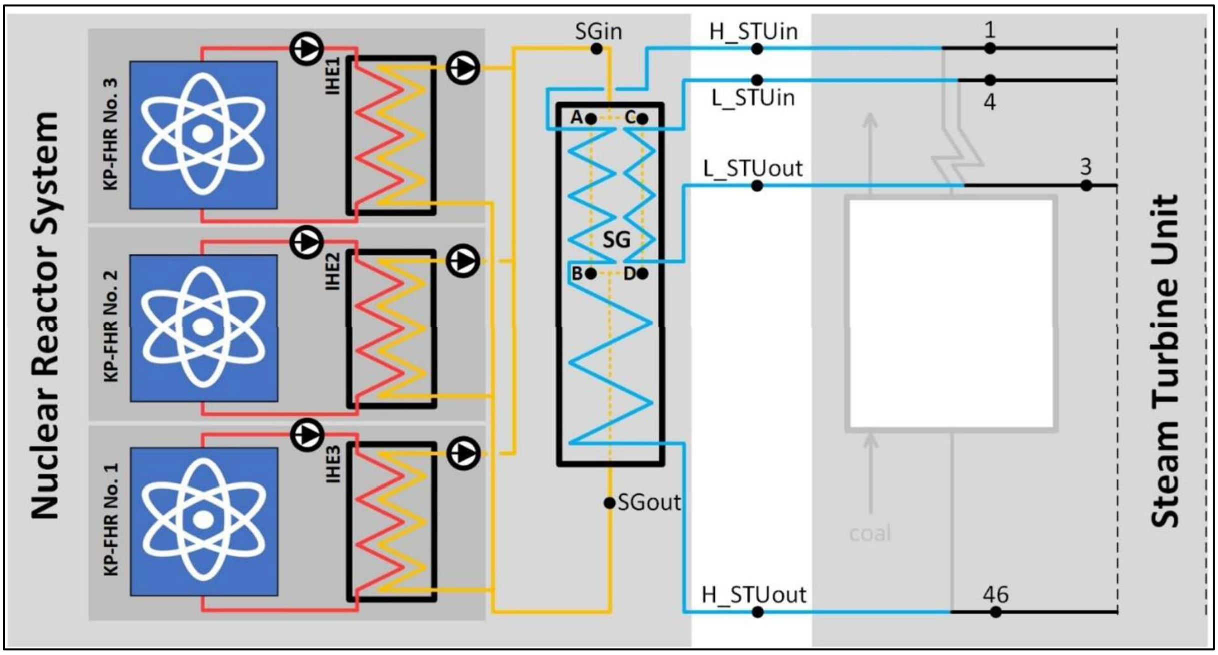

Figure 30 Schematic diagram of the connection of three KP-FHR reactors to one steam generator

6.4. Adapting technology to the steam turbine system of the unit for supercritical parameters

Based on technological, balance (technological equivalence) and economic analyses carried out by the Silesian University of Technology regarding the replacement of a coal-fired boiler with a fourth-generation reactor in a power unit selected for modernisation, the possibility of its interoperability with HTR-PM, IMSR400, KP-FHR and Xe-100 reactors was determined. The analysis showed the need to reduce the parameters of fresh and secondary steam and increase the temperature of the feed water.

The analyses considered many variants of feed water heating, such as:

- fresh steam regulation,
- secondary steam control

- steam regulation from bleed valves

The fresh steam control option proved to be the most advantageous, as the proposed solution allows the feed water temperature to be adjusted to the requirements of the steam generator across the entire load range. Due to the best temperature match between the reactor and the steam-water circuit of the unit, the KP-FHR reactor from the American company Kairos Power LLC was selected for further analysis.
For the remaining reactors, i.e. IMSR400, HTR-PM and Xe-100, based on the analyses carried out, it was found that their adaptation to the turbine circuit of the existing coal-fired unit (circuit of unit 5 or 6 of the Opole Power Plant) requires far-reaching design changes that reduce the attractiveness of the C2N solution under consideration, as well as a mismatch in terms of the required thermal power.

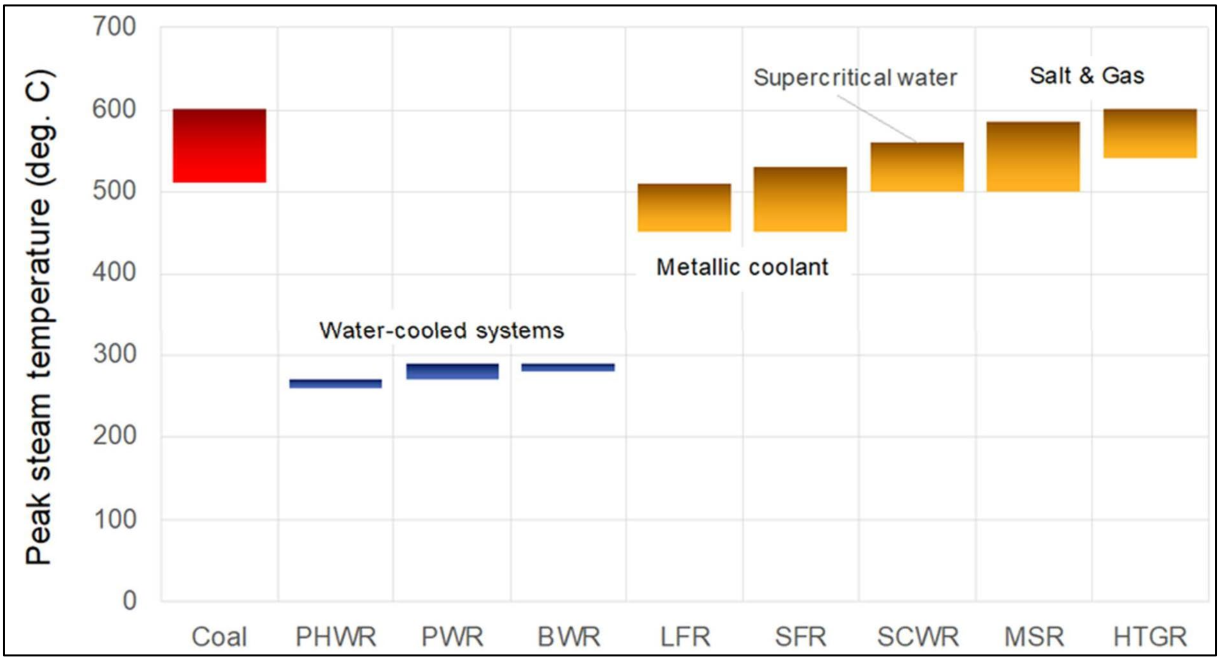

Figure 31 Comparison of peak fresh steam temperatures in nuclear and coal-fired power plants

As shown in the chart above, among the various types of nuclear reactors currently being developed and commercialised, molten salt reactors and gas-cooled reactors have the best chance of successfully integrating the water steam cycle with existing coal-fired power plant equipment with minimal modifications.

6.5. Technological Equivalence

The KP-FHR reactor selected for this project was presented in the previous sections. According to our knowledge and publicly available data, the reactor should be able to produce steam with the parameters listed in the table below.

Table 9 Steam parameters that can be obtained using the KP-FHR reactor

Parameter	Unit	Value
Thermal power	MW	~320
Fresh steam pressure	MPa	19
Fresh steam temperature from the boiler	°C	585/585
Feed water temperature	°C	300

This project involves the installation of six reactors to replace the existing BP-2455 coal-fired boiler in unit 6. No data has been provided by the owner of the facility in question for the purposes of this project, therefore, all infomation is derived from publicly available data on blocks 5 & 6 in Opole.

;

On this basis, it was assumed that the unit under investigation has the parameters of the main equipment as shown in the table below.

Table 10 Parameters of unit 6 in Opole

Parameter	Unit	Value
Boiler capacity (fresh steam flow)	t/h	2,455
Boiler thermal power	MW	~1,900
Fresh steam pressure from the boiler	MPa	26.0
Fresh steam temperature from the boiler	°C	603
Secondary superheat pressure	MPa	6.0
Secondary superheat temperature	°C	611
Feed water temperature	°C	~285
Electrical power of the turbine set	MWe	905
Steam pressure at turbine inlet	MPa	25.1
Steam temperature at turbine inlet	°C	600

For the above parameters, a thermal model of the steam-water system for a coal-fired unit was created in the Thermoflow programme. The database was based on publicly available information and the report from task No. 2 of the DESire project.

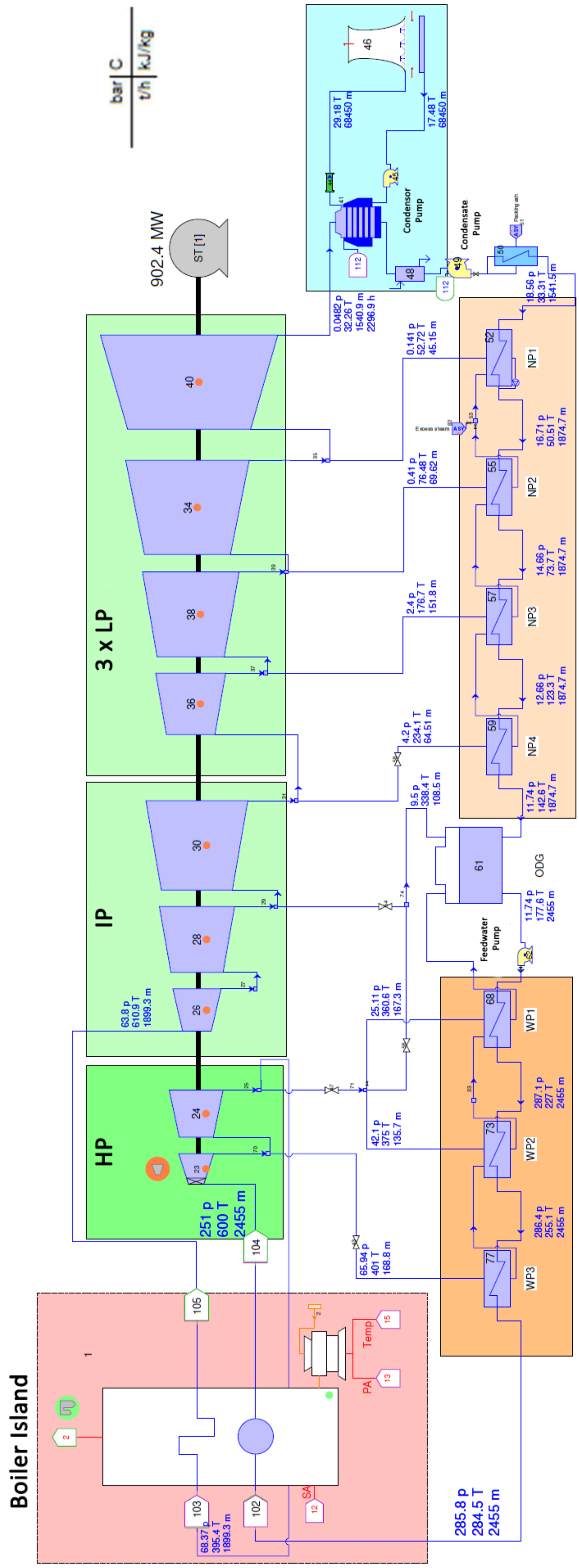

Figure 32 Thermal cycle of a 900 MW unit with a coal-fired boiler as a steam source

The next step in the analysis was to replace the boiler island with six reactors with a dedicated steam generator with pressure adjusted to the rated parameters of the coal-fired unit's steam turbine. In addition, a correction was made in the steam circuit in the form of an additional regenerative exchanger to heat the feed water to a temperature of 300 °C. The exchanger is powered by fresh steam, as this allows the feed water temperature to be adjusted to the requirements of the steam generator across the entire load range. Other methods of water heating were also analysed, but this one was found to be the most advantageous. The table below summarises the parameters of the unit after the implementation of the new heat source and the change in the temperature of the fresh steam and feed water.

Table 11 Parameters of block no. 6 cooperating with the nuclear reactor.

Parameter	Unit	Value
Fresh steam flow	t/h	2,455
Reactor thermal power	MW	~1,920
Electrical power of the turbine set (gross)	MWe	~881
Net electrical power of the unit	MWe	~816
Steam pressure at turbine inlet	MPa	25.1/4
Steam temperature at turbine inlet	°C	585/585
Feed water temperature	°C	300
DEMI water replenishment	t/h	17.6
Process water replenishment	t/h	1,264

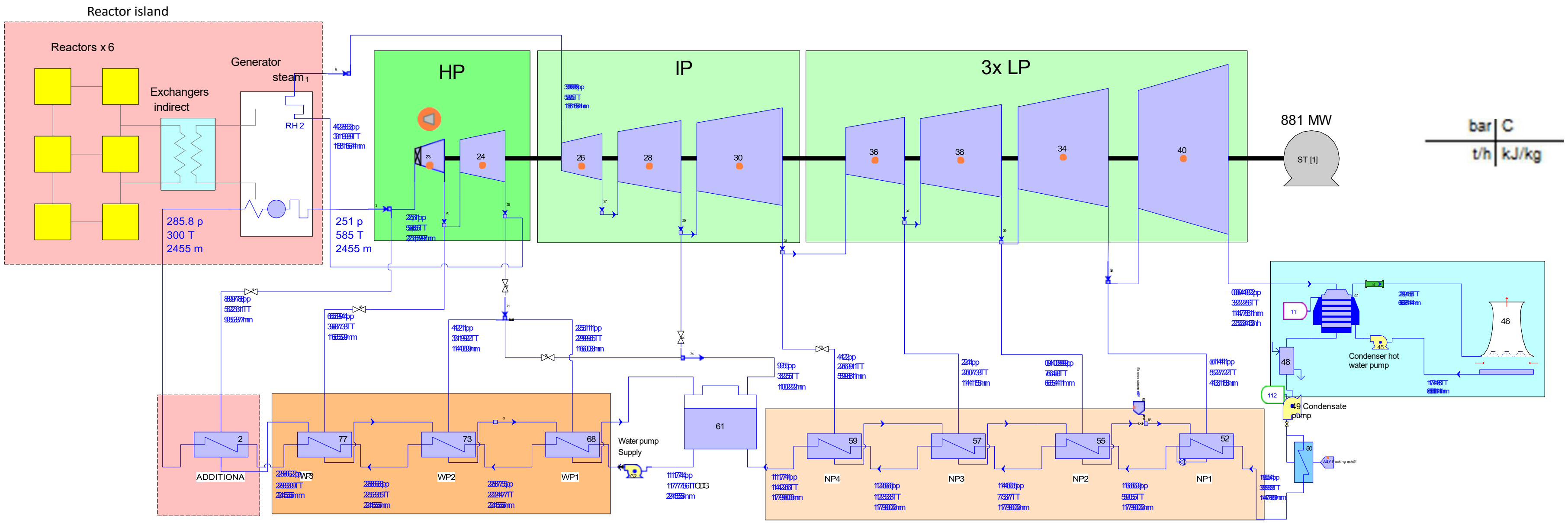

Figure 33 Thermal cycle of a 900 MW unit with a nuclear reactor as a steam source

The annual projected production and consumption of the analysed unit were determined for an availability level of 84.2%. This is the availability presented in the Polish Nuclear Power Programme. This level is close to the European average (82.5%). Similar availability rates have been reported in recent years in the Czech Republic (83.9%) and Switzerland (83.4%), where there are relatively few reactors, 6 and 4 respectively.

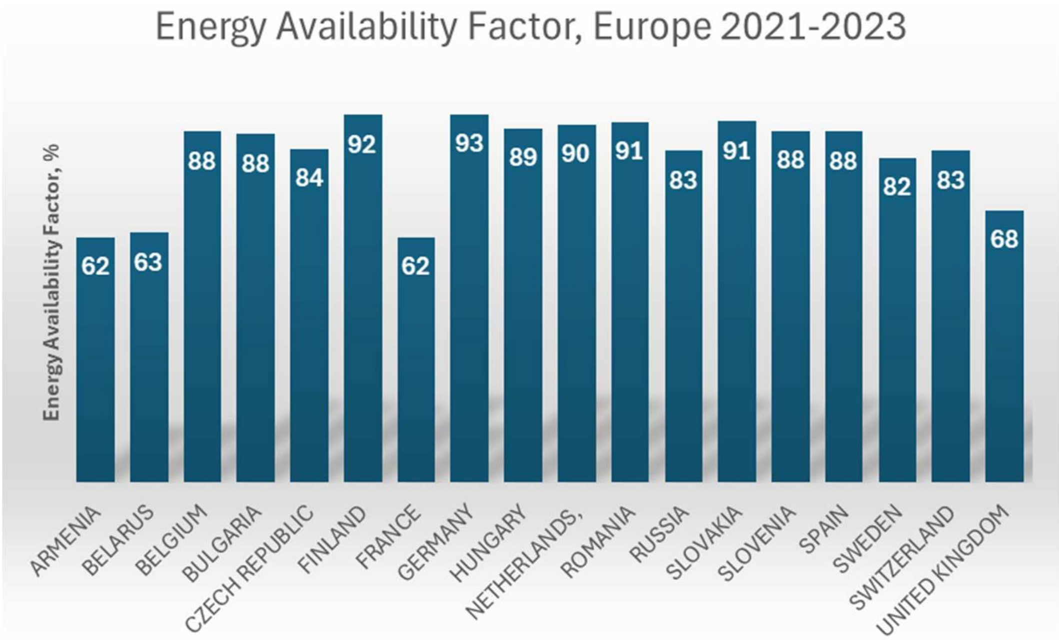

Figure 34: Nuclear power plant availability rate in Europe for 2021–2023, according to the IAEA[16]

Table 12: Forecast annual output of the 900 MW unit using a nuclear reactor.

Parameter	Unit	Value
Availability	%	84.2
Electricity production	GWh	6,498
Electricity sales	GWh	6,019
Water replenishment for the cooling system	thousand tonnes/year	9,324
DEMI water replenishment	thousand tonnes/year	130

The values presented will form the basis for an analysis of the economic efficiency of the project described, which will be presented in the next section of the study.

16 https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsEnergyAvailabilityFactor.aspx

6.6. Electrical system

The aim of the Coal-to-Nuclear project is to replace coal combustion with a nuclear reactor after approximately 20 years of operation of unit 6 of the Opole Power Plant, with the intention of continuing operation for several more decades.

Hypothetically, such an operation may be technically feasible, but due to the standards applied by technology suppliers, including those relating to safety assessment and approvals for use in nuclear facilities, it is only possible to a limited extent or is procedurally difficult, and therefore (potentially) economically unjustified.

Apart from risks related to standards and certification of the Facility, another risk for the implementation of the indicated project is the technical condition of the infrastructure and the possibility of its continued use throughout the entire project lifetime.

A typical power supply system for large power units, corresponding to the needs of nuclear power units and conceptually similar to the solution used in unit 6 of the Opole Power Plant, is shown in the figure below.

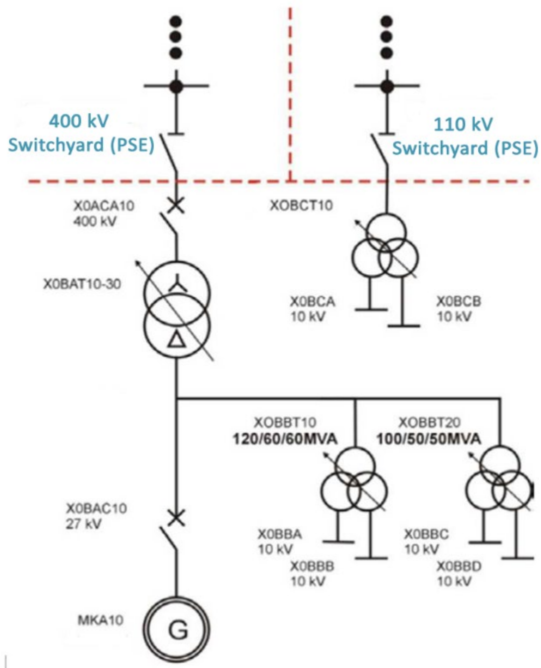

Figure 35 Conceptual electrical diagram of large power units operating in Poland.

6.6.1. Generators

The existing generator of Unit 6 of the Opole Power Plant is a unit that meets the current technical standards for this type of infrastructure. By adjusting the power of the new nuclear unit and its technical parameters to ensure a similar mechanical power to the turbine drive, the generator of unit 6 could potentially (from an electrical point of view) be used in the Coal-to-Nuclear project.

The generator of unit 6 has a power of ~1230 MVA and a rated voltage of ~27 kV.

The possibility of using the generator beyond matching its technical parameters to the new design requires that the technical condition of the unit allows for this. It is therefore necessary to operate unit 6 in a regime that ensures its longer operation.

It is planned to use only the generator, while assuming a complete replacement of accessories, transformers, measuring systems and the excitation system, with adaptation to the requirements for the maintenance of the generator/generating facility in cooperation with the power system, valid at the time of project implementation.

It is also permissible to keep the existing generator switch in operation, provided that its technical condition allows it.

6.6.2. Busbars

It is envisaged that the existing medium-voltage busbars will be used, assuming that the control and measurement equipment will be replaced, including the compressed air overpressure system.

The parameters of the busbars are adapted to the parameters of the generator and, while maintaining the power of the unit, are sufficient for the needs of the project.

6.6.3. Transformers (for internal use)

It is envisaged that the existing on-site transformers with a capacity of ~90/45/45 MVA could be utilised in the 'Coal-to-Nuclear' project, provided that their technical condition at the start of the project allows for their continued operation for a minimum of 20 years.

Based on the experience of the national energy sector, properly maintained transformer units are capable of operating without failure for over 50 years, and current methods of failure risk assessment, combined with regular testing, make it possible to detect potential failures before they occur.

However, the project envisages the replacement of transformer equipment, including cooling system components and technological safeguards, dehumidifiers, current transformers, etc.

6.6.4. Switchgear

Due to the anticipated age of the switchgear at the start of the project (>20 years) and its potential incompatibility with future energy consumption needs, it is assumed that new switchgear for own needs will be used in a system adapted to the needs of the new facility and the requirements for power supply reserves.

6.6.5. Block Transformers

It is anticipated that existing single-phase block transformers with a capacity of ~450 MVA each will be used in the Coal-to-Nuclear project. It is anticipated that the transformers will operate without failure for over 50 years, provided that the units are properly operated and inspected.

The advantage of the existing energy conversion system for units 5 and 6 is that it has two identical sets of single-phase transformers and one backup unit. Using the currently available methods for assessing the likelihood of transformer failure, this system allows the unit in poorer technical condition to be replaced with the backup unit and repaired without interrupting the power plant's operation.

The solution used in units 5 and 6 of the Opole Power Plant is optimal for economic and operational reasons, given the capacity of the units[17].

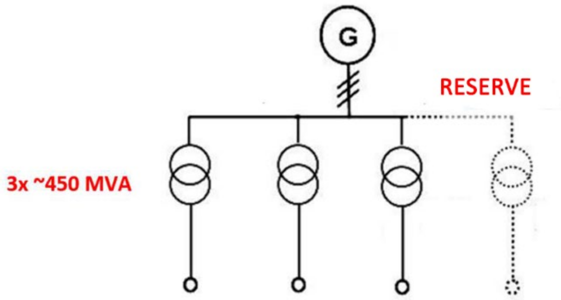

Figure 36 Power output using three single-phase block transformer units and one reserve unit (shared with the second twin unit).

The three single-phase units currently operating at the Opole Power Plant (for one unit) and one reserve unit are a solution with a lower investment cost compared to a three-phase reserve unit, while offering similar reliability.

Basic (accepted) technical data for single-phase block transformer units:

- Rated power: 450MVA
- Transmission ratio: 425/√3 / 27 kV
- Rated current: 1834 / 16,667 A
- GN insulation level: Li 1300 / AC 570 kV
- Insulation level DN: Li 170 / AC 70 kV
- Connection group: YNd11 for 3 units).
- Cooling type: ODAF (forced oil circulation radiators)

6.6.6. Block switch (circuit breakers at the front end of block transformers)

It is anticipated that the existing 400 kV block switch could be utilised in the Coal-to-Nuclear project, provided that its technical condition allows for this. The existing front field of block transformers is implemented in the form of a GIS (Gas-insulated switchgear) field, in an indoor design. Solutions of this type have a service life of up to ~50 years.

The field should undergo a thorough renovation as part of the project. Additionally, due to the fact that we are dealing with a GIS field, which in the event of a failure is characterised by a long downtime (the delivery of replacement equipment requires considerable time), it is recommended to ensure a reserve of basic spare parts on site, which will limit the possible downtime of the unit in the event of a failure.

6.6.7. Backup power transformers for internal and general use

It is anticipated that existing backup power transformers will be used both during the implementation of the Coal-to-Nuclear project to supply power to the reactor construction site and during operation for backup power supply.

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17 Study by ABB, Aleksander Gul, "Modern ABB solutions for power output for 1.0 GW nuclear power plant units"

6.6.8. Emergency power switchgear

There is a potential possibility of using the existing backup power distribution board with the option of convenient replacement during the operation of the modernised unit. The backup switchgear does not directly participate in supplying power to the power plant during its normal operation, which results in slower degradation (lower operating temperatures, fewer switching processes).

6.6.9. Power transmission lines

There is a potential possibility of using the existing 400 kV overhead line, connecting to the 400 kV switchyard of the Dobrzeń station, for the purpose of power transmission from the Coal-to-Nuclear project. Overhead power lines, provided that their operation is of sufficiently high quality, including in terms of anti-corrosion protection of tall structures, can be successfully operated without failure for well over 50 years.

As part of the Coal-to-Nuclear project, a comprehensive review of the line is planned, as well as replacement of the line's EAZ automation, adapting it to the current requirements of the Transmission System Operator at the time of project implementation.

6.6.10. The 110 kV emergency power supply system for the facility

The Opole Power Plant has three 110 kV overhead lines for backup power supply. It is assumed that at the start of the project, units 1 - 4 will already have been decommissioned, while the 110 kV switchgear and the entire 110 kV power supply system will be retained, including the 110 kV cable line currently providing backup power to units 5 and 6.

In order to improve the security of the nuclear facility's backup power supply, it is proposed that, after the decommissioning of units 1 - 4, one of the freed-up 110 kV lines be used to provide additional power to one of the backup power transformers, thus maintaining two (2) 110 kV lines in target operation.

6.6.11. Connection points to the National Power System

The connection point of the Opole Power Plant to the power system is the Dobrzeń power station. The station does not currently require modernisation.

If the existing power output and backup power supply systems are retained, the scope of the station modernisation will only require the fields to be adapted to the operator's standard for the year of project implementation and the possible replacement of equipment, including, in particular, current and voltage transformers and surge arresters. The EAZ automation system will also be replaced.

Power infrastructure, including power stations and substations operating at voltages of up to 400 kV, are technologically well-established solutions with a wide market of suppliers offering various technological solutions. In the case of this type of infrastructure, it is difficult to identify technological limitations that would prevent expansion, and any limitations are related to costs and implementation time. In the case of the project covered by this study, the implementation time for the construction of nuclear reactors is significantly longer than for typical grid-based power station modernisation projects. Consequently, no risk is anticipated in relation to the inability to expand the power station.

6.6.12. Legal Framework

Although units 5 and 6 of the Opole Power Plant are existing units under current regulations, the implementation of the Coal-to-Nuclear project will constitute a significant modernisation of these units, which will necessitate their adaptation to current technical and regulatory requirements.

In accordance with the Energy Law (Journal of Laws 2024.0.266) in force (as of the date of preparation of this technical description), an entity applying for connection to the grid must submit an application for determining the conditions for connection to the grid, hereinafter referred to as the "Connection Conditions", to the energy company to whose grid it is applying for connection, attaching the relevant documents and paying an advance payment towards the grid connection fee in the amount of PLN 30 (GBP £6.14) for each kilowatt of connection power specified in the application for determining the connection conditions. The amount of the advance payment may not exceed the amount of the anticipated grid connection fee and may not exceed PLN 3,000,000 (GBP £613,695). In the case of this project, due to its implementation based on existing connections, an advance payment may not be required, which results from the small scope of work involved in the connection.

Due to the size of the facility and the location of the connection point, the operator will provide a connection assessment, examining the impact of the modernisation of generation sources (power plants) on the power system. In this case, it is advantageous for the new project to be implemented as a change of primary energy source rather than as a new installation.

The Connection Conditions will specify the investment obligations of each party, including technical parameters, property boundaries, and electricity billing arrangements.

The new nuclear unit will be classified as a synchronous generation module type D (power above 75MW and connection voltage above 110kV) and will be required to comply with network codes, including the NC RfG (Network Code Requirements for Generators - NC RfG) together with its Polish implementation (as set out in Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators).

7. Estimated capital expenditure

7.1. CAPEX structure

In international nomenclature, CAPEX investment costs are divided into successive levels of complexity as follows:

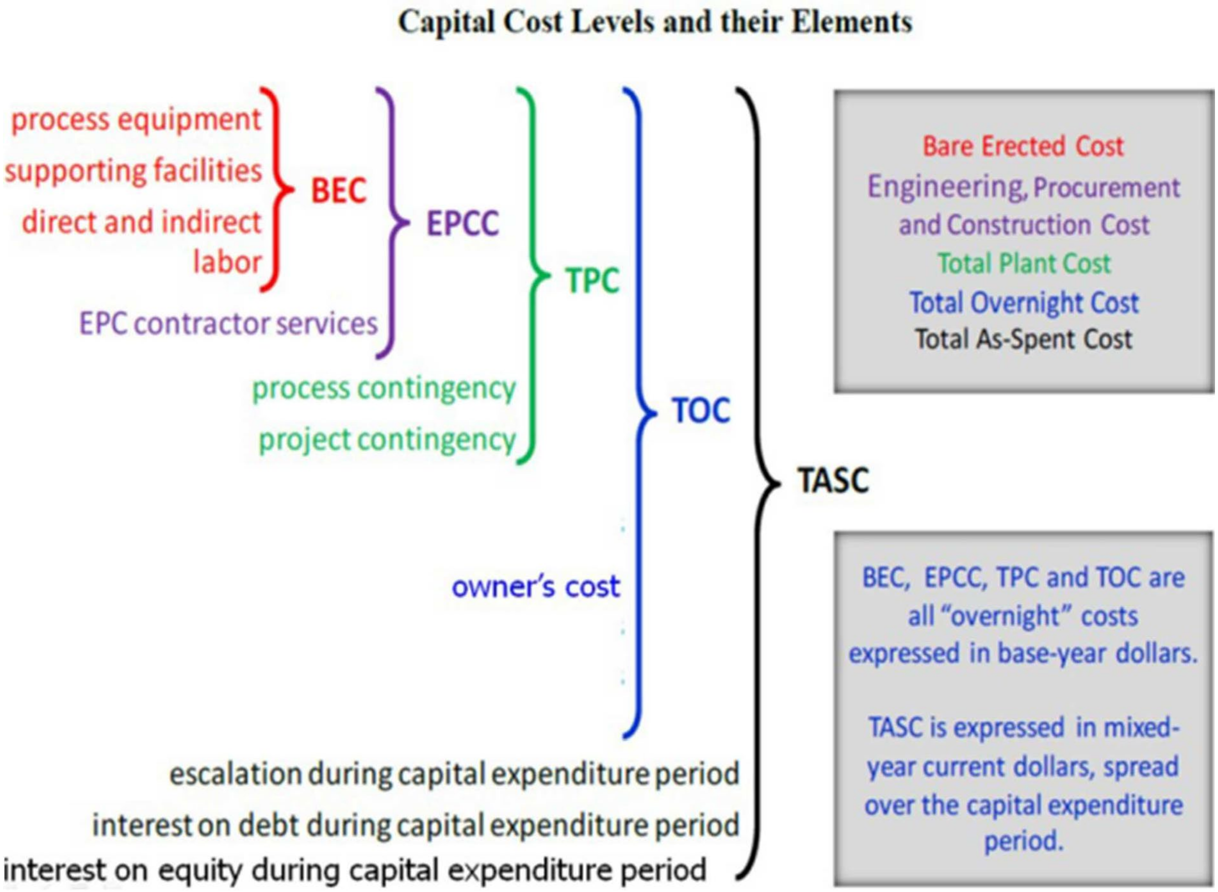

Figure 37 CAPEX structure

Data source: NETL, April 2011. Quality guidelines for energy systems studies: cost estimation methodology for NETL assessments of power plant performance. U.S. Department of Energy, National Energy Technology Centre, Pittsburgh, PA (Report DOE/NETL-2011/1455)

- BEC – these are so-called "hard, direct" costs, covering the supply of materials and equipment, labour costs and equipment costs.
- EPCC – these costs include BEC and the indirect costs of the EPC General Contractor (e.g. project coordination and management, certification and acceptance by Certification and Supervision bodies, preparation and maintenance of construction facilities, utilities during assembly, training, insurance, commissioning, etc.).

- TPC – these costs include EPCC and the contractor's risk costs and financial reserves for the project.
- TOC – these costs include TPC and the Investor's costs (e.g. the Investor's implementation team, Contract Engineer services, warranty measurements, fees, expert opinions, consulting, insurance, etc.).

Note: all CAPEX cost groups listed above are expressed in fixed prices.

- TASC – these costs include TOC and are converted into variable prices over the duration of the investment (from the construction period to commissioning), taking into account capital costs, interest and contract indexation.

This section of the study estimates the level of capital expenditure in the TOC cost group.

7.2. Methodology

In order to determine the costs of constructing six new MS-SMR Kairos Power 150 MWe units at the Opole Power Plant, the following steps were taken:

- The percentage distribution of the costs of individual CAPEX elements was determined according to an industry study;
- The unit cost of constructing a Kairos Power 150 MW MS-SMR unit in the Greenfield formula was determined on the basis of industry studies;
- The remaining costs associated with the location of new Kairos Power 150 MW MS-SMR units at the existing power plant were estimated, taking into account the savings in this respect.
- An estimated CAPEX for the construction of six Kairos Power 150 MWe MS-SMR units at the Opole power plant was developed.

7.3. Determination of the percentage distribution of investment expenditure

Below is a calculated breakdown of Capex for individual cost groups of the Kairos Power 150 MWe MS-SMR unit in the Greenfield formula, based on the document "Techno-Economic Analysis of Advanced Small Modular Nuclear Reactors" developed by Colorado State University and published in 2023. The percentage breakdown was calculated based on the chart in "Figure 1.".

Table 13 Percentage distribution of estimated capital expenditure for the MS-SMR unit

No.	Specification of TOC costs (1 Kairos Power 150 MWe MS-SMR unit) Greenfield	% share in investment capital.
1	Buildings and structures	9.3 %
2	Engine room equipment	17.2 %
3	Reactor equipment	23.3 %
4	Electrical equipment	5.2 %
5	Other equipment	2.8 %

No.	Specification of TOC costs (1 MS-SMR Kairos Power 150 MWe unit) Greenfield	% share in investment capital
6	Heat discharge system	2.0 %
7	Total indirect costs of the Owner and Contractor	40.2 %
8	Total share in investment capital	100.0 %
9	Direct costs (Nos. 1 - 6) % TOC	59.8 %
10	Indirect costs (No. 7) % TOC	40.2 %

Data source: estimation based on the document "Techno-Economic Analysis of Advanced Small Modular Nuclear Reactors"; Colorado State University; 2023.

7.4. Determination of the unit cost index for the construction of the Kairos Power 150 MWe MS-SMR unit according to industry studies

The study "Techno-Economic Analysis of Advanced Small Modular Nuclear Reactors" provides the following unit TOC costs for the construction of nuclear units:

- PWR12 – USD 4,599/kWe
- LW-SMR – USD 4,844/kWe
- MS-SMR – USD 3,985/kWe

From the above values, it was decided to use the percentage relationship between the costs of LW-SMR and MS-SMR. It states that the unit costs of TOC for MS-SMR units constitute approx. 82.2% of the construction costs of LW-SMR units.

The above unit values have not been used directly in this study, as it has now been confirmed that they are significantly underestimated. For example, the costs of a PWR12 class unit should be at least around USD 10,000/kWe, as presented in similar DESIRE studies for the Kozienice and Dolna Odra locations.

The projected costs of LW-SMR blocks have risen sharply in recent years. This is due to the impact of the pandemic, the tense geopolitical situation and the fact that as the technology is refined, its costs are also rising, thus overturning earlier optimistic CAPEX forecasts.

MS-SMR technology is at an earlier stage of technological and market development than LW-SMR, so it can be assumed that the projected CAPEX will also increase significantly over time as the technological solutions are refined.

The latest industry study, "Small Modular Reactors, Still Too Expensive, Too Slow and Too Risky" by the Institute for Energy Economics and Financial Analysis, published in 2024, presents the latest unit cost forecasts for LW-SMR units as follows:

- NuScale (77 MWe) – $21,561/kWe
- BWRX-300 (300 MWe) – $12,347/kWe

Since the Kairos Power MS-SMR unit has an electrical output of 150 MWe, it was decided to estimate the cost of a hypothetical 150 MWe LW-SMR unit as the average value between the costs of NuScale and BWRX-300. This value was USD 16,954/kWe.

As described and accepted above, the costs of MS-SMR units may constitute 82.2% of the costs of LW-SMR units, hence the estimated unit value of the construction of the Kairos Power 150 MWe MS-SMR unit was determined as follows:

Estimated unit cost of a 150 MWe LW-SMR unit: USD 16,954/kWe

↓

Ratio of MS-SMR to LW-SMR unit costs 82.2%

↓

Unit cost of constructing a 150 MWe MS-SMR unit: USD 14,000/kWe

16,954 x 0.822 = 13,936 USD/kWe ≈ **14,000 USD/kWe in the Greenfield formula**

7.5. Determination of additional costs and savings related to the location of the planned investment

The table below presents additional costs (increasing CAPEX), savings (reducing CAPEX) and potential avoided costs resulting from the location of the investment at the Opole Power Plant.

➢ **Additional costs**

The following additional costs must be incurred in order to carry out the investment at the Opole Power Plant

- Costs of adapting the existing facility to work with the nuclear island.

  These costs amount to approx. 7.4% of the total investment expenditure. They include the costs of:
  - connecting the steam system from 6 reactors to the existing turbine set
  - connecting the nuclear island to the existing heat discharge system
  - costs of clearing the site
  - costs of unforeseen work, which are difficult to estimate at the preliminary feasibility study stage.

These costs were estimated at PLN 2,545 million net (~£520,600).

The costs of expanding the electrical, control and measurement equipment and automation systems, and other systems and installations have been included as a balance of costs and savings in other CAPEX items.

➢ **Savings**

- Savings from the use of the existing technological system of the unit's engine room. (turbine set and auxiliary installations)

  These savings were estimated at PLN 8,669 million net (~£ 1,800,000).

- Savings from the use of existing buildings and structures. (engine room building and other buildings and structures)

  These savings have been estimated at PLN 2,343 million net (~ £480,000).

- Savings from the use of the existing heat discharge system (cooling tower and cooling water pipelines)

  These savings are estimated at PLN 1,008 million net (~ £206,000).

- Savings from the partial use of existing electrical installations, control and measurement equipment, other facility installations and the use of the power output system.

  These savings are estimated at PLN 2,016 million net (~ £410,000).

➢ **Potential avoided costs** (group outside the scope of nuclear power plant construction indicators)

Below is a summary of the costs avoided by using the location at the Opole Power Plant compared to a location not connected to the existing energy and logistics infrastructure. The potential avoided costs are based on the assumptions made by the author of the study on the basis of other nuclear power plant locations with different location conditions. Therefore, average hypothetical estimate values have been used in this calculation.

- The costs of constructing a power transmission line from the foreshore to the PSE station were assumed to be 1 km of line. These savings were estimated at PLN 10 million net (~ £2 million).
- Cost of constructing a water intake from the river – assumed to be 1 km of intake. These savings were estimated at PLN 40 million net. (~ £8.2 million)
- Costs of the access road - assumed to be 25 km. These savings were estimated at PLN 125 million net (~ £25.5 million).
- Costs of a single-track railway line – 25 km assumed. These savings were estimated at PLN 625 million net (~ £128 million).
- The costs of constructing the operator's power station, where the project is located some distance from existing stations, are estimated by the Power Grid Operator; depending on the terms of the bilateral agreement, the investor may contribute to these costs. The cost of such a station may amount to approximately PLN 70 million net (~£14.5 million)

7.6. Determination of CAPEX

➢ **Assumptions**

- All amounts given below are exclusive of VAT and are presented in constant 2025 prices.
- Based on industry publications presented in sections 7.4 and 7.3 of this study, the costs were divided into individual groups on a percentage basis and the unit level of capital expenditure for the construction of the Kairos Power 150 MWe MS-SMR unit was estimated at USD 14,000 net/1 kWe.
- Next, additional costs and savings resulting from the location of the investment at the Opole Power Plant were determined, taking into account savings exceeding the scope of the unit indicator for the construction of MS-SMR units. Details are presented in section 7.5 of this study.
- Elements outside the scope of the unit indicator for the construction of MS-SMR class blocks, as well as additional costs and savings, were estimated on the basis of publicly available market price bulletins for works and investment facilities published by such publishers as Bistyp and Sekocenbud, as well as price indicators from B.S.P.i R Energoprojekt - Katowice S.A., developed over many years of experience in designing and estimating the costs of installations similar in size and technical parameters.
- The following exchange rate was used for currency conversion: 1 USD = 4 PLN.
- Power of the Kairos Powet MS-SMR block used for calculations: 150 MWe (gross)

This study is at the preliminary feasibility study stage. In accordance with the AACE International Recommended Practice classification system, the expected accuracy of the valuation range is presented in the table below which shows the accuracy of the valuation range between the concept stage and the actual feasibility study:

Table 14 Classification of CAPEX estimation accuracy according to AACE International Recommended Practice

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Table 1 – Cost Estimate Classification Matrix for Process Industries

- **Calculations**

The total block costs for six Kairos Power 150MWe MS-SMR blocks were determined as follows:

USD 14 million/MWe x 150 MWe x 6 units = 14 x 150 x 6 = USD 12,600 million net

The dollar exchange rate according to the National Bank of Poland in 2024 and 2025 fluctuated around PLN 4. For the purposes of this study, this standardised value was adopted.

After converting the above at a rate of 1 USD = 4.0 PLN, we obtain: 25,000 million USD

x 4.0 PLN/USD = **50,400 million PLN net**

The above cost was then divided into individual components according to the assumptions presented in the above points, based on industry information, taking into account additional costs and savings related to the location of the facility in El. Opole.

The results of the calculation are presented in the table below.

Table 15 Estimated costs of constructing six MS-SMR 150MWe units at the Opole Power Plant

No.	Specification of TOC costs (6 MS-SMR Kairos Power 150 MWe units) Brownfield	Value [PLN million net]
1	Buildings and structures	2,344
2	Engine room equipment	0
3	Reactor equipment	11,743
4	Electrical equipment	1,310
5	Other equipment	706
6	Heat dissipation system	0
7	Costs of adapting the existing facility	2,545
8	Total indirect costs of the Owner and Contractor	16,297
8	Total share in investment capital	34,945
10	Direct costs (Nos. 1 - 8)	18,648
11	Indirect costs (No. 9)	16,297
	Unit indicator USD (1 USD = 4 PLN)	9,707 USD/kWe

Data source: own calculation

The above calculations do not include avoided costs, as they do not affect CAPEX, do not need to be incurred and are outside the scope of the nuclear power plant construction index, so they do not reduce the above-mentioned costs.

However, the avoided costs represent added value in light of the location of the investment at the Opole Power Plant. Their level varies greatly depending on the potential location of the nuclear power plant

.

Therefore, it is not possible to determine the exact savings, as such calculations can only be made in relation to another specific location.

The table below presents avoided costs based on average, hypothetical estimate values:

Table 16 Potential avoided costs based on hypothetical bill of quantities values

No.	Potential avoided additional costs related to the location of the investment in the Opole Power Plant	Value in PLN million net
1	Costs of constructing a power transmission line from the forefield to the PSE station; for Greenfield, 1 x 1 km was assumed	10
2	Costs of constructing a water intake from the river - 1 km intake assumed	40
3	Access road costs - 25 km assumed	125
4	Costs of a single-track railway line - assumed 25 km	625
5.	**Total potential cost savings**	**800**

Data source: own calculation

7.7. Comparison of Greenfield vs. Brownfield

A comparison was made of the costs of constructing six Kairos Power 150 MWe MS-SMR units in Opole versus Greenfield. The results are presented in the table below:

Table 17 Estimated construction costs of 6 Kairos Power 150 MWe units – Brownfield vs Greenfield

No.	Specification of works (6 Kairos Power 150 MWe units) (total 900 MWe)	Brownfield Value in PLN million net	Greenfield Value in PLN million net
1	Buildings and structures	2,344	4,687
2	Engine room equipment	0	8,669
3	Reactor equipment	11,743	11,743
4	Electrical equipment	1,310	2,621
5	Other equipment	706	1,411
6	Heat dissipation system	0	1,008
7	Costs of adapting the existing facility - adaptation of the steam system - connection to the heat discharge system - site clearance - other	2,545	0
8	Total indirect costs of the Owner and Contractor	16,297	20,261
9	Costs of constructing the power line from the front field to the PSE station; for Greenfield, 1 x 1 km	0	10
10	Costs of constructing a water intake from the river - 1 km intake assumed	0	40
11	Access road costs - 25 km assumed	0	125
12	Costs of a single-track railway line - assumed 25 km	0	625
13	Total investment expenditure	34,945	51,200

As can be seen from the table above, the estimated costs of Brownfield are approximately 32% lower than those of Greenfield. It should be noted that social aspects (employment of local residents at the power plant) and infrastructure aspects (use of energy and transport infrastructure, which would become redundant if the power plant were to be decommissioned) also speak in favour of the Brownfield location in Opole.

Indirect costs for the Brownfield option were assumed to be a similar percentage of total investment costs as for the Greenfield option, but were increased by an additional 30% due to the more difficult investment process associated with the reconstruction of the existing facility.

The above comparison is based on the assumption that for Brownfield we use one existing turbine unit working with six new MS-SMR reactors, each with a capacity of 150 MWe.

8. An analysis of economic efficiency for the specified assumptions, supplemented by an analysis of investment risk (sensitivity analysis regarding changes in the legal and economic environment),

8.1. Subject, methodology and purpose of the analysis

A DCF economic model was prepared for the project in question, using the FCFF (free cash flow to the firm) formula. As part of the analysis, the LCOE indicator was calculated, which determines the minimum price of electricity that balances the production costs in a given type of generation unit. It is also the minimum price at which the sale of energy allows the investment to exceed the break-even point.

Standard profitability indicators such as NPV and IRR were not calculated because the LCoE indicator makes it easier to compare different technologies and does not require assumptions about future electricity prices. Forecasting energy prices 70-80 years into the future, given the current realities and changes in the markets, is subject to a large margin of error.

LCOE [PLN/MWh] Levelised Cost of Energy - determines the average cost of producing 1 MWh of electricity, calculated according to the formula:

$$\text{LCoE} = \frac{\sum_{t=1}^{n} \frac{(I_t + M_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Figure 38 Formula for determining LCoH

where:

I_t - CAPEX investment expenditure in year t

M_t - OPEX costs in year t

r – pre-tax discount rate

E_t - heat production in year t

The economic analysis also includes an analysis of the sensitivity of LCoE to key variables in the economic calculation.

8.2. Assumptions

- The analysis period is 65 years, consisting of:
  - Investment implementation period: 5 years
  - Operational period: 60 years
- The calculation is made on an annual basis, in net prices (excluding VAT) and in real terms (without taking inflation into account).
- CIT income tax rate – 19%
- RV – residual value calculated as the net value of fixed assets

8.2.1. Investment expenditure

Capital expenditure is presented in detail in Chapter 7. The table below shows the capital expenditure schedule.

Table 18 Schedule of investment expenditure, PLN million net

Capital expenditure in	TOTAL	1	2	3	4	5
PLN million net	**34,945**	8,736	6,989	6,989	6,989	5,242

8.2.2. Discount rate

Pre-tax WACC discount rate in real terms equal to **6.98%**

$$WACC_{nom} = K_W * k_W * + K_{0*} k_0 * (1 - T_c)$$

K_w - cost of equity (15.3%)

$_{KW}$ = Risk-free rate (5.24% [18]) + Market risk premium (5.15% [19]) + Project risk premium (2%)

k_w - equity share (30%)

K_0 – cost of debt capital (7.24%)

$_{KO}$ = Risk-free rate (5.24%) + Debt margin (2%) $_{KO}$ – share of debt capital (70%)

T_c – corporate income tax (19%)

$$WACC_{realny} = \frac{WACC_{nom} + 1}{CPI + 1} - 1$$

CPI – inflation over a 5-year period (assumed to be 2.5% [20]) Details

of the WACC calculation are presented in the .xslx model

8.2.3. Exchange Rates

The EUR/PLN exchange rate was adopted on the basis of data published on the website nbp.pl, "Macroeconomic forecasts by professional forecasters. Results of the NBP Macroeconomic Survey, March 2024 round," at 4.3 as the median of forecasts for 2024-2026, and was left unchanged until the end of the calculation period.

The National Bank of Poland (NBP) set the exchange rate of the US dollar (USD) against the Polish zloty (PLN) on Friday, 22 March 2024, at PLN 3.9928, which rounded to two decimal places gives a value of PLN 4.00/USD. According to other forecasts, including those by Blomberg, a similar EUR/USD ratio will be maintained in the coming quarters, which is why analyses assume that this trend will continue.

[18] Announcement by the President of the Energy Regulatory Office; Q3 2024
[19] Damodaran - Equity risk premium Poland 01.07.2024
[20] Inflation target of the National Bank of Poland and the Monetary Policy Council

Table 19 Exchange rate forecast

Currency	Unit	Value
US dollar	[PLN//USD]	4.0
Euro	[PLN/EUR]	4.3

8.3. Operating costs

$$OPEX = variable\ OM\ cost + fixed\ OM\ cost\ per\ year$$

The economic analysis covers the following operating costs:

- Fuel costs
- Waste disposal costs
- Water replenishment costs (for the cooling system and DEMI)
- Repairs and upgrades
- Property insurance
- Civil liability insurance for nuclear damage
- Property tax
- Costs of salaries and employee benefits
- Costs of future decommissioning of the unit (decommissioning fund)

8.3.1. Fuel cost

Fuel costs were calculated based on the volume of electricity produced, expressed in MWh. The annual production of the unit was assumed on the basis of technological balances from point 6.5, with an assumed base availability, it will produce **6,498 GWh** of electricity annually.

In this analysis, the final LCOE of the Brownfield project was compared with the Greenfield investment, which meant that costs had to be estimated in two variants. It was assumed that the capacity of the Greenfield variant would be 900 MW (6*150 MW), i.e. several MW more. Similar unit availability was assumed, so the final electricity production for Greenfield will be **6,638 GWh.**

The unit price of nuclear fuel according to various sources over the years is shown in the graph and table below.

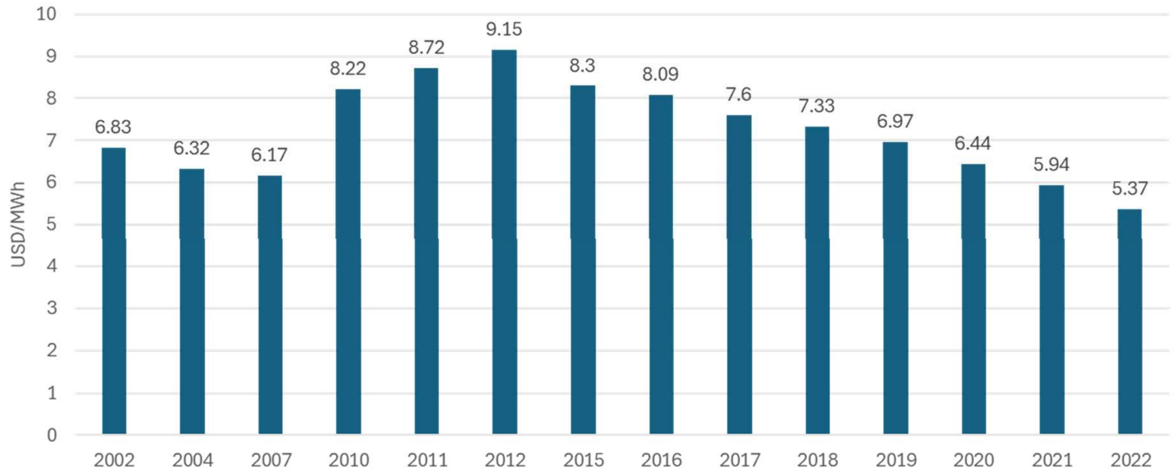

Figure 39 Nuclear fuel costs over the years

Source: NEI, Nuclear Costs in Context, 2023

Table 20 Sources of nuclear fuel prices

Other sources	Value	Unit/year
IAEA; Economic Assessment of the Long-Term Operation of Nuclear Power Plants	7.00	USD_{2018}/MWh
MIT; Overnight Capital Cost of the Next AP1000	6.15	USD_{2022}/MWh
MIT; 2024 Total Cost Projection of Next AP1000	6.25	USD_{2023}/MWh

For the calculations, the unit cost of fuel expressed in USD/MWh was assumed, based on a study by the Nuclear Energy Institute[21] to be **5.37 USD_{2022}/MWh** (after taking into account US inflation, fuel costs will amount to 5.73 USD/MWh). Finally, the annual fuel costs will amount to approximately **PLN 149 million for Brownfield and PLN 152 million for Greenfield.**

8.3.2. Costs of disposing of spent nuclear fuel

Fuel disposal costs were also calculated based on the amount of electricity produced. The unit indicator was adopted in accordance with the following studies:

- *A. Strupczewski, Analiza i ocena kosztów energii elektrycznej z różnych źródeł energii w Polsce – (Analysis and assessment of electricity costs from various energy sources in Poland), NCBJ, 2015.*
- *K. Kołacińska, R. Sasin, Analiza kosztów i korzyści wdrożenia energetyki jądrowej w Polsce – (Analysis of the costs and benefits of implementing nuclear energy in Poland), Energy Market, 2016.*

where the rates are 2.33 USD_{2015}/MWh and 2.17 $EURO_{2016}$/MWh, respectively.

A rate of **USD 3.53/MWh** (averaged value after indexation) was used for the analyses. This amount includes the removal, storage and disposal of spent fuel. Converted to annual values, the cost of fuel disposal is approximately **PLN 92 million** for Brownfield and **PLN 94 million** for Greenfield.

21 *Overnight Capital Cost of the Next AP1000; Koroush Shirvan; March 2022*

8.3.3. Water replenishment costs

Raw water and DEMI consumption was determined in section 6.5. A rate **of approx. PLN 10/t** was used to calculate DEMI water costs; a similar rate was used in the facility covered by KM4.1 Preliminary feasibility studies for Generation III reactors.

For raw water, it was assumed that raw water for cooling system replenishment would be taken from the river. The unit rate for raw water was set at **PLN 1.5/t** on the basis of the Council of Ministers Regulation on water abstraction rates[22] , which also includes the costs of physical abstraction of water from the river. The annual costs are as follows:

Table 21 Comparison of water replenishment costs

Cost	Brownfield, PLN million	Greenfield, PLN million
DEMI water	1.3	1.4
Raw water	14.0	14.3

8.3.4. Salaries and employee benefits costs

The standard number of people employed at a nuclear power plant (1 GWe reactor) ranges from 500 to 800 permanent employees for regular operation and maintenance.[23] Other sources[24] indicate a figure of 600 employees, although for AP-1000 units, in extreme cases, the number of staff can be reduced to around 400. Currently, the Opole power plant employs 1,300 people[25] who work in units 1-4 (a total of 1,532 MW) and 5-6 (1,810 MW), which translates into 0.4 full-time equivalent/MW. Therefore, there are approximately 360 people per 905 MW unit. Ultimately, the analysis assumed a workforce of **400 people**.

The gross remuneration of one person was assumed to be PLN 15,000 per month, which is consistent with information on current earnings in this sector. The level of social security and other benefits payable by the employer was assumed to be 21%.

The annual costs of salaries and employee benefits amount to approximately **PLN 85 million** in both variants.

8.3.5. Property insurance costs

The property insurance costs for the Brownfield option were calculated in relation to the valuation of the target nuclear unit, i.e., the sum of capital expenditure on the nuclear part and the valuation of the existing usable condition (excluding the boiler house, coal feeding system and flue gas discharge and purification system), which amounts to approximately PLN 5.3 billion.

Ultimately, property insurance costs were assumed to be 0.35% per annum of the total valuation of the target nuclear unit, which amounted to approximately PLN 40.4 billion. Annual insurance costs will amount to approximately **PLN 141 million.** The insurance rate was adopted based on data for existing 1000 MW coal-fired units.

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22 *REGULATION OF THE COUNCIL OF MINISTERS of 26 October 2023 on unit rates for water services*

23 *https://info.westinghousenuclear.com/poland/news-and-insights/kariera-w-przemysle-jadrowym*

24 *Overnight Capital Cost of the Next AP1000; Koroush Shirvan; March 2022*

25 *https://nto.pl/jubileusz-30lecia-elektrowni-opole-zapewnia-ona-8-procent-krajowej-produkcji-pradu-w-polsce/ar/c317830699#:~:text=The%20Opole%20power%20plant,one%20of%20the%20most%20important,chairman%20of%20the%20management%20board%20of%20Polish%20G*

In turn, for the Greenfield variant, insurance was calculated on the total investment outlays using the same percentage rate, which translated into an annual cost of PLN 179 million.

8.3.6. Civil liability insurance for nuclear damage

Civil liability insurance costs are calculated based on the assumed maximum amount of insurance coverage for nuclear damage and a fixed percentage of this amount, paid annually during the period of operation. The maximum amount covered by insurance is PLN 1,350 million (i.e. 300 million SDR in accordance with the Atomic Energy Act) and the annual insurance premium (as a percentage of the maximum amount covered by insurance) is 0.25%. The final insurance value, at an assumed SDR exchange rate of PLN 5.28, is approximately **PLN 4 million** in both variants.

8.3.7. Property tax

The property tax was calculated as a percentage of the value of the structures, which account for approximately 10% of the valuation of the target nuclear block (capital expenditure on the nuclear part plus the valuation of the existing usable condition). The tax rate on structures, in accordance with current regulations, is 2% per annum of the value of the structures. Ultimately, the annual tax costs amount to approximately **PLN 80 million** for Brownfield, while for Greenfield, the calculation was based on total capital expenditure **of PLN 102 million.**

8.3.8. Renovation costs (block maintenance)

The costs of maintaining the unit after retrofitting were adopted in accordance with the article *Techno-Economic Assessment of Coal-Fired Power Unit Decarbonisation Retrofit with KP-FHR Small Modular Reactors* [26]*,* which presents a similar analysis to that carried out in this feasibility study. The article uses a KP-FHR reactor to replace the heat source at the Łagisza power plant. It estimated the *Fixed O&M costs* of maintaining the unit, broken down into the turbine island and the nuclear island. The total unit costs amounted to €100/kW/year, with the nuclear island costs amounting to €84/kW/year and the turbine island costs amounting to €16/kW/year.

The presented levels of fixed O&M costs and non-fuel and non-emission variable O&M costs for coal-fired heating refer to a greenfield investment. Due to the age of the turbine set, the costs of the turbine part were increased by 30% in the analysed operating period.

Ultimately, the analysis assumed an indexation rate of €126/kW/year for the Brownfield option and €120/kW/year for the Greenfield option. The assumed index takes into account all periodic repairs and fixed maintenance costs of the unit, which amount to approximately **PLN 477 million** per year for Brownfield and approximately **PLN 464 million** for Greenfield.

In addition to the fixed costs of maintaining the unit, the study included variable costs related to the turbine island, including all types of materials and services required for the maintenance and proper operation of the steam turbine system, depending on the time worked (MWh produced). For the Greenfield option, the variable cost ratio is 1.2.

$€_{2021}$/MWh, and for Brownfield $€1.5_{2021}$/MWh. After indexation, the adopted indices are €1.4 and $€1.8_{2024}$/MWh, respectively, which, taking into account the assumed production level, will amount to **41 and PLN 50 million.**

26 *Techno-Economic Assessment of Coal-Fired Power Unit Decarbonisation Retrofit with KP-FHR Small Modular Reactors; Ł. Bartela, P. Gładysz, Ch. Andreades, S. Qvist, J. Zdeb*

8.3.9. Costs of future decommissioning of the facility

Based on the IAEA study[27], the costs of future decommissioning of the facility, which will begin after the end of the unit's operation and will last six years, were accepted. For this purpose, it was assumed that each year of operation, an amount corresponding to the future costs of decommissioning the nuclear facility will be set aside in equal instalments. The total cost may amount to approximately 15% of the total investment expenditure under the Brownfield option. The annual write-off to the renovation fund for one unit will amount to approximately **PLN 89 million** in both options.

Total annual operating costs were calculated at **PLN 1, 184 million** for Brownfield and **PLN 1,228 million** for Greenfield. The table below shows the values and shares of individual costs.

Table 22 Comparison of costs in the Brownfield and Greenfield options

Costs	Brownfield		Greenfield	
	PLN million	% of total	PLN million	% of total
Nuclear fuel	148.9	12.58	152.2	12.39
Waste disposal	91.8	7.75	93.7	7.63
Water costs	15.3	1.29	15.7	1.27
Employee costs	87.1	7.36	87.1	7.09
Insurance	144.8	12.22	183.2	14.91%
Local tax	80.5	6.79	102.4	8.34
Maintenance of block	527.0	44.50	505.2	41.13
Liquidation fund	88.8	7.50	88.8	7.23
TOTAL PLN million/year	**1,184**		**1,228**	

8.4. LCoE Results

For the previously described capital expenditures and operating costs with the assumed electricity production, the LCoE indicator was determined for the Brownfield and Greenfield variants. The structure of the LCoE broken down into the most important components is presented below.

27 *Economic Assessment of the Long Term Operation of Nuclear Power Plants: Approaches and Experience; IAEA Nuclear Energy Series*

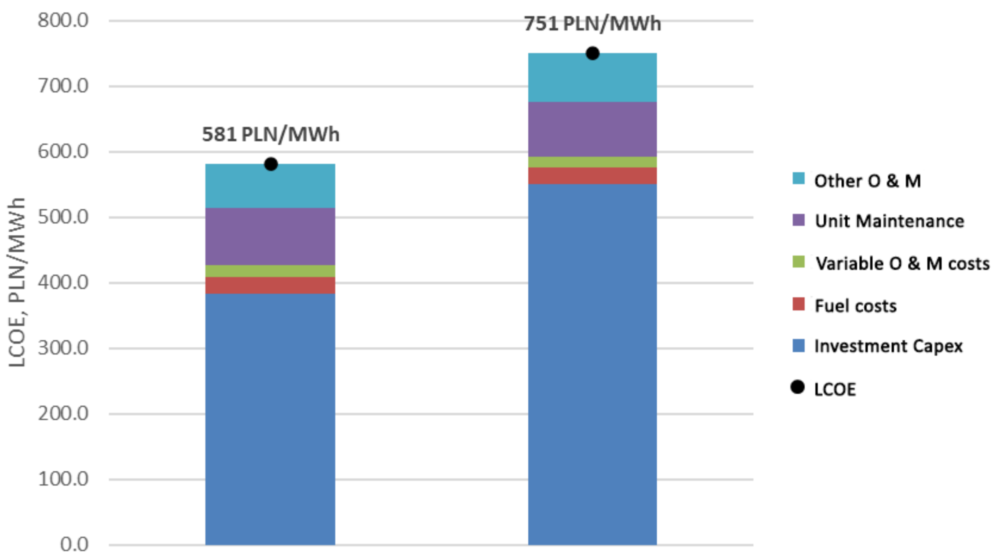

Figure 40 Comparison of Brownfield vs Greenfield LCOE

The LCOE for Greenfield investments is approx. PLN 751/MWh, while for Brownfield investments (analysed in this study) it is approx. PLN 170 lower. Capital expenditure has the greatest impact on LCOE levels; in the LCOE of Greenfield investments, it accounts for almost as much as the total LCOE of Brownfield investments, as shown in the chart.

8.5. Sensitivity analysis

Only the Brownfield variant and the following key variables were subjected to sensitivity analysis within a range of +/-50% (the first two items) or within a range of possible values (the last two items):

- capital expenditure,
- nuclear fuel price,
- unit operating/availability factor (GCF).
- weighted average cost of capital (WACC)

It was assumed that only one variable would change at a given moment. The other variables remained at the same base level.

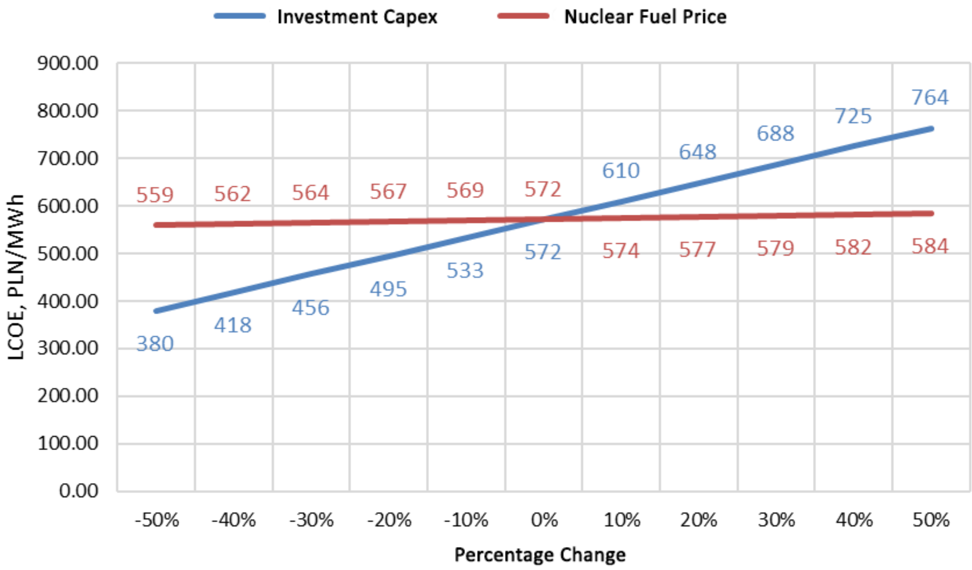

Figure 41 LCoE structure for the analysed solution

Capital expenditure has a greater impact on LCoE, while changes in fuel costs have a negligible impact on the cost of electricity generation.

Sensitivity analysis to production changes was conducted based on changes in the assumed gross capacity factor (GCF) ranging from 20% to 95%. The unit would likely not be able to achieve a GCF of 100%, therefore the maximum value of the work factor is 95% – the maximum unit availability.

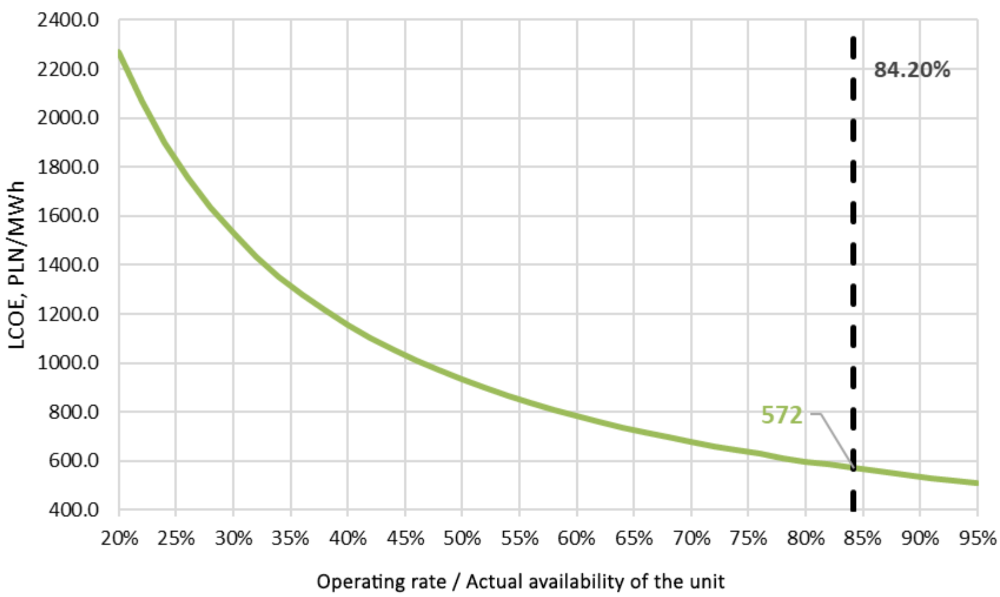

Figure 42 Sensitivity analysis results – unit availability

The presented relationship shows how strongly the LCoE indicator depends on electricity production; in the case of very low availability/production, the production cost rises to over PLN 2,000/MWh.

In addition, **the WACC discount rate** was subjected to a sensitivity analysis in the range of 4%–10%. The chart shows the assumed WACC rate of 6.98%.

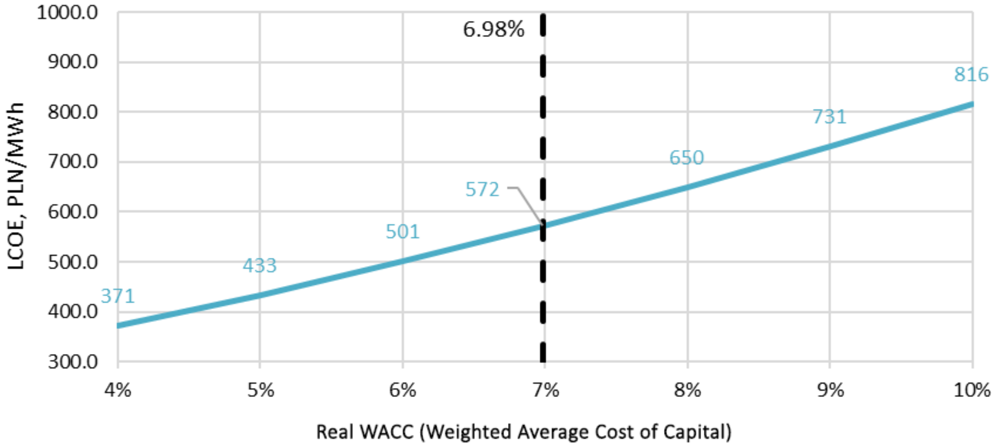

Figure 43 Results of the sensitivity analysis for the variable discount rate

A change in WACC has a significant impact on LCoE, but changing it is not easy in reality and depends on many macro- and microeconomic factors in the country.

8.6. Summary of the economic analysis

- Based on the assumptions adopted for modelling, the LCoE for the selected solution (Brownfield) is approximately PLN 581/MWh.
- The use of existing infrastructure significantly reduces the LCoE cost, while a greenfield investment will have an LCoE indicator that is approximately PLN 170 higher due to significantly higher capital expenditure.
- The LCoE structure shows that the main cost component is capital costs – approx. 67%, while in the Greenfield option it is approx. 73%.
- The sensitivity analysis showed that the project is most sensitive to changes in capital expenditure. The discount rate (WACC) is also an important parameter. The price of nuclear fuel has a negligible impact on profitability indicators.
- It is crucial to ensure adequate productivity of the unit on the market, as a decline in the unit's availability leads to a drastic increase in electricity generation costs.
- With the designated LCoE level, the implementation of this type of investment must be based on guaranteeing revenues at an appropriate level, e.g. through a contract for difference, which will ensure a return on the investment expenditure incurred.

9. Analysis of the required competencies for the management and operation of a nuclear power unit with characteristics appropriate for the investment option (based on the database of required competencies resulting from Research Task No. 6)

The energy transition from coal to nuclear technology (C2N) requires changes in the structure of technical and engineering staff. Adding value to the economy and society in this process may also involve utilising the skills of coal-fired power plant employees in nuclear power plants.

A rationally conducted power plant transformation process can have positive effects such as:

- no need to lay off a large proportion of employees;
- no need to recruit a large number of new employees;
- no need for some of the staff to relocate.

Significant negative effects and risks associated with the C2N transition for coal-fired power plant employees include:

- unemployment during the transition period;
- the need for further training;
- the need to acquire new qualifications.

The transformation of a coal-fired power plant into a nuclear power plant also results in a lack of demand for certain specialisations and the need to employ people with new specialisations.

A rational design of the C2N transition may therefore also take into account the course of action regarding the use of technical and engineering staff at coal-fired power plants.

The procedure for expanding or acquiring the competences required by engineering and technical staff can be started by determining the staff structure in existing and planned power plants and power units. The employment structure in a power plant or nuclear power unit determines the target human resources and their competences. The literature in this field presents lists of employee occupations together with the percentage share of a given type of position[28]. This data, together with the total number of employees, allow the target employment structure in individual occupations to be determined. Similarly, for coal-fired power plants, a list of occupations and their percentage share is available. A direct comparison of this data for a given location allows for an assessment of the possibilities for direct transition, often requiring only a slight expansion of qualifications.

In order to prepare procedures for expanding or acquiring the competences required by the engineering and technical staff of modernised power plants and power units, sample case studies were presented, the essence of which was to determine the positions and number of jobs that require staff with completely new qualifications or that require further training. Similarly, the positions and number of jobs were identified for coal-fired power plant personnel who would not be able to find employment in the new power plant or nuclear unit due to the need for complete retraining.

Based on these analyses, it is possible to examine in greater detail the competencies required for the most important positions at a nuclear power plant, along with identifying opportunities for further training or retraining. In this regard, it is also possible to indicate proposed paths for further training or retraining.

28 Hansen J., Jenson W., Wrobel A., Stauff N., Biegel K., Kim T., Belles R., Omitaomu F.: Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. Systems Analysis and Integration; Revision 2 Prepared for U.S. Department of Energy 13 September 2022 ;INL/RPT-22-67964

9.1. The most important elements of procedures for expanding or acquiring competences required by the engineering and technical staff of modernised power plants and power units

The use of the competences of the engineering and technical staff of a power plant or coal-fired unit in a nuclear power plant or unit can bring many economic and social benefits. These effects can be achieved by rationally defining possible procedures for expanding or acquiring the competences required in new power plants.

The most important issues to consider when designing the process are:

- determining the positions necessary in the new power plant or unit;
- determining the number of positions for each job in the new power plant or unit;
- determining the positions in the power plant or unit being decommissioned;
- determining the number of positions in the decommissioned power plant or unit;
- determining the timetable for the creation of positions and full-time positions in the new unit or power plant;
- determining the timetable for the liquidation of positions and full-time positions in the power plant or coal-fired power unit.

With the information provided, it is possible to determine the matrix of positions and jobs in the plant being liquidated and the one being established. Such a matrix makes it possible to determine the positions and jobs in which:

- there is little or no need to expand employees' competences;
- it is possible to retrain or acquire new competences in a relatively short period of time;
- for which complete retraining is necessary.

The timetables for the decommissioning and commissioning of power plants or power units allow the process to be supplemented with information on possible career paths and opportunities for employees to upgrade their skills, e.g., during the construction of a new power plant or unit.

9.2. List of positions with the highest employment in a nuclear power plant

The list of the most highly employed positions allows us to determine the demand for the most important positions. The analyses first determined the number of positions for ten positions (the most numerous in terms of the number of employees) for a nuclear power plant with an electrical capacity of 1GW (Table 21). The data was compiled on the basis of [9]. This source indicates that employment in a modern nuclear power plant built on the basis of 10 SMR units amounts to 341 full-time jobs (directly employed). This data was compared with the number of full-time positions that will be eliminated at a coal-fired power plant also with a capacity of 1 GW. In this case, it was assumed that the total number of direct full-time positions is 145.

Table 23 List of the most numerous jobs in a nuclear power plant

Coal-fired power plant				Nuclear power plant		
Percentage of employees	Number of full-time positions 1GW	Percentage of full-time positions increasing	Job title	Percentage of employees	Number of full-time positions 1GW	Percentage of positions increasing
0.31	-0.45	0.31	Nuclear engineers	13.07	44.64	13.07
0.31	-0.45	0.62	Nuclear reactor operators nuclear	10.96	37.44	24.03
0.52	-0.75	1.14	Security guards	10.96	37.44	34.98
0.62	-0.9	1.75	Nuclear technicians	7.17	24.48	42.15
4.33	-6.3	6.09	First-line managers of production and operational staff	5.06	17.28	47.21
5.37	-7.8	11.46	Electrical and electronic equipment repairers, power stations, substations and relays	3.06	10.44	50.26
0.52	-0.75	11.97	Training and development specialists	2.85	9.72	53.11
4.64	-6.75	16.62	Electrical engineers	2.85	9.72	55.95
0.83	-1.2	17.44	Architecture and Engineering Managers	2.74	9.36	58.69
3.20	-4.6	20.64	Industrial machine mechanics	2.74	9.36	61.43

An analysis of the data shows that the ten jobs listed account for as much as 61% of the jobs at a nuclear power plant. The same jobs account for about 21% of the jobs at a coal-fired power plant. These jobs include: Nuclear engineers Nuclear reactor operators; Security guards; Nuclear technicians; Training and development specialists; Architecture and engineering managers, whose share in a coal-fired power plant is less than one per cent. It can be assumed that these positions must be filled almost entirely by people from outside the nuclear power plant or by people from the coal-fired power plant who have undergone comprehensive training.

Due to the greater number of jobs in total at a nuclear power plant, some positions at coal-fired power plants may be transferred in their entirety to nuclear power plants. The positions in question include First-line managers of production and operational staff; repairers of electrical and electronic equipment, power plants, substations and relays; electrical engineers; industrial machine mechanics.

9.3. List of positions with the highest employment at a coal-fired power plant

To determine procedures for utilizing engineering and technical staff, it is also helpful to compare the job positions with the highest employment at a coal-fired power plant. As in the previous section, the demand for nuclear power plants can be compared to the job groups that will not be employed at a nuclear power plant or require full or partial training.

The analyses identified fourteen jobs with the highest number of positions (Table 24). Data from studies based on [29]

Table 24 List of the most common positions in a coal-fired power plant

Coal-fired power plant				Nuclear power plant		
Percentage of employees	Number of jobs 1GW	Percentage of full-time positions cumulative	Job title	Percentage of employees	Number of full-time positions 1GW	Percentage cumulatively
17.44	25.4	17.44	Power plant operators	0.63	2.2	0.63
7.02	10.2	24.46	Installers and repairers of power lines	0.74	2.5	1.37
5.37	7.8	29.82	Electrical and electronic equipment repairers, power stations, substations and relays	3.06	10.4	4.43
4.64	6.8	34.47	Electrical engineers	2.85	9.7	7.27
4.33	6.3	38.80	First-line managers of production and operational staff	5.06	17.3	12.33
3.61	5.3	42.41	Customer service representatives	0	0	12.33
3.20	4.7	45.61	Industrial machine mechanics	2.74	9.4	15.07
3.10	4.5	48.71	First-line managers mechanics, installers	2.53	8.6	17.60
2.37	3.4	51.08	Installers and repairers of control systems and valves, except for mechanical doors mechanical	0.21	0.7	17.81
2.06	3	53.15	Electricians	1.69	5.8	19.49
2.06	3	55.21	Distributors and electricity dispatchers	0.32	1.1	19.81
1.86	2.7	57.07	Chief executives and operational managers	0.74	2.5	20.55
1.75	2.55	58.82	Project management specialists and business operations specialists, all others	2.11	7.2	22.66
1.44	2.1	60.27	Management analysts	0.63	2.2	23.29

In the case of coal-fired power plants, 14 positions account for 60% of full-time jobs. These positions account for approximately 23% of the employees at a nuclear power plant. In this group of occupations, although some represent a small percentage of full-time jobs at a nuclear power plant, due to the significant disparities between employees at nuclear and coal-fired power plants only some of this group will not find employment at a nuclear power plant.

29 *Hansen J., Jenson W., Wrobel A., Stauff N., Biegel K., Kim T., Belles R., Omitaomu F.: Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. Systems Analysis and Integration; Revision 2 Prepared for U.S. Department of Energy 13 September 2022 ;INL/RPT-22-67964*

This applies in particular to Power plant operators, power line installers and repairers, customer service representatives, control systems and valve installers and repairers (except for mechanical doors), electricity distributors and dispatchers

9.4. List of jobs with the greatest shortage in nuclear power plants and the greatest surplus in coal-fired power plants

By comparing the number of jobs for individual positions at coal-fired and nuclear power plants, it is possible to identify shortages and surpluses. A list of the jobs with the largest surplus at coal-fired power plants and the largest shortage at nuclear power plants allows for an assessment of the possibility of retraining some employees to work at the new power plant. A list of the most important positions, together with the number of jobs for a 1GW nuclear and coal-fired power plant, is presented in Table 25.

Table 25 Summary of the most important positions with shortages and surpluses of jobs in coal-fired and nuclear power plants

Nuclear power plant	Shortage	Surplus	Coal-fired power plant
Nuclear engineers	44.19	23.19	Power plant operators
Nuclear reactor operators	36.99	7.68	Power line installers and repairers
Security guards	36.69	5.25	Customer service representatives
Nuclear technicians	23.58	2.73	Installers and repairers of control systems and valves, (except mechanical doors)
First-line managers of production and operational staff	10.98	1.92	Electricity distributors and dispatchers
Training and development specialists	8.97	1.8	Operational engineers and other construction workers equipment operators equipment
Architectural and engineering managers engineering	8.16	1.05	Plant and system operators water and sewage treatment
Industrial machinery mechanics	4.71	0.9	Stationary engineers and boiler operators Boiler
Project management specialists and business operations specialists, all others	4.65	0.78	Welders, cutters, solderers and brazers
Various front-line managers, security personnel	4.53	0.75	Gas plant operators
First-line managers of mechanics, installers and repairers	4.14	0.6	Accounting, auditing and auditing staff
Industrial engineers	4.02	0.6	Bus and lorry mechanics and diesel engine specialists
Health and safety specialists	3.57	0.6	Calibration technologists and technicians, and engineering technologists and technicians, with except draftsmen, all others

Personal services managers, all others; entertainment and recreation managers, except gambling, and managers, all others	3.42	0.6	Construction managers
Electrical engineers	2.97	0.6	Truck and tractor operators Industrial
Office clerks, general	2.91	0.6	Meter readers, utilities
Electricians	2.76	0.6	Mobile heavy equipment mechanics equipment, except engines
Production managers	2.76	0.6	Hydraulic engineers, pipeline fitters and steam fitters
Production, planning and dispatch clerks	2.76	0.45	Dispatchers, except police, fire brigade and ambulance services Emergency services
Repairers of electrical and electronic equipment, power plants, substations and relays	2.64	0.45	Electrical and electronic draftsmen
Training and development managers	2.37	0.45	Assistants — installation, maintenance and repair
Chemists	2.07	0.45	Lawyers
Chemical technicians	1.92	0.45	Maintenance workers, machinery
Mechanical engineers	1.86	0.45	Plant and systems operators,
Service managers and facilities	1.83		
Executive secretaries and administrative assistants Administrative assistants	1.62		
Engineers, all others	1.56		
Technical writers	1.44		
Compliance specialists	1.41		
Security analysts information	1.35		
Industry engineers, technicians and technicians	1.29		
Inspectors, testers, sorters, samplers and weighers	1.14		
Chemical engineers	1.08		
Crisis management directors Directors of	1.08		
Environmental and safety technicians protection technicians, including health services	1.08		

Based on the data provided, it can be seen that the largest group of positions in a coal-fired power plant for which there is no equivalent in a nuclear power plant are power plant operators (control, operation and maintenance of machinery and equipment for electricity generation and auxiliary systems). These positions require specialized technical knowledge and skills related to machinery, equipment, and installations that are not available in large numbers, or at all, in nuclear power plants.

Due to their technical education and the relatively large number of jobs available, they may consider undertaking supplementary studies which, after completing an internship, would enable them to work in technical and engineering positions related to reactor operation. This retraining path is quite long and may involve a temporary reduction in salary (during the period of re-education and internships), so it may be more suitable for younger people. Often, during the transition from a coal-fired power plant to a nuclear power plant, there may be a longer period during which the coal-fired power plant is no longer in operation and the nuclear power plant is not yet commissioned. On the one hand, this gives time to retrain some of the employees, but on the other hand, it may be unacceptable due to the temporary lack of livelihood (taking up employment during the training period may be burdensome).

The analyses also highlight another group of people working as power line installers, where there is a surplus of jobs in relation to coal-fired power plants. These positions are often filled by people with electrical training who can obtain jobs as electricians, electrical and electronic equipment repairers, or electrical engineers, where there may be shortages.

9.5. Summary of information on selected positions at a nuclear power plant

The literature contains a range of information on jobs in nuclear power plants and the nuclear sector.

[30] presents a summary of literature with characteristics in which classifications of occupations related to the nuclear sector can be found. It lists several studies, mainly from countries where the nuclear sector is of significant importance. These summaries differ significantly in terms of the names of positions and their characteristics, which may be due to the fact that different countries often draw on their own experience in this field.

[31] contains a list of positions related to the nuclear sector, including the operation of nuclear power plants. Selected positions are described in terms of initial qualifications, competences (divided into the scope of knowledge and responsibility), additional training and development. Within the indicated areas, additional distinctions are made between technical, operational, business and personnel issues.

Based on [32],it can be concluded that the positions that are significant in terms of the number of jobs and the need for training are: nuclear engineers and nuclear reactor operators. These positions are described in more detail in the following subsections.

9.6. Nuclear engineer

According to the Standard Occupational Classification (SOC)[33] which was the basis for the analysis of the matrix of positions and posts, this position involves conducting research on nuclear engineering projects or applying the principles and theories of nuclear science to problems related to the release, control and use of nuclear energy and the storage of nuclear waste.

30 ERIKSSON, A. and ERIKSEN, B. Job Classification and Taxonomy in the Nuclear Sector, European Commission, Petten, JRC132572

31 *C. Chenel Ramos, Nuclear Job Taxonomy. Final Report, EUR 29126 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-73842-5, doi 10.2760/090414, JRC110868*

32 *Hansen J., Jenson W., Wrobel A., Stauff N., Biegel K., Kim T., Belles R., Omitaomu F.: Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. Systems Analysis and Integration; Revision 2 Prepared for U.S. Department of Energy 13 September 2022 ;INL/RPT-22-67964*

33 Standard Occupational Classification Manual Executive Office of the President; Office of Management and Budget; United States, 2018

Based on [34] this position can be described in terms of functions, knowledge and skills.

Functions:

- Responsible for core calculations in strict compliance with nuclear safety regulations during all operations with new and spent nuclear fuel.
- Calculation of the nuclear reactor core and spent fuel pool.
- Determining reactor operating limits based on authorised or licensed fuel operating limits. Compliance with fuel specifications for new fuel. Receipt and inspection of new fuel. Monitoring and collecting data on the condition of the reactor core during operation.
- Performing calculations to ensure safety (core/reactor cooling system conditions within licensed limits) and performance (neutron flux distribution, core burn rate).
- Ensuring compliance of reactor core operating manoeuvres.
- Fuel load design (fuel movements, location of the fuel assembly in the reactor core/spent fuel pool).
- Modelling and predicting reactor core behaviour under changing operating conditions.
- Supervision of nuclear fuel-related activities during refuelling operations.
- Development of working documents (procedures, programmes, instructions) for reactor start-up.
- Preparation and evaluation of reactor core tests prior to start-up.
- Collecting data and monitoring radiation damage to the reactor core and pressure vessel structures.
- Monitoring, data collection and control of nuclear materials (i.e. fuel assemblies, core monitoring instruments) and other core-related equipment: sources, fuel connections, control rods

Job requirements Knowledge (Cognitive competences) EQF level (1-8)

Reactor physics theory 7 Nuclear safety principles and requirements 6 Safety culture 6 Engineering graphics, drawings and diagrams 6 Radiation protection 6 Nuclear physics 6 Nuclear safety regulations 6 Nuclear engineering 6 Nuclear apparatus in and outside the core (fission chambers, neutron flux monitoring) 6 Numerical methods of reactor design 6 Thermal-hydraulic design and analysis 6 Nuclear fuel (thermal limitations, operating limitations, etc.) 6 Core tests prior to start-up 6 Reactor core operation, limitations and set points 6 Nuclear power plant: reactor fundamentals, reactor and power plant process systems, auxiliary process systems, ionising radiation, heat generation and removal systems, steam supply system, nuclear chemistry, Measurement and control systems, electrical systems 5 National and international codes and standards 5 Industrial safety 5 Operational experience 5 Basic measuring instruments and procedures 5 Visual inspection 5 Materials science and radiation damage 5 Occupational safety and personal protective equipment 4 Quality assurance and control 4 Project management, planning methods and tools 4 Knowledge of information and communication technologies 4 Technical writing 4 Nuclear security 4

34 C. Chenel Ramos, Nuclear Job Taxonomy. Final Report, EUR 29126 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-73842-5, doi 10.2760/090414, JRC110868

Skills (technical and functional competences) EQF level (1-8)

Using and interpreting engineering data and technical documentation. 7 Planning, coordinating, implementing and monitoring project activities. 6 Ensuring the implementation of engineering codes and standards. 6 Identifying possible interactions and interactions with other related disciplines. 6 Conducting reactor core analysis and designing fuel configuration. 6 Mapping the location of fuel assemblies in the core and spent fuel pool. 6 Calculating the neutron distribution flux map. 6 Calculating criticality and neutronics. 6 Collect data and monitor core operating conditions. 6 Determine reactor operating limits. 6 Monitor nuclear fuel safety operating parameters. 6 Monitor reactor core performance 6 Predict/model/analyse reactor core behaviour. 6 Design reactor core operating manoeuvres. 6 Develop core operational manoeuvre procedures. 6 Receive and inspect new fuel. 6 Develop/verify new fuel acceptance and inspection procedures. 6 Collaborate on the development of technical specifications for new fuels. 6 Interpret core monitoring instrument readings. 6 Use and update databases of reactor fuel assemblies, connections, control rods, sources, etc. 6 Design reactor core test procedures, analyse and monitor results. 6 Ensure compliance with statutory regulations and QSE organisational requirements. 5 Create and communicate requirements specifications, technical specifications, procedures and reports. 5 Identify safety requirements. 5 Retrieve technical information using computer-aided techniques. 4 Monitor and maintain a safe working environment. 4 Conduct work analysis, break down activities and assign tasks. 4 Evaluate performance and identify measures and indicators to improve or correct performance. 4 Maintain nuclear materials.

9.7. Nuclear reactor operators

According to the Standard Occupational Classification (SOC)[35] 'the main tasks in this position are operating or controlling nuclear reactors; moving control rods; starting and stopping equipment, monitoring and adjusting controls, and recording data in logs; implementing emergency procedures when necessary; being able to respond to malfunctions, determine causes and recommend corrective actions. This position is also described as: Nuclear Control Room Operator, Nuclear Reactor Operator, Nuclear Power Plant Operator.

This position can be described in terms of functions, knowledge and skills.

Functions:

- Responsible for all aspects of the safe operation of the reactor facility
- Ensures and controls the safe and trouble-free operation of the reactor facility in accordance with the requirements of technical specifications: (radiation situation, chemical regime, technological limitations and conditions)
- Provides overall supervision of all activities related to the operation of the reactor facility and its auxiliary systems, and directly manipulates the controls of the equipment and systems
- Monitors and controls the core, reactivity, and systems that may affect reactivity

35 Standard Occupational Classification Manual Executive Office of the President; Office of Management and Budget; United States, 2018

- Ensures and controls strict compliance with nuclear safety and radiation protection requirements in all activities related to the operation of the reactor facility
- Reports to the unit shift manager on the operational status of the reactor facility and/or any incidents that have occurred
- Coordinates maintenance and testing activities and equipment start-up after maintenance
- Monitors the parameters of assigned equipment during operations and ensures response to system or unit malfunctions, diagnoses the cause, recommends or applies corrective actions, and reports incidents
- Responsible for recording and continuously updating operational records
- During a fuel supply interruption, coordinates and monitors activities in the controlled area
- In the event of an abnormality or emergency, strictly follows the instructions of the Unit Shift Manager in accordance with Emergency Operating Procedures and the internal emergency plan
- Collaborate with other departments within the organisation as part of your responsibilities
- Responsible for implementing operational procedures, such as controlling start-up and shutdown activities, including periodic testing of relevant equipment

Job requirements Knowledge (Cognitive skills) EQF level (1-8)

Nuclear engineering: reactor physics, thermal limitations of nuclear fuels, nuclear power plant systems, heat transfer in reactors and fluid flow 6 Occupational safety and personal protective equipment 6 Operational experience 6 Nuclear power plant operation: operation of reactor systems: reactor start-up, normal, transient and emergency operation, measurement of operating parameters, power plant dynamics and control, reactor core operation, instruments and applications 6 Nuclear safety 6 Physics and chemistry theory: thermodynamics, fluid mechanics 5 Applied techniques and engineering: electricity generation, energy conversion, mechanics, electrical engineering, operation of the power system, electrical engineering, energy conversion, sensors, measurements, signal processing, instrumentation and control, pipeline systems, pumps and turbines, hydraulic and pneumatic installations 5 Technical drawings and diagrams 5 Nuclear safety culture 5 Emergency preparedness 5 Nuclear energy science Understanding complex regulations and procedures 5 Industrial chemistry 4 National and international regulations, codes and procedures related to safe operation 4 Radiological protection 4 Human error prevention techniques 4 Corporate procedures 4 Accident analysis and accident modelling 4 Risk assessment 3 Materials science 3

Skills (technical and functional competences) EQF level (1-8)

Maintaining energy equipment in safe and economical operating conditions in accordance with technical specifications and procedures. 6 Recognising and reporting abnormal situations in the power plant. 6 Monitoring the condition of technical equipment and systems. 6 Predicting the results of actions in systems and components and carrying out any necessary corrective actions. 6 Identifying measures or indicators of system performance and predicting how changes in conditions or actions will affect results. 6 Communicating instructions using safe and effective communication techniques. 6 Implementing operational and emergency plans and procedures. 6 Operating and monitoring computer-controlled equipment. 6 Adjusting operating parameters using information from recorders and displays. 6 Reading and interpreting technical drawings and diagrams. 5 Preparing technical reports and operational records. 5

Verifying the condition of equipment using measuring and testing instruments. 5 Correcting abnormal conditions in accordance with standard practice and instructions received. 5 Maintaining and updating repair logs, tracking and reporting systems. 4 Providing data for the preparation of nuclear safety documentation.
4 Monitor and maintain a safe working environment. 4 Perform visual inspections. 4 Comply with statutory regulations and organisational safety requirements. 4 Contribute to the design of requirements specifications. 4 Operate computers using specified software. 4

Based on [36], this position can be described as follows:

Entry qualifications: Degree in engineering or a related scientific field and/or rigorous training programmes related to nuclear energy and significant experience.

Job description

The reactor operator is responsible for manipulating the power plant controls, monitoring its operation, directing the direct operation of equipment, and performing licensed activities during start-up, shutdown, power changes, emergency and accident situations, as well as in special configurations. Reactor operators primarily operate the power plant controls from the control room.

Competencies (Technical (T), Regulatory (R), Business (B), Personal (P))

A reactor operator should be able to:

- Manipulate power plant controls in accordance with plant procedures. (T, R)
- Apply theoretical knowledge in practical situations. (T)
- Analyse the operation of power plant equipment and take corrective action for normal and abnormal conditions in accordance with plant procedures and available information. (T, R)
- Use plant procedures and technical specifications to implement appropriate actions under normal, unusual and emergency conditions. (T, R)
- Maintain the power plant in a safe condition in the event of uncertain or unexpected conditions. (T, R)
- Effectively control and coordinate the activities of subordinates and other persons. (R, B)
- Act as an effective member of the shift team in the control room. (B, R)
- Perform duties in support of the emergency plan. (R, P)
- Take a conservative approach to plant operations. (R, P)
- Cooperate with other groups to solve problems. (P, B)

The reactor operator should understand:

- The concepts, philosophy and responsibilities of the unit operator in the management of reactivity and reactor core safety. (T, R)
- Advanced technical fundamentals, plant design, theory, and interdependencies of systems for which operators are responsible. (T)

36 *Standard Occupational Classification Manual Executive Office of the President; Office of Management and Budget; United States, 2018*

- Relationships between different departments within the plant – quality assurance, engineering, maintenance, training, radiation protection. (T, B)
- Administrative procedures and regulatory requirements for plant management. (T, R)
- Concepts of probabilistic safety assessment and the importance of key components in mitigating the effects of accidents. (T, R)
- Procedures, programmes, company policies, industry guidelines and best practices. (T, R)
- Error prevention techniques and human performance tools. (T, B)
- How to conduct pre- and post-operational briefings. (T, B)
- How to make conservative decisions, with the highest priority given to protecting the health and safety of personnel and the public. (P, T)

*Recommended training/CPD: (*Technical (T), Regulatory (R), Business (B), Personal (P)):

- Advanced technical fundamentals, e.g. plant systems description and reactor operator theory. (T)
- Radiological protection. (T)
- Reactor thermohydraulics. (T)
- Operating licences and technical specifications. (T, R)
- Simulator training: integrated normal plant operations, diagnostics, emergency procedures, responses to accidents and transient operating conditions. (T, R)
- Probabilistic safety assessment. (T, R)
- Safety analysis reporting. (R)
- Advanced transient and accident analysis. (T, R)
- Mitigation of core damage effects. (T, R)
- Error prevention techniques and human performance tools. (T, B)
- Teamwork. (P)
- Conservative decision-making. (T, B)
- Nuclear safety and safety culture. (T, R)
- Operational experience and emergency planning. (T, R)

Work-related policies and procedures. (T, R, B)

10. Risk analysis in the area of organisation and safety of modernisation and operation of power units with nuclear reactors (based on the results of Research Task No. 3, which formulates key requirements and recommendations for nuclear safety for selected locations), -

10.1. Legal requirements

10.1.1. General requirements for the location of nuclear power plants

Polish law sets out general requirements for the location of nuclear power plants, aimed at ensuring the safety of both the population and the environment. The key requirements, contained in the Act of 29 November 2000 – Atomic Law, concern the assessment, planning and selection of suitable locations for nuclear power plants.

10.1.1.1. Radiological safety and health protection of the population

A nuclear power plant must be located in such a way as to ensure maximum safety for the population against the effects of potential accidents, including the release of radioactive materials. The choice of location should take into account the reduction of the risk of radiation exposure to the population and compliance with the requirements for radiological protection specified in national and international regulations.

10.1.1.2. Seismic and geological risk analysis

Atomic law requires that the location of a nuclear power plant take into account all possible geological hazards, such as earthquakes, landslides, flooding or terrain deformation, which could affect the stability and safety of the nuclear facility. A detailed geological and seismic assessment is necessary to minimise the risk associated with the impact of natural forces on the operation and safety of the facility.

10.1.1.3. Environmental protection

The location of a nuclear power plant must meet environmental protection requirements, which means that a comprehensive environmental impact assessment (EIA) must be carried out. This assessment analyses the potential impact of the investment on air, water, soil, fauna and flora. The EIA process must also take into account the impact on water resources that may be used to cool the reactors, as well as on the local climate and ecosystems.

10.1.1.4. Compliance with spatial development plans

A nuclear power plant must be located in accordance with local spatial development plans. The planning process requires cooperation with local authorities and relevant public administration bodies to ensure that the investment is compatible with local conditions. The impact on transport infrastructure, transport accessibility and possible evacuation needs must also be taken into account.

10.1.1.5. Distance from population centres and critical infrastructure

The location of a nuclear power plant should be sufficiently distant from large population centres and key critical infrastructure. Limiting the impact of potential accidents on the surrounding area is a priority, which is why the location must meet specific standards and regulations regarding the minimum distance from residential areas and strategic facilities.

10.1.1.6. Availability of technical infrastructure

The requirements also apply to the availability of appropriate technical infrastructure necessary for the operation of the power plant, including power connections, access to water sources for reactor cooling, transport infrastructure (road and rail), and emergency and communication infrastructure.

10.1.1.7. Ensuring an adequate level of physical protection

The location of the power plant must allow for adequate physical protection of the facility against external threats, including acts of sabotage, terrorism and air attacks. Regulations impose an obligation to use modern protection and security systems that minimise the risk associated with external factors.

10.1.1.8. Cooperation with the local community and public consultations

Public consultations and information campaigns are required in order to present the impact of the power plant location on the surrounding area and to gather the opinions of residents and interested parties. Such activities are aimed at increasing the transparency of the location process and building public acceptance for the project.

10.1.1.9. Compliance with international regulations and IAEA regulations

As a member of the International Atomic Energy Agency (IAEA), Poland must comply with international standards and guidelines regarding the location and safety of nuclear facilities. In this context, best practices in risk assessment, emergency management and environmental protection are taken into account.

In summary, the selection of a location for a nuclear power plant in Poland is subject to detailed analysis in accordance with the requirements of the Atomic Energy Act, aimed at ensuring maximum safety, minimising environmental impact and guaranteeing an adequate level of public health and safety.

10.1.2. General requirements for the design of a nuclear reactor and nuclear power plant

The Regulation of the Council of Ministers of 31 August 2012 on nuclear safety and radiation protection requirements (Journal of Laws 2012, item 1048) specifies detailed requirements for the design, construction and operation of nuclear facilities, including nuclear reactors, in Poland. The purpose of these requirements is to ensure the maximum level of nuclear safety and radiological protection for the public, personnel and the environment.

10.1.2.1. Basic principles of nuclear safety

- Defence in depth: The design of the reactor and the entire power plant must be developed in accordance with the principle of defence in depth, which means the use of multiple physical and organisational barriers to prevent the release of radioactive substances. This requires the existence of systems to prevent, detect and mitigate the effects of possible accidents.
- Protection against accidents: The design must minimise the risk of accidents and ensure that the possible consequences of accidents are controlled and limited in order to prevent serious consequences for the population and the environment.

10.1.2.2. Design of safety systems

- System reliability: All safety systems, including reactor cooling systems, must be highly reliable. Redundancy (duplication of key components) and technical diversity are required to prevent failures resulting from a single point of failure.
- Passive and active systems: Safety systems must be capable of operating both passively (without the need for electrical power) and actively in order to ensure the highest possible level of safety.
- Ability to shut down safely: The design must take into account the possibility of safely and immediately shutting down the reactor in an emergency situation and ensuring long-term heat removal after shutdown.

10.1.2.3. Protection against external and internal hazards

- Resistance to external factors: The nuclear facility must be designed to withstand various external factors, such as earthquakes, floods, extreme weather conditions, fires and aircraft crashes.
- Internal hazards: The design must take into account protection against internal hazards such as system failures, internal fires, explosions and possible human error.

10.1.2.4. Radiological protection

- Minimisation of radiation exposure: The design must ensure that radiation exposure to staff and the public is minimised through the use of physical barriers, appropriate radiation protection and monitoring systems.
- Ventilation systems: Ventilation systems must be designed with the capability of filtering air contamination and controlled release of radioactive substances into the atmosphere, in accordance with applicable standards.

10.1.2.5. Facility monitoring and control

- Monitoring systems: The power plant design must include advanced systems for monitoring and controlling reactor operating parameters, including systems for detecting failures and safety breaches.
- Automated control systems: It is recommended to use automated control systems that allow for rapid detection of irregularities and the implementation of appropriate corrective or preventive measures.

10.1.2.6. Physical security and facility protection

- Physical protection: The facility design must provide an adequate level of protection against unauthorised access, sabotage or external attacks.
- Integrated security systems: This includes monitoring, alarm systems and access control to prevent deliberate actions that could threaten the security of the facility.

10.1.2.7. Contingency and emergency procedures

- Emergency response plans: The power plant design must include detailed plans for responding to both internal and external emergencies and provide for the possibility of rescue operations involving external services.
- Evacuation and personnel safety systems: Consideration of evacuation routes, personnel protection procedures and other elements ensuring minimisation of the effects of a potential accident.

10.1.2.8. Requirements for radioactive waste management

- Safe storage of waste: The design must include systems for the safe collection, storage and management of radioactive waste generated during the operation of the power plant.
- Waste minimisation: Efforts should be made to minimise the amount of radioactive waste and to store and process it appropriately in accordance with regulations.

10.1.2.9. Technical qualification of components and materials

- Compliance with norms and standards: All elements and components must be designed and manufactured in accordance with international norms and standards for nuclear safety.
- Certification and testing: Appropriate testing, certification and quality verification of the materials and equipment used is required.

The Regulation of 31 August 2012 imposes a wide range of technical requirements on nuclear facility designs to ensure the highest level of safety, radiation protection and resistance to various hazards. Each design must be developed in a comprehensive manner, taking into account the specific technological characteristics, radiological safety, hazard protection and emergency management.

10.2. Opole Power Plant

The DEsire project is considering a nuclear retrofit according to the Direct path for the case of the power unit(s) at the Opole power plant. This requires a heat source (nuclear reactor) capable of generating a heat transfer medium at temperatures exceeding 600°C. The reference unit is the molten salt reactor design developed by Kairos Power.

Replacing the coal-fired boilers in one of the units at the Opole power plant with a Kairos Power nuclear reactor is a complex undertaking that requires a thorough analysis of safety aspects.

Kairos Power is developing molten salt reactor (MSR) technology, which differs from traditional light water reactors. Due to the fact that this technology is still under development, safety analysis is very difficult and uncertain.

10.2.1. Technological safety of the Kairos Power FHR Reactor

The FHR reactor uses fluoride salt as a coolant and moderator, which distinguishes it from more traditional water-cooled nuclear reactors. Molten salt has a high boiling point and good heat conductivity, which reduces the risk of boiling and related failures, such as sudden pressure increases. Kairos Power's technology features a low-pressure cooling system, which limits the possibility of coolant leakage and reduces the risk associated with pressure damage in the reactor system. This is an important difference compared to water reactors, which can have higher operating pressures and associated risks. FHR reactors offer high thermal stability and can withstand rapid temperature changes, reducing the risk of thermal damage from unplanned events. Salt cooling also minimises the risk of hydrogen explosions, which are a significant hazard in traditional water reactors.

10.2.2. Radiological safety and fuel management

The Kairos Power FHR reactor uses TRISO (tristructural-isotropic) coated ceramic fuel, which is characterised by very high temperature resistance and self-contained radionuclide containment. This fuel minimises the risk of radioactivity release even in the event of a serious accident. The TRISO fuel coating limits the release of radionuclides, so that even in the event of an accident, the release of radioactive isotopes is significantly reduced. This is a significant advantage over conventional nuclear fuel. However, the fuel and fission products require proper storage after use. Radioactive waste management systems must be developed, which in the case of Kairos Power technology includes not only spent fuel but also the handling of cooling salt.

10.2.3. Adaptation of existing infrastructure at the Opole power plant

Replacing coal-fired boilers with a nuclear reactor requires adapting the power plant's infrastructure, including the construction of a new reactor and cooling systems. Radiological safety and accident protection systems must also be taken into account.

The transition from coal to nuclear technology requires the introduction of new safety procedures, including the establishment of emergency planning zones, which cover, among other things, the evacuation and protection of the population in the event of an accident. It will be necessary to implement an advanced radiological monitoring system and control the reactor operation process.

10.2.4. Responding to emergency situations

The introduction of a nuclear reactor requires the development of new emergency response plans that take into account the risks associated with radioactive emissions and the possibility of accidents. Kairos Power, as a modern technology, assumes a low risk of radioactive substance release, but it is necessary to develop comprehensive documentation and civil protection plans. Training power plant personnel in reactor operation and safety procedures is essential to minimise the risk of failure.

10.2.5. Environmental safety

The Kairos Power FHR nuclear reactor does not directly generate greenhouse gas emissions, which can be beneficial in terms of reducing the carbon footprint. Replacing coal-fired power plants with the FHR reactor contributes to the decarbonisation of the power system.

10.2.6. Socio-political security

The installation of a nuclear reactor to replace coal-fired boilers may be met with mixed reactions from the public. It will be crucial to conduct an information and education campaign on Kairos Power technology, environmental benefits and safety levels. Before construction, the necessary approvals must be obtained and Polish legal standards for nuclear facilities must be met, which may be time-consuming but is essential from a safety perspective. This is where the greatest uncertainty lies, given that the reactor is in the design phase and the licensing process has not yet begun.

10.2.7. Cyber security

Kairos Power reactors, like other modern nuclear units, rely on advanced control systems, which require adequate cyber security measures to prevent potential attacks that could affect the safety of the facility's operation.

In summary, replacing coal-fired boilers in one of the Opole power plant units with a Kairos Power FHR reactor has many advantages related to modern and safe molten salt cooling technology and TRISO fuel. However, it requires extensive risk analysis, infrastructure adaptation, implementation of appropriate safety procedures and full cooperation with regulatory authorities to ensure the safety of people and the environment. However, the implementation of these tasks requires detailed information and data that are not available at this stage.

10.3. CONCLUSIONS

The safety aspects of nuclear retrofitting for the three locations under consideration were assessed from a legal, technical and organisational perspective.

The law basically regulates most issues related to reactor design, in particular the required safety systems, and thus imposes technical safety assessment criteria. Since the AP1000 and EPR reactors are designs licensed by nuclear regulatory authorities virtually worldwide and are already in operation at several locations, they certainly meet all legal requirements. The Kairos Power FHR reactor is currently under design, but it must meet all requirements in order to undergo the certification process.

Polish nuclear law and regulations also define the criteria for selecting nuclear facility locations. From this point of view, all three locations under consideration are feasible. However, the construction of nuclear power units at these sites requires detailed environmental studies, verification of geological and hydrological conditions, and compliance with spatial development plans.

Organisational aspects include the processes of developing detailed designs, zoning planning, safety and emergency procedures, and, of course, the preparation and implementation of the construction process.

Transport issues at all stages of the investment should also be taken into account here. This part of the safety assessment is quite problematic, but it should be assumed that IAEA recommendations and standards will be used here and that the process will be planned in accordance with best practice, based on current knowledge.

11. Diagnosis of legal and legislative barriers for the investment process

The implementation of coal-to-nuclear investments (i.e. replacing coal sources in the area of electricity generation with nuclear energy), despite their potential benefits, may encounter numerous legal and legislative barriers. The complexity of administrative procedures and the inadequacy of existing regulations to the requirements of such projects can significantly hinder their implementation. An important element of the preliminary feasibility study for a coal-to-nuclear investment is understanding the procedural path required to obtain a construction permit and identifying key legal and legislative barriers.

11.1. Description of the procedural path for obtaining a building permit for a nuclear facility

A building permit for a nuclear facility is a key document enabling the commencement and conduct of construction works. Before submitting an application for its issuance, the investor must prepare design documentation in accordance with legal requirements and obtain a number of formal documents and administrative decisions. In the case of nuclear facilities, this process includes both the standard construction procedure and an additional path that takes into account the specific requirements related to nuclear proceedings.

The standard construction procedure is based on the Act of 7 July 1994 – Construction Law (Journal of Laws 2024, item 725), hereinafter referred to as the Construction Law. This legal act regulates the construction process, including investment preparation, obtaining a building permit, construction works, commissioning of facilities and their maintenance in proper technical condition. The Act defines the rights and obligations of participants in the investment process, indicates facilities requiring a building/demolition permit or notification, describes the procedures for obtaining them and the rules of operation of public administration bodies. It also specifies the requirements for design documentation and formalities necessary in the construction process. The technical documentation required when applying for a building permit consists of three elements: two parts of the construction design — the land development design and the architectural and construction design. The third part, i.e. the technical design, must be prepared and kept on the construction site before work begins. All elements of the construction design must be signed by engineers with the appropriate qualifications, in accordance with the scope of the documentation.

The nuclear procedure and the additional requirements and simplifications applicable therein result from the Act of 29 November 2000 – Atomic Law (Journal of Laws 2024.1277), hereinafter referred to as the Atomic Law, and the Act of 29 June 2011 on the preparation and implementation of investments in nuclear energy facilities and accompanying investments (Journal of Laws 2024, item 1410), hereinafter referred to as the Special Act.

The body responsible for issuing decisions under the nuclear pathway is the National Atomic Energy Agency (PAA), represented by the President of the PAA.

The first and one of the most important decisions in the process of constructing a nuclear facility is **the fundamental decision** issued by the minister responsible for energy at the request of the investor. This document specifies the permitted parameters of the investment related to the construction of a nuclear power plant. It also constitutes the basis for applying for further administrative decisions, including the decision on determining the location of the investment in the construction of a nuclear power plant and other permits necessary for the preparation, implementation and use of the facility. The purpose of the fundamental decision is to protect the public interest, in particular in the context of implementing state policy objectives, such as energy policy, and ensuring national security (Article 3a of the Special Act).

The fundamental decision enables the investor, among other things, to submit an application for **a decision on environmental conditions** (abbreviated as 'DoŚU'), which is necessary in the further process of obtaining a building permit for a nuclear facility. DoŚU is issued for projects that may always have a significant impact on the environment and for projects that may potentially have a significant impact on the environment. The rules for issuing it are regulated by the Act of 3 October 2008 on the provision of information on the environment and its protection, public participation in environmental protection and environmental impact assessments (Journal of Laws 2024.1112). The EIA is intended to ensure that the planned investment has the least possible negative impact on the environment. If the investment may have a significant impact on the environment, an environmental impact assessment is carried out before a decision on environmental conditions is issued. The assessment is based on an environmental impact report prepared by the applicant. This report presents data on the impact of the investment on the environment, covering both the methods of construction and the operational phase, taking into account aspects such as noise, emissions and the impact on residents.

For energy facilities classified in the third geotechnical category, such as nuclear power plants, it is also necessary to prepare **geological and engineering documentation** (abbreviated as DGI), which is attached to the construction design as part of the technical design. The requirement to prepare DGI stems from the Act of 9 June 2011 Geological and Mining Law (Journal of Laws 2024, item 1290) and the implementing acts to this Act, including the Regulation of the Minister of the Environment of 18 November 2016 on hydrogeological documentation and geological and engineering documentation (Journal of Laws 2016, item 2033) and the Regulation of the Minister of Transport, Construction and Maritime Economy of 25 April 2012 on determining the geotechnical conditions for the foundation of buildings (Journal of Laws 2012, item 463).

Geological and engineering documentation (DGI) should be prepared independently of the obligation to prepare a geotechnical opinion, ground investigation documentation and a geotechnical design. In accordance with the provisions of the Geological and Mining Law, DGI requires approval by the competent authorities. The process begins with the development of a Geological Works Project, which is agreed upon and approved in the form of an administrative decision. After its approval and notification of the intention to commence field work, the planned geological works (at the earliest 2 weeks after approval), laboratory tests and analyses necessary for the preparation of the DGI are carried out. Once the documentation has been completed, an application for its approval must be submitted. The decision in this matter is issued by the district administrator (supported by the district geologist) or the provincial governor (with the assistance of the provincial geologist).

The next step in the investment process is to obtain **a decision on the location of the investment for the construction of a nuclear power plant**, which is issued by the locally competent provincial governor. Pursuant to Article 15(6) of the Special Act, this decision replaces the decision on development conditions required in the standard procedure (for non-nuclear investments) in the absence of a current Local Spatial Development Plan. The decision on the location of the investment grants the right to use the land necessary for its implementation. It includes, among other things, the designation of the property covered by the project, requirements for the protection of third party interests and conditions for the implementation of the investment, such as technical, environmental, conservation and fire safety requirements. The application for this decision must be supplemented by a number of opinions from other authorities, as specified in Article 5 of the Special Act.

A prerequisite for issuing a decision on determining the location of a nuclear energy facility investment is obtaining a prior decision on environmental conditions. It is worth noting that this decision may be submitted by the Investor in the course of proceedings for issuing a decision on determining the location of a nuclear energy facility investment.

In addition to the fundamental decision and the decision on the location, the investor should also obtain **a permit to carry out activities involving exposure related to the construction of a nuclear facility** (hereinafter referred to as a nuclear facility construction permit). One of the conditions for obtaining a permit for the construction of a nuclear facility is compliance with the requirements for nuclear safety, radiological protection, physical protection and security of nuclear materials. In addition, the investor must ensure adequate financial resources for the completion of construction and maintenance of the safety of the nuclear facility (Article 38g(1) of the Atomic Law). The licence is issued by the President of the PAA within 24 months of the date of submission of the application together with the required documents. The application should include, among other things, a preliminary safety report, a location report, a design for the physical protection system of the nuclear facility and nuclear materials, a decision on environmental conditions, an opinion of the European Commission issued on the basis of Article 43 of the Treaty establishing the European Atomic Energy Community, as well as other documents specified in the Regulation of the Council of Ministers of 30 August 2021 on documents required when submitting an application for a licence to perform activities involving exposure to ionising radiation or when notifying the performance of such activities (Journal of Laws 2021.1667). The application must also be accompanied by **water law permits and notifications**, if required (Article 388(5) of the Water Law Act of 20 July 2017, Journal of Laws 2024.1087).

Upon receiving an application for a licence to construct a nuclear facility, the President of the PAA enables public participation in the proceedings by publishing the content of the application together with a summary safety report in the Public Information Bulletin. All interested parties may submit comments and motions, as well as participate in the administrative hearing (Article 39d of the Atomic Energy Act).

Pursuant to Article 39e of the Atomic Energy Act, when considering an application for a licence, the President of the PAA has the right to carry out inspections on the site where the activity covered by the application is planned. To this end, he may use the services of authorised laboratories and expert organisations, as well as require tests or expert opinions to be carried out in order to verify compliance with nuclear safety and radiation protection conditions.

Pursuant to Article 39f of the Atomic Energy Act, before issuing a licence, the President of the PAA submits a request to the Council for Nuclear Safety and Radiological Protection for an opinion on the draft licence. After obtaining this opinion, the draft is forwarded to the applicant, who has one month to submit comments. After considering these comments, the President of the PAA issues a decision on the granting of a licence for the construction of a nuclear facility. This decision, together with the content of the application and a summary safety report, is made public.

A licence for the construction of a nuclear facility specifies the conditions for carrying out the activities covered by the licence, including, among others, design requirements, the obligations of the organisational unit with regard to the safety of the nuclear facility, equipment, employees, the public and the environment, including radiation protection, emergency planning and procedures, nuclear facility management, and operating limits and conditions (Article 39g of the Atomic Law).

Obtaining a permit for the construction of a nuclear facility is a prerequisite for issuing a building permit. It may be submitted by the investor in the course of proceedings for the issuance of a building permit. The content of the permit, together with the decision on the location of the investment, is binding on the provincial governor who issues the building permit (Article 15(2) of the Special Act).

The final stage of the procedural path for obtaining a building permit for a nuclear facility is to submit an application for **a building permit** together with the construction design and all necessary formal attachments. The entire application is reviewed by the competent administrative authority for compliance with the regulations. The first step in the verification process is to assess the completeness of the application (formal verification), which the authority is required to carry out within 14 days of its submission, in accordance with Article 33(6) of the Building Law. If the application contains formal deficiencies, the authority calls on the applicant to remedy them within a specified period. If the applicant is unable to remedy the deficiencies within the specified time, they have the right to submit a request for an extension of the proceedings. In such a situation, the administrative authority may postpone the procedure in accordance with Article 64 of the Code of Administrative Procedure (Journal of Laws 2024.572). After the applicant has made any corrections and the authority has accepted the application as valid, the office notifies the interested parties of the initiation of administrative proceedings. The next step is a substantive verification, during which the content of the application and attachments is analysed. Also at this stage, the architectural and construction authority has the right to request the applicant to correct any irregularities in the application, setting a deadline for their correction. The applicant may then supplement the documentation, provide additional explanations regarding the solutions used, or request the legal basis for the authority's request. After the design has been corrected/clarified, the authority may close the case by issuing a decision.

Once the building permit has been obtained, a construction log is issued, a site manager is appointed, construction documentation is prepared, and then work can begin, starting with preparatory work and then moving on to the actual construction activities.

In addition to the main decisions described in this chapter, depending on the scope and complexity of the investment, other decisions and agreements may be required under separate regulations (e.g. permission to cut down trees, permission to access a public road if the investment is located on a national or provincial road, etc.). Most often, decisions are attached as appendices to the building permit application.

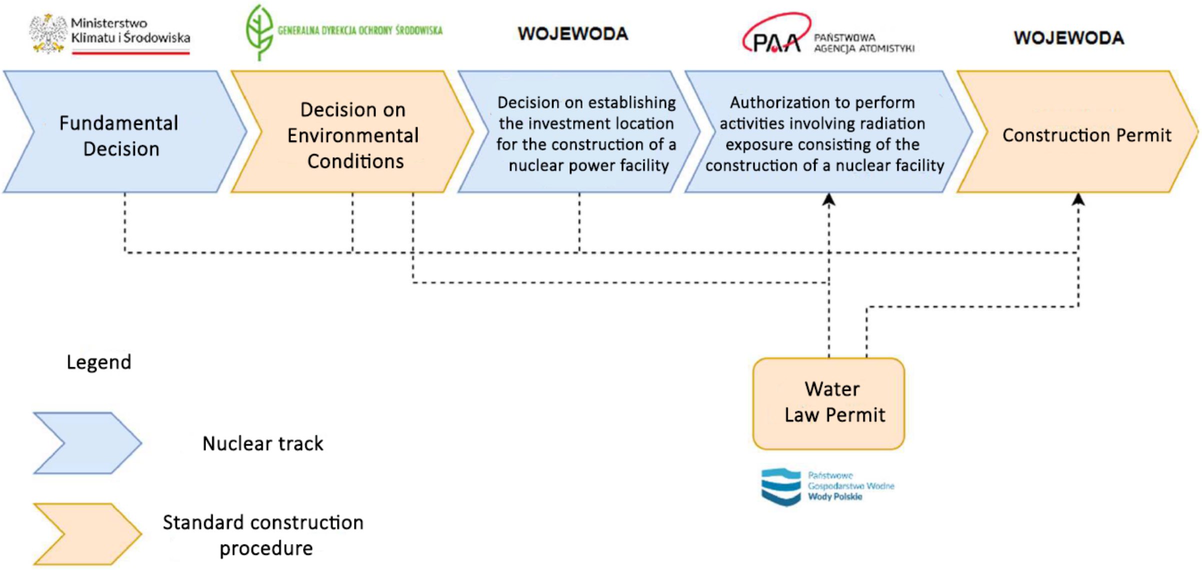

Figure 44 Simplified diagram showing the process of obtaining a building permit for a nuclear facility.

11.2. Legal and legislative barriers to the investment process

Obtaining a building permit for a nuclear power plant in Poland is a complex process that faces numerous legal barriers. An analysis of the Atomic Law, the Construction Law and the Special Act indicates the following obstacles:

11.2.1. Scattered and imprecise regulations

The regulations governing the process of obtaining a building permit for a nuclear facility are scattered across numerous legal acts, which makes them difficult to interpret and apply. The Atomic Energy Act and the Special Act introduce certain simplifications, but they do not eliminate all barriers. In addition, the applicable legal regulations contain provisions that are sometimes unclear and leave room for interpretation.

11.2.2. Lack of experience of the administrative bodies involved in issuing decisions in the process of obtaining the necessary permits and authorisations

One of the significant barriers to obtaining a permit for the construction of nuclear power plants in Poland is the lack of experience of administrative authorities. To date, no such investment has been carried out in Poland, which means that officials and institutions responsible for project assessment do not have sufficient practical experience in the specific requirements of this type of undertaking.

The process of obtaining permits for the construction of a nuclear power plant is complex and requires consideration of many legal, technical, environmental and construction aspects. Of particular importance is the precise application of regulations concerning nuclear safety and radiological protection, as well as compliance with national technical and construction standards.

A lack of prior experience in assessing this type of investment may lead to a lengthy decision-making process and ambiguous interpretation of regulations. In addition, administrative authorities may adopt an overly cautious approach in an effort to avoid potential errors, which may result in additional requirements and delays in project implementation.

11.2.3. Two separate paths for assessing nuclear power plant construction projects and the lack of a separate derogation path for nuclear facilities

In the Polish legal system, the construction of a nuclear power plant is subject to assessment by two separate authorities: the President of the PAA and the provincial governor. The problem stems from the different assessment criteria adopted by these authorities. The President of the PAA focuses on nuclear safety and radiological protection, allowing solutions based on foreign norms and standards if they are confirmed by international certificates. This system allows for a certain degree of flexibility in the approach to projects, especially in the case of "standard plant" projects, which are based on proven solutions used worldwide and which can be adapted to Polish conditions. The provincial governor, on the other hand, must strictly apply Polish technical and construction regulations.

In practice, this means that standard plant designs, although based on recognised foreign standards, must be adapted to the requirements of Polish construction law. The special act does not provide for exemption from the requirement to comply with national technical and construction regulations, which means that standard plant designs often require modifications or exemptions. In the case of derogations, there is no separate procedure for nuclear facilities, which means that the President of the PAA does not participate in the process of granting derogations. As a result, a situation may arise in which a design meets nuclear safety requirements but is not approved by the provincial governor due to non-compliance with local building regulations, or vice versa.

11.2.4. No path for adapting existing facilities

One of the significant legal barriers in the process of implementing investments related to the construction of nuclear power plants is the lack of regulations concerning the adaptation of existing facilities, installations or infrastructure to the requirements of such projects. Facilities originally designed and used for other purposes may not meet the technical and formal standards necessary for operation within a nuclear power plant.

Current regulations do not provide for a dedicated procedural path that would allow for the conversion and adaptation of existing buildings, installations or infrastructure elements in a manner consistent with the requirements for radiological protection and nuclear safety in the construction of a nuclear power plant. There are also no guidelines specifying the scope and type of technical documentation that would need to be submitted in the event of such adaptation in order to document compliance with nuclear safety requirements.

11.2.5. Recommendations:

- Developing and implementing detailed legal provisions enabling the conversion of facilities originally designed for other purposes in a manner consistent with the requirements for nuclear power plants.
- Preparation of detailed guidelines specifying the technical standards that adapted facilities must meet in order to be eligible for use as part of a nuclear power plant infrastructure. These guidelines should also cover the type and scope of technical documentation required to demonstrate compliance with safety standards.
- Introduction of a procedure enabling the assessment of the compliance of adapted facilities with technical requirements and requirements concerning radiological protection and nuclear safety. This process could be carried out by supervisory authorities such as the National Atomic Energy Agency.

12. Investment schedule

The construction of a power unit with a fourth-generation nuclear reactor in Opole is planned for the period from 2030 to 2044. The schedule specifies a multi-stage sequence of formal, design and implementation activities, with clearly marked dependencies between successive phases. The investment will commence in 2030 with the preparation of a feasibility study. This document, which will take a year to prepare, is intended to assess the technical and economic viability of the investment and will form the basis for further decisions. In 2031, the investor will make a decision on the implementation of the project, which will trigger a five-year process of obtaining environmental, location and basic decisions, as well as preliminary safety analyses. At the same time, work on the final safety report will begin in 2034.

In 2036, the project enters the permit acquisition stage. First, a permit for preparatory work is issued, and in the same year, the process of obtaining building permits.

The construction design is developed in 2037–2038 and ends with the formal obtaining of a building permit in 2038. With the completion of the formal procedures, the implementation of detailed designs and deliveries begins in 2038 and continues until 2043. At the same time, construction also begins.

Between 2038 and 2041, measures related to the adaptation of existing facilities are being implemented. In the same year, the construction of a fourth-generation reactor also begins, which will last until 2042. This stage is crucial for future operation. From 2042, a series of technological and functional tests will be conducted, which will be completed in 2044.

At the same time, from 2041, the investor begins the process of obtaining a start-up permit, and then in 2042, it conducts the actual technological start-up, which will be completed in 2044. In the same year, after all tests and commissioning have been completed, the process of obtaining an operating licence will begin, which will end in 2044. The schedule also includes information that the existing coal-fired unit is planned to be decommissioned in 2037.

13. SWOT analysis

Table 26 SWOT analysis

	POSITIVE	NEGATIVE

INTERNAL	**STRENGTHS** • Increased energy security • Maintaining generation capacity at the current level (approx. 900 MW) • Possibility of utilising local human resources and local companies • Reduction of emissions of of electricity production compared to coal-fired power plants • Possibility of utilising the existing technical infrastructure of the analysed facility • There is no need to vacate the entire site of existing coal-fired power stations and their auxiliary facilties • The Direct model reduces investment expenditure compared to the Greenfield model	**WEAKNESSES** • The need to use the infrastructure of the existing coal-fired power station • Implementation of a unit based on fourth-generation solutions, currently in the experimental phase • Construction of a nuclear power unit while continuing to operate the coal-fired power unit • The need to adapt existing (currently in operation) equipment to new requirements • Adjustment of the investment schedule to the decommissioning of coal-fired power units • High investment expenditure compared to other technologies
EXTERNAL	**OPPORTUNITIES** • Implementation of plans to decarbonise the Polish energy sector in line with the Coal-to-Nuclear concept • Local development – the power plant remains in its current location. • Preserving/increasing jobs, reducing the adverse impact on the local aquatic environment of the Odra River, which may translate into better cooperation with environmental organisations	**THREATS** • Construction of a nuclear reactor on the site of an existing coal-fired power plant, using the infrastructure of coal-fired units • Financing – difficulty with financial arrangements • Adaptation of regulations to the Coal-to-Nuclear approach • Accumulation of nuclear investments at one time • No guarantee from the technology supplier for the operation of the entire unit