

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



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Introduction

The transformation of the Polish energy sector is a necessity stemming from both established climate goals and the need to ensure the country's energy security. Faced with the ongoing depletion of domestic coal-fired power plants (CFPPs) (many units are over 50 years old) and increasingly stringent environmental regulations, a gradual shift away from fossil fuels in favour of energy sources with lower emissions is essential. At the same time, the transformation must be implemented in a way that ensures the stability of the National Power System (KSE), guaranteeing the security of energy supply, and an acceptable overall economic cost. This requires replacing coal-fired power in a coordinated manner, preferably while adhering to the requirements of a 'Just Transition' for regions whose health is often closely linked to locally developed fuel and energy industries. In practice, this means increasing the role of nuclear energy, because **without investment in nuclear power plants, achieving climate goals while maintaining long-term economic growth may prove impossible.**

The current geopolitical and economic situation further reinforces the urgency of adapting the country's energy policy to new challenges. The energy crisis and war in Europe have demonstrated the importance of **energy sovereignty**. Becoming independent from fossil fuel imports from unstable supply sources and securing a continuous supply of affordable energy for both citizens and industry are priorities for national decision-makers. The energy transition is a strategic element of strengthening the country's international standing. Decisions made now will determine the condition of the Polish economy and industry for decades to come.

Poland's utility energy sector is based on large, centralised generation sources, which, in response to growing demand, have grown out of the country's decades of development and now mature expertise. The utility/commercial sector plays a key role in the national energy mix, ensuring base load and stabilising the operation of the National Power System. Large-scale power plants operating in energy basins, and combined heat and power plants located in the vicinity of the largest urban agglomerations still use mainly coal, which, on the one hand, underpins the country's energy security, but on the other hand also affects the competitiveness of the national economy, mainly due to the increasing costs of coal fuel procurement and environmental costs.



Poland is committed to radically reducing the share of coal in its fuel mix, which is a direct result of EU climate policy. Replacing decommissioned coal-fired units with new, dispatchable sources is becoming a major challenge. The absence of such sources in the system will result in the risk of a power capacity deficit, threatening the security of supply. Currently, only gas-fired power generation and, in the long term, nuclear power can guarantee the expected generation potential. However, viewing gas sources as the ultimate foundation of the country's energy security is inappropriate. This stems from the high risk of natural gas price volatility, which would need to be additionally sourced from regions with unstable political situations, in order to meet high consumption. It should also be remembered that the combustion of natural gas, like coal, generates carbon dioxide emissions. In the vision of the energy transformation, gas sources should maintain their role as balancing sources, temporarily providing a large volume of usable energy, which should be reduced as new nuclear power units are commissioned. So-called gas-fired peaking plants, typically gas turbines with a capacity of up to 50 MW, could continue to play a significant role even after 2050.

Urgent action is needed to implement the nuclear energy development plans outlined in strategic government documents, in parallel with the development of renewable energy sources. Nuclear energy offers stable energy generation without greenhouse gas emissions, making it a natural pillar for the decarbonisation of the energy sector. **The share of nuclear energy should be increased by replacing the installed capacity of coal-fired power plants with new nuclear units, preferably located at their current locations or in close proximity to decommissioned coal-fired power plants.** This approach simultaneously allows for both achieving climate goals and maintaining the continued good health of local economies. Utilising the electricity transmission infrastructure and elements of the local infrastructure offers an opportunity to reduce the costs of building nuclear power plants. Investments of this nature are consistent with the **Coal-to-Nuclear (C2N)** transition concept, which is growing in popularity around the world, mainly in regions that owe their economic development to the important role of coal in the energy sector, which are now facing the need to decarbonise their economies. This is why the C2N concept has garnered the greatest interest in the USA and China. However, thanks to early analytical studies and promotional activities carried out since 2019, Poland is among the pioneering countries in assessing and implementing the C2N concept into its energy strategies. The pioneering nature of the work of Polish scientists has been recognized in numerous important reports on the C2N pathway, including the 2022 report by the United States Department of Energy [1], which forms the basis for the current global interest in this investment concept. The report indicates that in the United States alone, as many as 215 locations (with a combined potential of over 260 GW) could be covered by the C2N pathway, bringing tangible economic and social benefits. It estimates, among other things, that converting a typical 1,200 MW coal-fired power plant to a nuclear unit could double the number of jobs and increase the value of the regional economy by \$275 million annually. **The C2N pathway is seen as an opportunity to reconcile climate goals with protecting jobs and industrial potential in the regions,** a point emphasised not only by the national scientific community but also by political decision makers.

What is this document?

This document, the Plan for the decarbonisation of the Polish power sector through modernisation using nuclear reactors, is of a recommendatory nature and is the result of the **DEsire** research project, carried out in 2022 and 2025 by a consortium of five institutions: the Silesian University of Technology (project leader), the Ministry of Energy, the Institute of Nuclear Chemistry and Technology, BSPiR Energoprojekt-Katowice S.A., and the Sobieski Institute Foundation. The project was implemented as part of the **Gospostrateg VI** program, financed by the **National Centre for Research and Development**. This plan expands on and details the objectives and implementation of the C2N transformation path, which was outlined in the draft update of the Polish Nuclear Power Program (PPEJ) [2]. This Plan responds to dynamically changing market conditions, growing climate requirements, social expectations regarding a 'Just Transition', and progress in the development of nuclear technologies. Putting the transformation in a broader context, the Plan not only outlines a recommended course of action for investments planned in the nuclear energy sector, but also identifies possible tools, important accompanying activities, and potential outcomes resulting from adopting this transformation path. The document is addressed to the government, potential investors, system operators, technology developers, financial institutions, and local communities. It is a compendium of knowledge, indicating necessary legislative reforms, financing models, and measures to ensure public acceptance. The document is a synthesis of the results of the work carried out, which were published in extensive partial reports and publications of the DEsire project. These, in turn, were the result of analytical work conducted by entities involved in the DEsire project, as well as a series of meetings with national stakeholders regarding the potential adoption of the C2N path.

The role of nuclear energy in the transformation – context and conditions for C2N investments

Nuclear energy is currently experiencing a worldwide renaissance. Faced with climate challenges, many countries are reconsidering their approach to nuclear power, recognising that achieving their emission reduction targets without it will be very difficult. This belief is shared by 14 of the largest global financial institutions, which pledged their support for nuclear investments in September 2024. Countries such as the US and China have announced ambitious plans to build new reactors (200 GW by 2050 and 400 GW by 2060, respectively). Changes in attitudes toward investment are also visible in Europe - the Netherlands, Finland, the Czech Republic, the UK, Sweden, Slovenia, and Bulgaria are among the countries planning new nuclear power plants. Italy and Switzerland, previously sceptical of nuclear energy, are considering a return to nuclear power. Poland, one of the countries where nuclear energy enjoys high public support, has also decided to build large-scale nuclear power plants – PPEJ [2] (in accordance with the draft update from 2025) assumes the commissioning of 6 to 9 GW of nuclear power units by the end of 2042. According to the plans, generation systems based on large-scale Gen. III+ reactors are to cover part of the gap left by the decommissioned coal-fired power plants and will modernise the generation system. When formulating subsequent national policies (for the post-2040 period), it should be borne in mind that, depending on the economic situation, the scale of challenges may increase significantly in relation to the goals formulated in the 2020 update of the PPEJ. Analyses by some institutions indicate a potential need for national implementations in the nuclear energy sector, which could reach up to 20 GW of capacity by 2050. Small modular reactors (SMRs) may provide an opportunity to meet such high needs, especially given the high global interest in investments, and the unfortunately, still low market readiness of technology giants. This refers not only to Gen. III+ reactors, but also Gen. IV reactors. Although over 80 SMR projects are being developed worldwide [3], it is estimated that only a small portion of them have a chance of commercialisation. Fortunately, market leaders such as EDF, GE Vernova Hitachi, KHNP, Rolls-Royce, and Westinghouse are among those developing designs. The extensive market experience of these companies, demonstrated by their engineering capabilities, ability to conduct licensing procedures, and establish supply chains, enhances the credibility of implementing these technologies. In Poland, plans to implement the BWRX-300 reactor are particularly advanced. The Orlen Synthos Green Energy consortium, in collaboration with GE Vernova Hitachi, plans to commission the first such reactor in the 2030s (the second in the world) and develop a fleet concept for the product in the following years. Włocławek is the planned location for the construction of the first and subsequent five reactors. At the same time, Nuward, a French company with financial ties to EDF, is working on its own reactor design. The same is true for Rolls-Royce and Westinghouse. Research is underway in the area of high-temperature, Generation IV reactors. China took a significant step by commissioning two HTR-PM (gas-cooled reactors), making it the only country where Gen. IV reactors are currently synchronized with the grid and in trial operation.

There are still over a hundred coal-fired power units in operation in Poland, with a total capacity of approximately 28 GW. These include both lignite-fired units (Bełchatów – the largest power plant in

the EU with a capacity of 4.4 GW, Turów – 1.5 GW, Pątnów – a total of 1.1 GW) and hard coal-fired units (including Kozienice – 4.0 GW, Opole – 3.3 GW, Rybnik – 1.8 GW, Jaworzno – 1.5 GW, Połaniec – 1.8 GW, Dolna Odra – 1.3 GW, Ostrołęka B – 0.7 GW, Łągisza – 0.5 GW and others). Many units are approaching the end of their technical operating life (the average age of Polish units exceeds 40 years). Even the newest coal-fired units (supercritical units commissioned in 2019–2020 in Jaworzno and Opole) will be technically obsolete by 2050. It is precisely with a view to the middle of this century that we need to plan the generation system today, safely assuming that no coal-fired units will be operating in the national power sector by 2050.

According to government declarations, Poland intends to end the use of coal for electricity generation by 2049 at the latest (this timeframe was adopted in agreement with the miners' trade unions). This means that over the next 25 years, almost the entire current fleet of coal-fired units must be replaced with new sources. Part of this gap will be filled by gas-fired units during the transition period (some energy companies have completed or are implementing investments in combined cycle units, e.g., Dolna Odra, Ostrołęka, Rybnik), which is a consequence of the transition's focus on achieving climate neutrality. In this situation, **the primary burden of decarbonising the system's core will undoubtedly, and ultimately rest on nuclear power, followed by renewable energy sources supported by energy storage** [4].

From the perspective of the KSE's stability, the proper location of new energy sources is crucial. The existing transmission network was designed to accommodate large thermal power plants located primarily in southern and central Poland, close to energy consumption centres, mainly industrial zones and municipal customers. Investment activities are already underway in the locations planned for the first nuclear power plant on the Baltic Sea. Offshore wind farms herald a significant shift of zones with high installed capacity density to the northern regions of the country, far from the main demand centres. This entails significant infrastructure development costs and limits business model choices. To avoid excessive transmission losses and costly grid expansion, it is advisable to locate additional large generation sources where coal-fired power plants have previously operated. Utilising existing high-capacity grid nodes and existing lines deriving power from these nodes will save time and money. It should also be remembered that many existing coal-fired power plants are located close to large energy consumers, which creates additional opportunities for selecting a business model and financing C2N projects. The proximity of electricity consumers to the sources of electricity production reduces energy losses resulting from long-distance transmission. Furthermore, maintaining energy production in traditional energy centres is crucial from a social perspective – it prevents a sudden collapse of labour markets and the degradation of local economies, which are often heavily dependent on the economic needs of the energy sector. In this way, C2N investments perfectly align with the idea of a 'Just Transition', giving a new lease on life for regions that have been dependent on coal-based energy for decades. Replacing a coal-fired power plant in a region with a nuclear source means maintaining continuity of employment, and even job growth, while maintaining tax revenues. These two factors provide a real guarantee against the threat of socio-economic collapse, and on a national scale, the risk of losing skills that have been

successfully developed in Poland for the construction and maintenance of conventional energy. These skills can largely be successfully utilised for the needs of the nuclear sector.

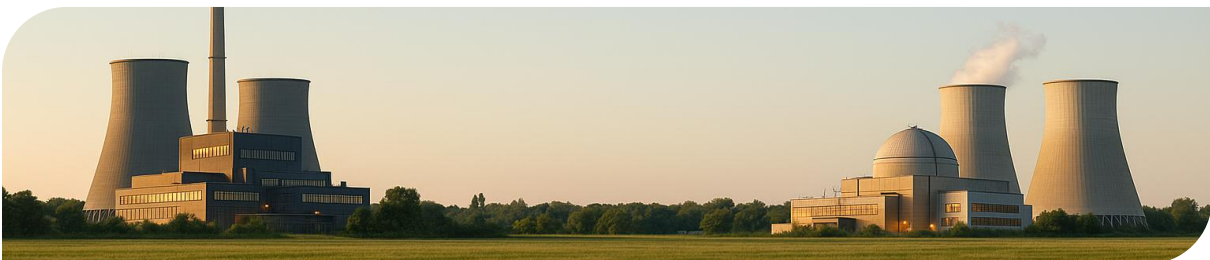
In summary, the development of nuclear energy in Poland is now more desirable than ever before. It is a prerequisite for maintaining energy security and economic competitiveness, which are under pressure from rising emissions costs and geopolitical uncertainty. Nuclear power should become an integral element of a diversified energy mix – alongside renewable energy sources (RES) and other low-carbon technologies (energy storage, and in the future, possibly hydrogen or CCS). Although nuclear technologies appear to be crucial in the energy transformation process, the planned nuclearisation of the mix must nevertheless take into account practical constraints, including the particularly long investment lead time, high capital costs, and the need to prepare the regulatory and social environments. Investments classified in the C2N group may differ significantly from one to another. Investments may take place both on the sites of currently operating power plants and at a distance from them. Although in the first case, elements of the infrastructure of the decommissioned facility are used in the investment process, the scale of their adaptation may vary – from adaptation of the site alone, through the adaptation of the auxiliary infrastructure (power output, cooling systems, buildings, roads), to adaptation of the basic infrastructure (in theory, even the steam turbine unit).

Classification of C2N investment paths

This section outlines four investment paths that involve the construction of a nuclear power facility on, or at a certain distance from a coal-fired power plant. These paths are: greenfield, brownfield, direct, and indirect [5]. The first two describe the location strategy, while the second two describe the method of integrating the new technology with the existing core infrastructure of the coal-fired power plant. In practice, these paths create a matrix of options in which the investor compares site conditions, the maturity of the network and cooling systems, the condition of the technological assets, regulatory requirements, schedule, and costs. This approach is consistent with recommendations in the literature on the subject, and the experience of the first projects in the world, which show that so-called repowering of coal-fired sites can shorten schedules and reduce expenditure, provided that the scope of reuse is realistically tailored for the specific site and the selected technology. According to the US DOE/INL analysis [1], for the reference site, overnight capital savings compared to a full greenfield site may range from a dozen to several dozen percent thanks to the use of existing assets, with a critical approach to the quality and compatibility of the elements inherited from the coal-fired unit being key.

The **greenfield path** involves the construction of a nuclear power plant in a new, greenfield location, without any connection to a decommissioned coal-fired power plant, but maintaining geographical proximity. Its essence lies in complete freedom in optimising the technological layout, water and cooling management, power transmission system, and safety zones, thus minimising design compromises. The typical scope of the pre-investment activities involves a more complex process due to the need to purchase land and obtain environmental and location permits (required not so much for the foundation of the nuclear facility, as for organising basic construction works), as well as the need to build grid connections, access roads, and facilities from scratch. What the greenfield path shares with the other C2N paths is the ability to utilise electricity transmission infrastructure, including a high-capacity grid node, although there is a need here to build a direct line from the facility to the node. As with the other paths, great value is added by the access to the local workforce and potentially high social acceptance for energy projects.

The **brownfield path** involves the construction of a nuclear power plant on the site of an existing coal-fired power plant, or in its immediate vicinity, with the intention of utilising as much of the existing technical infrastructure as possible. Its essence lies in capitalising on existing grid connections and power transmission systems, rights to water intakes and cooling systems, roads and sidings, and buildings. In global practice, this category includes projects that take over the skeleton of the site and grid framework, while the scope of secondary reuse of mechanical elements is assessed on a case-by-case basis. Analytical results cited in the 2022 US DOE/INL report [1] show that up to 80% of coal-fired power plant sites surveyed in the US meet the basic adaptation criteria, which demonstrates a large pool of potential locations for brownfield investments. Adapting the brownfield path can shorten the investment cycle and reduce expenditure, but also imposes design constraints resulting from the geometry of existing facilities, hydrological conditions, and the environmental history of the site. In Europe, one brownfield aspiration, among others, is the Romanian project in Doicești, on the site of a former coal-fired power plant. Investors and development institutions are pointing to the potential for accelerating investment preparation courtesy of the site's resources. In North America, Canada's SaskPower has taken a similar approach, narrowing the choice of the first location for SMRs to the Estevan region, in the immediate vicinity of coal-fired assets and existing water and grid infrastructure. The brownfield path was the focus of the DEsire project. This path was chosen as the subject of analysis as it is more challenging to implement than the greenfield route. It can be assumed that if the analysis demonstrates justification for investment at the site of an operating coal-fired power plant, then the greenfield investment will also be justified. The final choice of the investment location should then be determined by the analysis results of the benefits and barriers for both investment options.

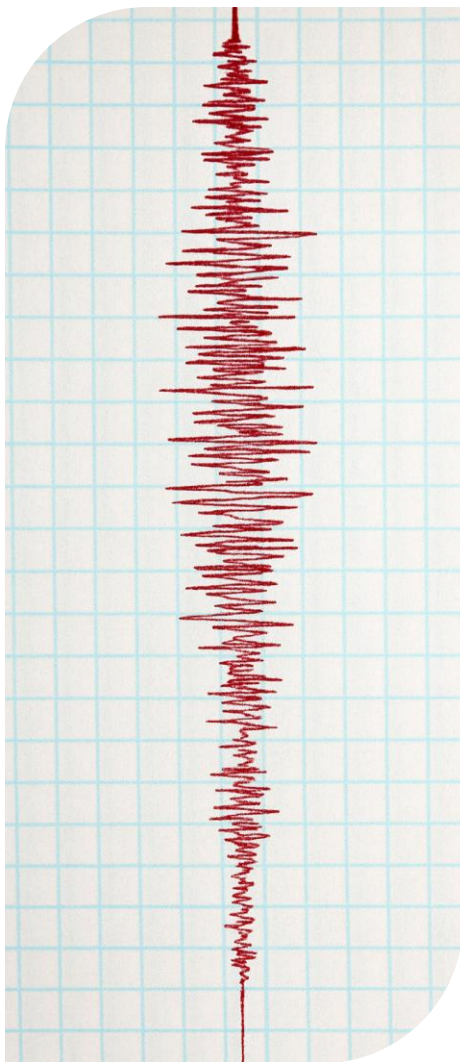


The *direct* and *indirect paths* can be classified together. These paths assume integration, in which a nuclear reactor (or reactor system) powers the existing thermal cycle of a steam turbine unit, which is part of the core infrastructure of a decommissioned coal-fired unit. Therefore, these paths are not so much an investment option for a new power plant, but rather an option for modernising a specific coal-fired unit through the use of nuclear technologies. This investment can potentially lead to the highest capital savings due to the reuse of as many of the unit's core infrastructure components as possible, i.e., the steam turbine, generator, condenser, and cooling system. Pioneering analyses conducted in Poland [6] have demonstrated that the financial investment savings resulting from adopting the direct path can be as high as 35%. In the most favourable case, from the perspective of costs incurred, only the heat source is replaced – the boiler island is replaced with a reactor island. In the case of the indirect path, an additional element is used compared to the direct path, a thermal storage tank, which is located in the thermal structure of the system between the reactor island and the turbine island. The thermal storage, which acts as heat coupling, can make the unit's operation more flexible – it can maintain the desired, and thus constant and nominal, load of the reactor island, while the turbine island's load can be varied to match demand. The disadvantages of the direct and indirect paths stem from the requirements to ensure thermodynamic compatibility. This limitation results in the need to use high-temperature reactors in the project, capable of producing steam at temperatures and pressures appropriate for the design conditions of steam turbines, which are currently widely used in conventional power generation (including those with supercritical parameters). An additional challenge is the design and licensing definition of the nuclear safety zone boundaries, as key elements of the secondary circuit were designed in accordance with other standards. The research and implementation experience of EPRI, INL, and NASEO confirms that the paths discussed above remain primarily an engineering option, analysed using case studies, and are not yet a commercially implemented practice. These conclusions are confirmed by the analyses carried out by the DESire project. The concept of deep utilisation of the core infrastructure of a coal-fired unit can be only a hypothetical option in European conditions, because: (i) the infrastructure of even the latest coal-fired units operating in Europe is entering a mature stage of operation, which means that their technical condition at the time of potential commissioning of a nuclear power plant does not bode well for further long-term operation; (ii) Generation IV nuclear reactor technology is not readily available in Europe. The results of analyses of the direct and indirect paths, which were also the subject of the DESire project, can be found in publications [6,7,8]. Due to the identified lack of implementation potential in national conditions, and thus the rather academic nature of the analyses, this document does not extensively address this repowering option. Direct and indirect paths are of interest to research centres in China [9,10], where they have a much higher implementation potential.

The classification presented should not be used as a basis for quick conclusions, but rather as a tool for investment planning, based on information gathered on the condition of the infrastructure components of the decarbonised coal system, their characteristics, the maturity and availability of nuclear technologies, and the expected functionality of the planned investments. Reports and guides – from the US DOE/INL [1], through PNNL [11] and NASEO [12], to the Repower Initiative [13] – consistently emphasize that the key is an early, reliable assessment of the investment site, and proper identification of barriers and risk factors, so that the benefits of repowering are not reduced by haste or excessive optimism regarding the investment feasibility.

Criteria for assessing coal-fired sites

The criteria for determining the suitability of a given site for a nuclear investment are primarily those related to **nuclear safety**. These are formulated based on applicable international standards and requirements, and every planned nuclear investment is subject to them, which means that the locations designated for the C2N path are not exceptional cases (they are treated according to standard rules). Undoubtedly, the conditions particular to a specific site, which was never initially intended for a nuclear investment, may significantly hinder or even prevent the investment. The assessment may contribute to shifting interest towards the greenfield path, as often moving the future construction site, even by a few kilometers, may eliminate significant limiting or even exclusionary factors. Safety requirements are identified for the entire investment process, i.e., licensing, commissioning, operation, and decommissioning processes. A number of criteria in this area form the basis for the assessment after the selection of the nuclear reactor technology itself, as well as the method of handling nuclear fuel and radioactive waste. In the area of nuclear safety, four areas of assessment can be identified [14]. These are:



Formal requirements and recommendations imposed by international and national organisations on the design and operation of nuclear power systems. The assessment criteria in this area derive directly from the Regulation of the Council of Ministers of August 10, 2012 [15]. A number of criteria from this case constitute a set of factors that may determine the inability to establish a nuclear facility in a given area. These criteria are of colossal importance in assessing the appropriate locations for operating coal-fired power plants. Although these CFPPs were subject to assessment of ground properties, seismic activity risk, flooding or waterlogging, or proximity to protected areas, in many cases the scale of these criteria cannot be compared to the requirements accompanying the assessment of the site for a nuclear facility. Other exclusionary factors may include the presence of mineral deposits in the region, local mining activity (even within the last 60 years), military facilities or areas, chemical, biological, or mechanical plants, and civilian airports. The site designated for a nuclear investment should be seismically stable (Poland generally meets this condition) and not at risk of floods, landslides, etc.

A special case is locations adjacent to active open-pit coal mines – this applies, for example, to Bełchatów and Turów, where power plants are located in close proximity to very large lignite mines. The proximity of underground mines to the investment site also poses a potential threat, which poses a real challenge in regions such as Silesia and Zagłębie. Such proximity can create geotechnical risks (land subsidence) and make it difficult to obtain permits (mines may not meet standards for substrate stability and seismic impact). Therefore, in such cases, the recommended alternative is a greenfield investment. While this does not allow for the deep use of elements of the coal-fired power plant infrastructure with the nuclear investment, it does remove potential geotechnical barriers, and also upholds the most important arguments underlying the rationale for implementing a C2N investment: the use of transmission infrastructure and the beneficial impact of the investment on the comfort of local communities.

Potential nuclear hazards for plant personnel and the local population. One of the most important criteria in this field is the population density in the region where the plant is located (i.e., within 30 km of the nuclear facility) due to the potential exposure of the local population to ionising radiation in the event of a plant failure. Another criterion in this field is the degree of development of the transport infrastructure, which related to the possibility of evacuation and rescue operations in emergency situations. The more extensive the infrastructure (rail and road), the more favourable the assessment for the location may be. Two further criteria in this field, namely the hydrogeological conditions and local wind conditions, are significant from the perspective of the potential spread of radioactive substances outside the nuclear facility. The presence of underground water reservoirs poses a potential threat of contamination of a large area. Many coal-fired power plants are located outside cities (e.g., Koźienice Power Plant is approximately 80 km from Warsaw, Połaniec Power Plant is located far from larger cities, and Bełchatów Power Plant is located far from large urban agglomerations). However, there are also those that border large urban areas (Jaworzno Power Plant, Rybnik Power Plant), which means that this aspect requires thorough analyses in these cases.

The reactor safety systems, the steam turbine thermal cycle, and the auxiliary infrastructure. In this regard, a number of criteria are identified, which can be used as the basis for evaluation, solely based on knowledge of the reactor design to be used within a given investment project. The following factors are subject to assessment: the number of safety systems, the redundancy of the cooling systems, the potential consequences of a major accident involving damage to the containment system, and the level of technological advancement. The evaluation process also utilises a criterion related to access to local water sources in sufficient quantities for cooling the nuclear facility. This criterion is based on the assumption that, in emergency situations, access to water required for reactor cooling is crucial for safety.

Management of spent nuclear fuel and radioactive waste. In this area, difficulty in assessing the location may result from the stage of investment planning, where technology choices have not yet been made. In this case, in addition to knowledge of selected nuclear reactor solutions, this evaluation process also requires knowledge of future management of spent fuel, which in Poland is determined at the government decision level. Therefore, it can be concluded that developing a path

for nuclear fuel and radioactive waste management extends far beyond the early site assessment stage.

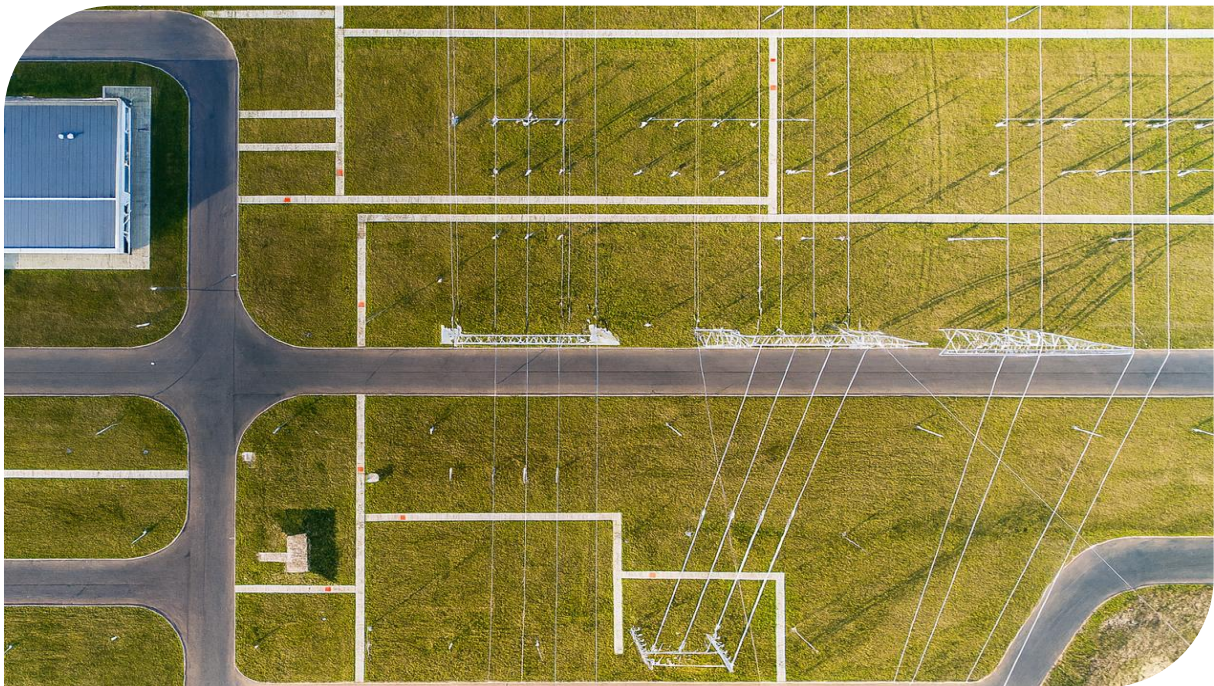
The specific nature of C2N investments requires a broader perspective on location conditions. This information serves as the basis for assessing investment sites, especially for those locations that are precisely suited to currently operating coal-fired energy systems. The essence of C2N investments is focused on the possibility of leveraging previously developed infrastructure which operated within coal-fired power plants. This requires an assessment of the feasibility of adaptation, which may be influenced by the technical characteristics and condition of existing infrastructure elements.

Technical evaluation criteria include:

Water availability for condenser cooling. A large nuclear power plant requires significant amounts of cooling water, primarily due to the need to condense steam in the steam turbine cycle, which is not directly related to nuclear safety aspects. Ideally, a coal-fired power plant should be located on a river or lake, or have access to extensive reservoirs of process water. For example, Koźlenice, Połaniec, Dolna Odra, and Ostrołęka power plants have direct access to rivers (the Vistula, Odra, and Narew), while Rybnik and Pątnów power plants have access to large water reservoirs. For power plants located near lignite open-pit mines, there is great potential for developing excavations for the creation of water reservoirs for nuclear facilities. However, preparing these excavations and filling them with water requires a lengthy period of time and must be part of the region's water management planning. Assessing the availability of water resources is one of the key challenges in assessing a location for a nuclear investment, and the specific volume of available water will determine the choice of cooling technology and the maximum power capacity of the development (this also depends on the reactor technology and must be correlated with the efficiency of the steam turbine thermal cycle, which is designed for the steam parameters generated by the nuclear heat source). Due to the multitude of condenser cooling technologies (including dry cooling), water availability is not a critical factor, but it can significantly determine the technical, and therefore economic efficiency of a nuclear power plant. Nevertheless, water availability is not the most significant factor when it comes to the costs of energy production by a nuclear power plant. Factors related to investment financing (e.g. capital costs) and the operating regime (the energy market and the Transmission System Operator policies, which influence the degree of utilisation of installed capacity) have a decidedly greater impact.



Power transmission potential (grid nodes). The current power infrastructure is assessed to ensure it has the capacity to receive and transmit the power of the new power plant. Large coal-fired power plants are typically connected to the grid by several high-voltage lines. The points where these lines connect to the transmission grid constitute important system nodes. This capital can be exploited by implementing the C2N investment concept. The largest transmission nodes in Poland are located near power plants in energy basins – e.g., in the areas of Bełchatów, Koźienice, Połaniec, Konin, Turoszów, and in the Silesian and Zagłębie regions (Rybnik, Łągisza, Jaworzno). Their preservation facilitates the integration of new capacity without costly network expansion. The grid structure, which extends across the entire country, is strongly determined by the locations of the currently existing grid nodes.



Land availability. A nuclear power plant (especially one with at least two units) requires a large area of land for technical buildings, safety zones, and construction facilities. Large coal-fired power plants often have extensive industrial or forest areas at their disposal – some of which can be used for new investments. Analyses indicate that the available land on the sites of most Polish coal-fired power plants is sufficient for the construction of a system with at least two high-power reactors (over 1,100 MW). However, the need to demolish some existing infrastructure (e.g., cooling towers, buildings, storage facilities) and the phasing of works to ensure space for the construction of new facilities must be taken into account. The overlap between the start date of preparatory and investment work, and the end date of operation and decommissioning of coal-fired units may be a challenge in developing a schedule for brownfield path projects.

Auxiliary infrastructure. This infrastructure includes existing access roads, railway lines, sidings, storage yards, utility connections, water intakes, etc. These elements, originally built for the requirements of coal-fired power plants, can largely be reused in the construction of a nuclear power plant, significantly reducing costs and shortening the investment schedule. For example, most coal-

fired power plants have their own railway sidings, which are or were used for coal deliveries, and which can be used to transport heavy machinery, equipment, and structural components. CFPPs also have water treatment plants, workshops, and warehouses. Once adapted, many of these features can be used as part of the investment project, and even in the operation of the new facility. For the direct and indirect paths, it is much more important to assess the core CFPP infrastructure potentially subject to modernisation.

The DEsire project developed rankings of locations suitable for large power plants and combined heat and power plants following the brownfield path, and rankings for the newest coal-fired power units using the direct path. The methodology is described in detail in the project's interim reports. The assessment results can also be found in this publication [16]. The rankings developed should not constitute the basis for drawing far-reaching conclusions regarding the selection of second and subsequent locations for national nuclear investments. The location assessment was primarily aimed at identifying locations of interest for the preliminary feasibility studies planned in the DEsire project. A preliminary assessment of locations suitable for repowering coal-fired power generation systems can also be conducted using the RepowerScore tool [17], developed by the international Repower Initiative [13], with the support of the DEsire Energy Transformation Platform, which was established as one of the results of the DEsire project.

Preliminary feasibility studies for drawing conclusions and formulating recommendations

To illustrate the practical aspects of the Coal-to-Nuclear transformation, the DEsire project conducted **preliminary feasibility studies**. These studies covered three potential investments, two of which were brownfield and one of which was direct. The studies covered Kozienice Power Plant [18], Dolna Odra Power Plant [19], and one of the 900 MW units operating at Opole Power Plant [20]. The aim of these analyses was to examine how investment processes could proceed with realistic site conditions, and what technical and economic outcomes they could achieve. Site development concepts and investment schedules were developed, taking into account all key stages, from the analysis phase, through obtaining permits, to the construction and commissioning of new nuclear systems.

Kozienice Power Plant

Facility characteristics: Kozienice Power Plant is the largest hard CFPP in Poland (installed capacity: 8 x 220 MW + 2 x 570 MW + 1 x 1075 MW = approx. 4000 MW). Located on the Vistula River, it boasts excellent cooling conditions and extensive grounds. It is a key network node in central Poland. Most of the units (220 MW) date back to the 1970s, with the newest unit, B11 (1075 MW), was built in 2017. **The brownfield investment concept** proposed by Energoprojekt-Katowice focused on the construction of **two Generation III+ nuclear units** (e.g., EPR, APR1400, or AP1000) with an electrical capacity of 2 x 1100–1650 MW, with a total capacity comparable to the power plant's existing capacity. These units would be built on a separate section of the power plant site, replacing the decommissioned old coal-fired units. The existing 400 kV connections, water infrastructure (including operations must begin immediately (2025/26). supply canal from the Vistula River), some internal roads, and adaptable buildings would be used. A preliminary development plan has been prepared, integrating the new technology with the existing spatial layout – e.g., the reactors would be located a safe distance from existing equipment, yet allowing for the use of the existing transformer station and water channels.

The investment scenario for Kozienice Power Plant calls for the closure of the CFPP by 2032, and the construction of two nuclear units between 2035 and 2044, with the aim of restoring the installed capacity of this important energy hub by the mid-2040s. The period of approximately 12 years (2033–2044) is how long the region would have to function without the power plant. Therefore, it is crucial to secure the region economically and socially. On a national scale, this example demonstrates that the implementation time for a full-scale nuclear project can be 18–20 years, meaning that operations must begin immediately (2025/26) to meet the deadline of 2045. While the time horizon for the investment is long, it should be noted that it was guided by a conservative approach, taking into account possible delays and the requirements of safety procedures.



Photograph: ENEA

Schedule: A schedule analysis indicates that the entire process, from initial studies to commissioning of the 2nd nuclear unit, could take approximately **20 years** (2026–2045). The following key stages have been identified:

2026: **Start of the preparatory phase** – development of a feasibility study (12 months), investor's decision to proceed with the project.

2027–2032: **Phase of obtaining decisions and preliminary permits** – site selection, decision in principle, environmental impact report and environmental decision, preparation of a preliminary safety report and location report. This is scheduled to take **66 months**. Pursuant to the Nuclear Act, a location decision should be made by 2028. Obtaining the decision in principle and the decision on the location of the nuclear facility is expected by mid-2032.

2032–2034: **Issuance of the relevant nuclear safety and construction permits** – first, a permit for preparatory work (around July 2032), then, after submitting the construction design and obtaining approvals, a basic permit for the construction of the NPP (late 2033/early 2034). The Plan indicates that although the statutory time for issuing a building permit is short, the preparatory process takes approx. 2 years. Realistically, construction would begin in 2034.

2033–2035: **Preparatory work on the construction site** (earthworks, dismantling, construction of auxiliary infrastructure) – approx. 2 - 3 years. All existing coal-fired units are expected to be decommissioned by the end of 2032 (in practice, unit B11 could operate longer, but full decarbonisation has been assumed).

2035: **First concrete poured** – i.e., the start of actual construction work on reactor No. 1 is planned for March 2035. For reactor No. 2, the first concrete will be poured a year later, in March 2036.

2035–2042: **Construction of reactor buildings, equipment installation** – the unit is expected to take approx. 8 years to construct. Equipment delivery and design work (part of the detailed design) are planned in parallel, which will begin before obtaining a building permit, and will continue until the end of assembly (design and delivery by June 2034–September 2043).

2041–2043: **Commissioning and testing of unit No. 1** – approx. 2 years (plan: October 2041–October 2043, cold and hot tests), followed by obtaining a nuclear commissioning permit (November 2041–August 2042), a facility occupancy permit (Jun 2042), and an operating permit (July 2044). These dates are based on the rigorous testing and acceptance process. Unit 1 is expected to be commissioned around 2044 (commercial operation begins).

2042–2045: The analogous **Unit 2 start-up and commissioning** - shifted by one year relevant to Unit 1, which results in Unit 2 being ready for operation in early 2045.

Full power from both nuclear units would therefore be available from early 2045.

Dolna Odra Power Plant

Facility Characteristics: Dolna Odra Power Plant is a baseload power plant in Western Pomerania, originally comprising eight 200 MW units (totalling 1.6 GW). Currently, some of the coal-fired units have been decommissioned, and in their place, the owner, Polska Grupa Energetyczna S.A., has built two large combined cycle steam-gas units (2 x 700 MW). The feasibility study scenario assumed that a nuclear investment is an alternative to the combined cycle units or is implemented after their operational end. Therefore, it was assumed that their current location could be used for a nuclear investment. The power plant has access to the Odra River and has a large area at its disposal. It is also approximately 20 km from Szczecin. The Polish border with Germany is even closer, approximately 3 km from the power plant, which may pose a significant challenge in conducting cross-border consultations. Due to space and network constraints, the nuclear investment scenario assumed the construction of **a single large-scale nuclear power unit with a Generation III+ reactor**, which would largely replace the capacity of all the units currently operating on-site. The new nuclear power unit would be located on the power plant's premises. As part of the study, a site plan was developed showing the layout of the reactor buildings, turbines, security zone, etc., while preserving existing infrastructure elements (cooling water pipelines drawn from the Odra River, railway siding, and the area occupied by the old boilers). The project also factors in the dismantling of selected sections of track and the construction of new ones to serve the reactor construction site, as well as the establishment of new internal roads and a fence delimiting the nuclear power plant area.

The schedule for the investment planned for the Dolna Odra Power Plant is similar to that prepared for the Kozenice Power Plant, despite the fact that it assumes the construction of only one nuclear power unit. In this case, the coal-fired units were also assumed to be completed by the end of 2032, more than a decade before the nuclear power plant's commissioning. The gap in electricity generation in the region could be filled by gas-fired power units. Keeping these in operation would need to be factored into the planning of the site and construction work.



Photograph: PGE

Schedule: The schedule for this investment project calls for a project start in 2026 and completion around **2044** (i.e., approximately 18 years). Key stages include:

2026: Start of the preparatory phase – development of a feasibility study (12 months), investor's decision to proceed with the project.

2027–2032: Phase of obtaining decisions and preliminary permits – location selection, in-principle decision, environmental impact report and environmental decision, preparation of a preliminary safety report and location report. This is scheduled to take approximately 66 months. Pursuant to the Nuclear Act, a location decision should be made by 2028. Obtaining the in-principle decision and the decision on determining the location of the nuclear facility is expected by mid-2032.

2032–2034: Issuance of the relevant nuclear safety and construction permits – first, a permit for preparatory work (approximately July 2032), then, after submitting the construction design and obtaining approvals, a basic permit for the construction of the nuclear power plant (by July 2034).

2033–2035: Preparatory work on the construction site (earthworks, dismantling of selected old equipment, construction of auxiliary infrastructure) – approximately 2–3 years. At the Dolna Odra Power Plant, decommissioning of all existing coal-fired units is planned by the end of 2032.

2035: First concrete poured – commencement of actual construction work on the reactor is planned for March 2035.

2035–2042: Construction of the reactor building, assembly of equipment – the expected construction time for the unit is approximately 8 years. Equipment delivery and design work (part of the detailed design) are planned in parallel, beginning before obtaining a building permit and continuing until assembly is completed (the schedule assumes design and delivery for June 2034 – September 2042).

2041–2043: Unit commissioning and testing – approximately two years (planned: October 2041 – October 2043, cold and hot tests), followed by obtaining a nuclear commissioning permit (scheduled for November 2041 – August 2042), a facility occupancy permit (June 2042), and finally an operating permit (January 2045).

These dates are based on the rigorous testing and acceptance process. The unit is expected to be commissioned in early 2045 (commencement of commercial operation).

Feasibility studies have confirmed that **the implementation of C2N projects in Poland is technically feasible**, although it requires efficient organisation and favourable environmental conditions. A significant aspect, particularly from the perspective of ensuring the system has available sources, is the **long time horizon** that characterises all nuclear investments. It takes 15 to 20 years from obtaining formal decisions and permits to commissioning a nuclear unit. This means that commissioning new capacity into the system in the 2040s would require planning to begin in the coming years. The most time-consuming procedures are the formal ones (obtaining approvals, safety reports) and the construction and commissioning itself. The Plan must take this schedule into account, as any delays in decisions will result in a power capacity deficit, particularly due to the planned shutdowns of many coal-fired units in the 2030s.

From a security of supply perspective, it may be problematic to subject power plants that have the potential to maintain electricity production in the long term to a nuclear investment following the brownfield path. In the cases analysed, in connection with potential C2N investment, there is a gap of several years between the decommissioning of the last coal-fired units and the commissioning of nuclear units (Kozienice Power Plant 2033–2044, Dolna Odra Power Plant 2033–2043). This interruption in operational use also poses a potential threat to the ability to maintain a high level of employee competence for the nuclear power plant operation in the investment locations. The break in operation also threatens the maintenance of a high standard of living for local communities, which may also contribute to mass migration. Efforts should be made to minimise the duration of interruptions in energy production, e.g., by gradually decommissioning units so that some of them operate for longer, or by introducing temporary replacement sources (e.g., gas sources, energy storage, or other heating sources). Where possible, it is also advisable to accelerate the construction process of the nuclear facilities e.g., by conducting some of the preparatory work in parallel before obtaining all decisions (at the investor's risk) or by optimising supplies.

Detailed investment plans included in the feasibility studies took into the account the use of not only former coal-fired power plant sites, but also selected infrastructure elements. At Kozienice and Dolna Odra Power Plants, utilising existing water cooling channels, intakes, and discharges is not a major challenge. Power lines and distribution stations could potentially remain operational, with ongoing monitoring and maintenance. However, analyses carried out as part of the feasibility studies did not confirm the optimistic savings levels indicated in the US DOE/INL report [1], based on an assessment of the adaptability of infrastructure elements in power plants operating in the USA. In that report, savings from the development of existing coal-fired power plant infrastructure were estimated in relative terms and in relation to greenfield investment expenditures (not a C2N investment) to range from 15% to 25%. For a potential C2N investment, which could be for the Dolna Odra Power Plant, the analogous savings amounted to just under PLN 1.3 billion in absolute terms, which translates to a relative saving of approximately 1.8%. For the Kozienice Power Plant investment, this would be just under PLN 1.4 billion, with a relative saving of only about 1.4%. In the context of potential cost savings investment, each location eligible for C2N investment should be considered individually, as the technical condition of infrastructure elements in domestic power plants, and therefore the potential for their development, varies significantly. Regardless of the size

of the savings, the use of selected infrastructure elements can be very beneficial, as, for example, the construction of new water intakes and power transmission lines is often a bottleneck for energy projects. These stages of work can often be saddled with long implementation times, also due to emerging public resistance, which is often manifested in protests.

Table. Cost comparison for C2N/brownfield investments and for a typical greenfield investment

No.	Cost category	<i>Net costs, PLN million</i>			
		Kozienice PP		Dolna Odra PP	
		<i>C2N /Brownfield</i>	<i>Greenfield</i>	<i>C2N /Brownfield</i>	<i>Greenfield</i>
1	Reactor Island	15,179.0	15,179.0	10,746.7	10 746,7
2	Preliminary fuel inventory	8,515.0	8,515.0	6,028.6	6 028,6
3	Turbine Island	12,649.1	12,649.1	8,955.6	8 955,6
4	Condenser and heat discharge system	2,529.8	2,529.8	1,791.1	1 791,1
5	Electric island	4,216.4	4,216.4	2,985.2	2 985,2
6	Supporting infrastructure	12,649.1	12,649.1	8,955.6	8 955,6
7	Other apparatus and devices	1,686.6	1,686.6	1,194.1	1 194,1
8	Land and land rights	0	364.9	0	258,4
9	Other costs (ownership, transmission)	11,799.4	11,799.4	8,353.9	8 353,9
10	Total indirect costs	30,410.7	30,410.7	21,530.8	21 530,8
11	Savings from the use of the intake, discharge and pumping station building for cooling water	-25.0	0	-25.0	0
12	Power output costs	8.0	20.0	10.0	20,0
13	Costs of building a canal, taking in and discharging	0	220.0	0	220,0
14	Access road construction costs	0	125.0	0	125,0
15	Railway line construction costs	0	625.0	0	625,0
16	Total investment outlays	99,618.1	100,990.0	70,526.6	71 790,0

The locations analysed in the studies have the advantage of access to railway lines, which allow for the transport of heavy components. Existing railway sidings are easily adapted to the needs of nuclear investments. Watercourses can also play an important role in supply logistics. However, seasonal variations in water levels in the Vistula and Oder rivers (which determine their navigability), pose a significant risk to meeting investment deadlines, making river transport problematic for nuclear investments in inland locations.

During the feasibility studies, no disqualifying factors were identified regarding nuclear safety. Every nuclear investment must undergo very detailed and rigorous studies of seismic and hydrogeological conditions. Such studies form an indispensable basis for decisions which result in the selection of the investment location. Political aspects, which were not analysed in the DEsire project, pose a potential risk of delaying or even abandoning the investment. The proximity of the location to the national border may be particularly sensitive. The location of the Dolna Odra power plant, which is situated close to the Szczecin metropolitan area, and is close to the German border, can be considered problematic. For this reason, the location of the Dolna Odra Power Plant (but also, for example, the Turów Power Plant) should be considered difficult to process through cross-border consultations, which are a step in the process for obtaining an environmental decision.

Kozienice Power Plant received a very good rating from a nuclear location perspective. The generating system is located in a relatively isolated area, with high-density population centres a considerable distance from the investment site. No significant environmental conflicts were identified. This is a major advantage for the smooth commencement of the preparatory processes aimed at launching the investment, and is why this location has been included on the shortlist of potential locations for the second nuclear investment in Poland in the draft PPEJ update [2].

In summary, the case studies demonstrated the technical feasibility of the C2N scenarios. The organisational challenge remains: ensuring the investment is carried out on schedule and in accordance with the assumptions. This requires the creation of appropriate conditions in the legal, financial, and social spheres.

Infrastructure modernisation and integration of new sources

Transforming a coal-fired power plant into a nuclear power source involves not only the construction of new nuclear units but also the **comprehensive modernisation of the associated energy infrastructure**, ensuring it is adapted to the requirements of nuclear energy while fully utilising its potential. The most important areas of such modernisation are discussed below.

Transmission grids and substations. Under the C2N concept, new nuclear units will be integrated into the existing grid system, which will require adaptation. Only a few coal-fired power plants have installed capacities higher than the potential capacities of two nuclear units using the largest reactors (2x1650 MW). These power plants include Bełchatów, Kozienice, and Opole. This creates good prospects for the deployment of large-scale nuclear reactors in these locations. The resulting excess capacity can be used to deploy additional sources, such as gas peakers, energy storage

systems, or, in the future, SMRs. Each of these indicated locations currently operates supercritical power units – the potential technical usefulness for these system may be applicable until 2050. Only the operation of unit B14 at Bełchatów, with a capacity of 858 MW, may be limited by the availability of locally sourced lignite. The potential need to keep the supercritical units in operation should be taken into account when assessing the potential of a given location. The planning process should also consider ongoing or mature investments in gas-fired power units. Each location requires analyses of the condition of existing high-voltage lines, including the need to build additional lines and modernise transformer stations. The Plan envisages that the transmission system operator (PSE S.A.) will be involved in the process at an early stage, will conduct assessments and, if necessary, implement appropriate accompanying investments (e.g., adding new bays in substations, replacing autotransformers with units with higher short-circuit power, or modernising security measures). Fortunately, most locations have infrastructure reserves – for example, 400 kV nodes at power plants were designed with expansion in mind, so there is reserve space for additional transformers or switchgear. The priority is to ensure that power transmission from the new nuclear power plant does not constitute a bottleneck for the investment. Therefore, grid investments must be synchronised with the construction schedule for nuclear units. The Plan assumes close cooperation between the investor and PSE S.A. and the inclusion of joint projects in the *Transmission Grid Development Plan*.

Water management and cooling. Nuclear power plants, like coal-fired power plants, require the access to copious amounts of water. Water availability must be considered both from a nuclear safety perspective and for condenser cooling needs. In quantitative terms, significantly more water is required for the steam condensation process. Due to the lower thermal efficiency of steam turbine cycles operating in nuclear units, the amount of heat dissipated at the condenser level is higher in relation to the unit's installed power capacity than in standard coal-fired units. The amount of water required for a nuclear unit equipped with a light-water reactor can be more than double the amount of water needed to ensure proper cooling conditions in a modern supercritical unit. The identified amount of available water at the nuclear investment site is the basis for selecting the cooling method. This can be based on an open system, where heat is extracted directly from the cooling system by water drawn from a river or reservoir, or a closed system, where heat is extracted by water circulating in a closed loop between the condenser and the cooling tower (or fan), which discharges the heat to the atmosphere. In the latter case, water is required to supplement this closed loop. It should also be noted that dry cooling is possible, which reduces water consumption to negligible levels, although this comes at the expense of the unit's efficiency – the water is then used only to supplement the reactor and water-steam circuits.

In practice, a nuclear power unit with an electrical capacity of 1000 MW requires an open-loop water intake of approximately 50 m³/s. Water replenishment requirements for a closed-loop system are significantly lower and, depending on weather conditions and technology, can range from 0.7 to 1.5 m³/s. Preliminary analyses have shown that water resources used in coal-fired power generation can be successfully adapted to meet the needs of new nuclear investments in many locations [21]. From a technical vantage, it is even possible to implement investments involving the use of open cooling systems across several locations. Considering environmental protection, as well as the dynamically

changing hydrological conditions in river systems (due to global warming), open systems are not recommended to be included as part of nuclear investments in inland locations.

Infrastructure elements such as reservoirs, weirs, and channels should be utilised. The use of other cooling system components, such as cooling towers, does not seem justified due to their technical condition and the longevity these key components require for operating in nuclear facilities.

Securing water rights is crucial for the C2N pathway. A priority should be to ensure that the country's water management plans provide the necessary resources for nuclear systems, which will be the basis for ensuring the country's energy security.

Site development and cleanup. Before the actual construction work can begin, it is necessary to dismantle the redundant coal-fired power plant infrastructure and reclaim the land. These activities are important both for ensuring the required conditions for construction work, and for the subsequent operation of the nuclear facility, including monitoring by regulatory bodies. This scope of this work will include the removal of above-ground infrastructure elements, including fuel storage facilities, as well as the decommissioning of combustion waste storage sites (ash and slag heaps), if they are located within the perimeter of the planned nuclear power plant. Land reclamation is essential, especially if old settling ponds or landfills on the project site. Any soil contamination from coal combustion products must be neutralised before the construction of nuclear facilities. Despite many years of operation of coal-fired power systems at the site designated for the nuclear investment, geological surveys must be conducted, which may lead to recommendations regarding the need for ground reinforcement (e.g., piling, compaction), especially in those places where heavy reactor and turbine buildings will be located. These measures must be taken into account during the design phase. It is also recommended that reclamation activities be undertaken after mining operations cease, particularly those located in areas targeted for C2N investment, to take into account the need to limit geological impacts, such as the risk of inducing seismic activity.

Transport infrastructure. The construction of a NPP involves the delivery of many large-scale, heavy technical infrastructure components (pressure reactor vessels, turbines, generators, transformers, etc.). It is advantageous to use existing transport infrastructure. Where possible, the heaviest components can be delivered by water transport. The investment decision should be preceded by a detailed logistics plan that identifies all investment challenges in this area. It is necessary to plan and schedule work to prepare the ground in the nearest vicinity for heavy construction equipment. It should be noted that the land required for the construction of a road network that meets load-bearing requirements, the organisation of equipment storage facilities, as well as building and construction materials and assembly yards, may be larger than the area currently directly available to the power plant subject to the C2N investment. Therefore, pre-investment plans should anticipate the need to purchase or lease land adjacent to the power plant, and in this regard, also involve state authorities to ensure efficient processing of contracts.

Other utilities and auxiliary systems. A nuclear power plant requires a number of systems, some of which may be supported by the infrastructure of a former coal-fired power plant. This may include backup power supply systems and internal and external networks. However, nuclear power plant

safety systems must be founded on infrastructure components with a high reliability rating, so this aspect of the planning should be done independently. The heating infrastructure located near the power plant may potentially be of high material value. Some coal-fired power plants supply heat to local networks. An example is the Bełchatów Power Plant, which supplies heat to the city of Bełchatów. Decommissioning the CFPP in this location will require the development of a new heat source, which will entail considerable financial costs. Local heat markets are an important argument for implementing C2N-type investments - they can be a desirable way of connecting sectors, or maintaining the natural integration (of heat and power) that was present throughout the long operation of CFPPs.

Fuel and waste management. Planning for fissile material management within the framework of a nuclear investment is an independent process, and is done with the intention to maintain high safety standards. It should be mentioned that no specific characteristics of C2N investments have been identified as problematic in this regard. Nevertheless, to build trust among a wide cohort of stakeholders for nuclear projects, it is recommended that early planning on this topic is subject to consultation with technology developers and investors.

Physical security systems. A nuclear power plant requires markedly higher standards of physical security than a coal-fired power plant. Fencing and access control points are fundamental parts of the security system. As the site will need to be organised for construction purposes, and due to non-compliant safety standards, fencing and monitoring equipment must be removed from the C2N project area. If remaining coal-fired power units are continuing to run next to the C2N conversion, then there must be a physical separation between the area of the construction work, and the operational power plant. Existing security infrastructure on the project site could potentially be used to create separate storage areas for materials and tools, outside of the area designated for the main construction work.

The investor (e.g., an energy company) should prepare a detailed infrastructure modernisation/decommissioning plan for CFPP infrastructure that could be reused in a nuclear power plant, as an annex to the application for a decision in principle or a building permit. State administration bodies should develop and implement legal mechanisms to facilitate the implementation of such work (e.g., enabling the process of obtaining demolition permits).

Regulatory and legal framework for plan implementation

Implementing a programme as complex as replacing coal-fired power plants with nuclear power plants requires an appropriate legal framework and support from public administration. Adjustments to the Polish legal system are necessary, along with consideration of EU regulations (e.g., state aid rules). This section presents key regulatory issues and recommendations for changes or actions in this area.

Investment Process and Licensing of Nuclear Facilities: Poland currently has a legal basis for the construction of nuclear power plants (the “Atomic Energy Law” Act and the “Special Act on the Preparation and Implementation of Investments in Nuclear Energy Facilities of 2011”, amended several times). These procedures were developed mainly for the first nuclear power plant (Lubiatowo-Kopalino site). To facilitate the implementation of further nuclear investments, particularly in already industrialised areas, it is advisable to consider certain procedural simplifications, such as:

- *Integration of administrative decisions.* An example would be combining certain stages or issuing joint decisions. For C2N investments, it may be justified to issue a single decision on the location of a nuclear facility and a decision on the decommissioning of an old coal-fired power plant, to avoid duplicate procedures.
- *Shortening review deadlines.* Currently, the process of agreeing on reports (e.g., environmental reports) can take months. For projects imperative to energy security, the government should establish a special fast-track procedure, obliging authorities to prioritise cases and allocate additional funds for this purpose..
- *Expanding the catalogue of accompanying investments.* The special nuclear law defines the concept of "accompanying investment" (e.g., access roads, power lines) and indicates those facets subject to simplified procedures (ZRID decision). It is worth ensuring that the procedures also formally cover the modernisation of existing infrastructure, and not just the construction of new infrastructure. Where this is not the case, regulations should be amended to ensure that, for example, the expansion of an existing station or line also benefits from the special procedure.

State support. Investments in nuclear energy systems are capital-intensive and usually require state support (State Treasury debt guarantees, contracts for difference, etc.). At the same time, as an EU member, Poland must notify the European Commission of such mechanisms each time to obtain their approval for state aid. This is a complex and time-consuming process – for example, the CfD mechanism for Hinkley Point C in the UK was thoroughly examined by the EC. This Plan assumes that when implementing the C2N programme, the Polish government will prepare an effective model for supporting nuclear investments and initiate dialogue with the EC early enough to avoid delays. Possible approaches include:

- *Contracts for Difference (CfDs),* are aimed at ensuring a fixed price for energy from new nuclear units, where the state/regulator pays the difference when the market price is lower than the fixed price. The CfD mechanism is recommended in the PPEJ for Poland’s first nuclear power plant. It

can also be extended to C2N projects if investors decide to implement such a mechanism. This requires notification to the European Commission. This plan envisages starting this process no later than the end of 2026, in order to secure EC approval before 2030 (when investment decisions are likely to be made). However, the use of CfDs may pose a problem in the form of a low installed capacity utilisation rate, as EC case law in this area (two decisions for the Dukovany II project and one opening decision for State Treasury - Polskie Elektrownie Jądrowe - PEJ) prioritises energy trading from RES. This means a significant increase in the cost of energy production at the NPP, which in turn could undermine public acceptance of such a project (increasing already very high energy bills for end users).

- *Equity participation by state-controlled energy consumers* (KGHM, Azoty, PKP Group, Węglokoks, PGZ, etc.) in nuclear projects based on cooperative models. Combined with similar participation by private energy consumers, this ensures the stable and reliable consumption of energy produced by the NPP, and allows for the dispersion of investment risk, which in turn improves the project's bankability, lowers the cost of debt capital, and ultimately lowers the cost of energy production. Furthermore, it provides end users with access to affordable energy from the NPP at production costs, essentially without a profit margin and without the cost of intermediaries in the form of trading companies. This type of model is currently being discussed for a potential Betchatów NPP project.

- *Credit guarantees and public financing* – provision by the state or controlled banks (BGK, PFR) of loan repayment guarantees, political risk insurance, etc. This result will be a reduction in the cost of capital. If this is not implemented on market principles, it requires the consent of the European Commission (unless we accept them as mitigation measures within the IPCEI – a major EU project, which is an option well worth exploring).

- *State capital participation*, which, for example, results from the fact that in the Polish model, the first nuclear power plant is being built by a company with a majority stake held by the PEJ. Similarly, C2N projects could have a public capital component. The model could assume the participation of the State Treasury through the capital involvement of companies such as PGE S.A., Enea S.A., or Tauron S.A., which own coal assets and are seeking economically and socially efficient ideas to decarbonise these. However, if private entities are involved, the support must be non-discriminatory. A possible instrument here is the Just Transition Fund, which allocates EU funds specifically to post-mining regions. Although the EU officially excludes nuclear funding from the JTF funding, discussions are underway to relax this rule, particularly in light of the taxonomy, which recognises nuclear energy as sustainable. The Plan recommends active government action within the EU to secure agreement on providing certain forms of support for nuclear repowering projects, aimed at the transformation of coal-fired regions.

- *Long-term PPA contracts*. If these are potentially used, the problem lack of acceptance by the European Commission arises – as was the case for the Dukovany II project and the opening decision for the PEJ company. Past practice shows that the European Commission only accepts financial (virtual), short-term (up to 1 year) PPAs concluded on market terms, with a limit on the volume of energy offered by the NPP, and with the assumption that priority will be given to

renewable energy sources. This type of PPA means the NPP cannot ensure high capacity utilisation, and generates similar problems as CFDs. It is also problematic from the perspective of the project's bankability and negotiations with financial institutions (higher risk, higher debt costs). Nevertheless, this form of energy sales may be considered by future investors if significant changes occur in EU regulations and Commission case law.

It should be emphasised that the long-term nature of nuclear investments requires regulatory stability. No investor will risk billions of zlotys if they fear that the rules of the game will change in 5 or 10 years (e.g., withdrawal of support, changes in government policy, etc.). Therefore, the Polish state must provide solid guarantees of continuity of nuclear policy, regardless of changes in government. State Treasury guarantees, and a clearly communicated and sustainable path for energy transformation are critical not only for financing processes, but also for public interest in training personnel for the nuclear sector—the potential lack of personnel may prove to be one of the most important bottlenecks in nuclearization of the Polish economy. Therefore, stronger cooperation between national ministries in communication of policy is recommended.

As a general rule, the government should strive to minimise public aid for nuclear energy and provide it only to the necessary extent. This is dictated largely by the risk of European Commission rulings that could undermine the economic viability of nuclear projects.

Integration of the Plan with strategic and planning documents. The assumptions outlined in this Decarbonisation Plan, following a consultation process, should be formally incorporated into national strategies. This could be achieved through:

- *Updating the Polish Energy Policy (PEP)* – e.g., by introducing a provision on the development of nuclear energy, including through C2N projects, as a natural path to decarbonisation of the Polish energy sector, taking into account the potential role of SMRs after 2035, with appropriate forecasts of the capacity to be replaced.
- *Updating the Polish Nuclear Power Program* – the next PPEJ update proposes to implement this Plan's recommendations regarding C2N. The current PPEJ focuses on large-scale units (6–9 GW in two locations). The new edition could include further implementation plans for nuclear energy, expanding the list of potential investment locations to include the most promising regions for currently operating coal-fired power plants and CHP plants.
- *Include C2N projects in provincial 'Just Transition' plans and spatial development plans.* Provincial governments in coal-fired regions (Silesia, Łódź, Lublin, Lower Silesia, etc.) should potentially include new nuclear investments replacing coal-fired power plants in their strategies. For example, it may be necessary to include such investments in local spatial development plans ('MPZPs'), as current MPZPs often allow for coal-fired power systems but say nothing about nuclear systems. This expression of regional interest in nuclear investments could be a useful adaptation, and should be brought to public awareness.
- *Coordination with Industrial Policy* – the coal-fired power transition will impact heavy (energy-intensive) industry. It would be beneficial for the Ministry of Funds and Regional Policy, and the Ministry of Infrastructure to develop a local supply chain for nuclear power in their documents

(e.g., the Industry Strategy). The law should support domestic companies that participate in these projects.

- *Strategies of energy groups (Enea, Energa, PGE, Tauron)* should formulate tasks to assess the potential of including their own sites in C2N investments. Implementation of staged tasks should be included in strategy updates. Conducting research and feasibility studies can be an effective method of building knowledge. Obtaining Nuclear Ready status for individual locations [22] is an idea developed as part of the DEsire project. This can validate potential investments in business and society, thereby providing an impetus for creating paths for economic and individual development in regions interested in C2N investments.

Nuclear safety oversight. Despite the widespread interest in the C2N concept among many countries, the standardisation of targeted formal procedures is still at an early stage. There are currently no detailed requirements or guidelines for the stages of work that need to be carried out by supervisory bodies at relevant CFPP sites. This applies both to the pre-investment and the investment phases. Poland's National Atomic Energy Agency (PAA) and the Office of Technical Inspection (UDT) will play a key role in approving the location and use of infrastructure for nuclear investment projects. The Plan recommends the forming of dedicated teams within the PAA and UDT to develop uniform regulatory procedures, working together with representatives of foreign regulators. The high interest in the C2N transformation idea expressed by the International Atomic Energy Agency, (see publication [23]), may herald standardisation work in this field. Additionally, the creation of an independent expert organization (TSO, Technical Support Organization) to support nuclear supervision, and institutions to ensure the real 'unbundling' of roles will increase transparency and credibility, which will in turn strengthen investor and public confidence in new C2N investments.

Staff and competencies – human resources transformation

The transformation of the power sector involves not only a shift in technology, but also a transformation of the employment structure, skills and competencies within the industry. The planned closure of coal-fired power plants, as outlined in energy groups' strategies, means that current employees will need to find their place in this new reality. In an ideal scenario, a coal-fired power plant will be subject to a C2N investment. The utilisation of qualified personnel will benefit both the plant operator (particularly given the current shortage of specialists on the market), and employees - after appropriate training, their knowledge can be used in the operation of the nuclear facility. In this way, the C2N concept fulfils the premise of a 'Just Transition', with its extremely vital social impact. For regions that often built their capital, and grew economically by the construction and operation of coal-fired power systems, choosing the C2N pathway helps avoid mass layoffs and the degradation of labour markets. This section presents a human resources action plan, highlighting differences in employment structure, recommendations for training programmes, and potential timelines for transferring employees between the old and new centres. The specific nature of the C2N transformation on the theme of building human resources for nuclear energy should be reflected in the updates to *the Human Resources Development Plan for Nuclear Energy* [24].

Differences in Employment Structure – Comparative Analysis

Nuclear power plants differ from coal-fired power plants in terms of the types of specialists required, and the number of staff in individual positions. As part of the DESire project, efforts were made to obtain information on the staffing structures specific to operating domestic power plants on which the feasibility studies were performed. Unfortunately, due to the lack of appropriate consents for the disclosure of this data from energy companies, the US DOE/INL report [1] was used to prepare the recommendations. DESire summarised the results of comparative analyses of the employment structures for coal-fired and nuclear power plants with the same electrical capacity (1000 MW). The good news for employee expectations is that not only will the number of employees at CFPPs be maintained, it will even need to be doubled. However, the advent of higher demand does not mean that every employee with specific skills will find a job at the new power plant, without requisite retraining.

Nuclear power plants have unique positions, including those not found in coal-fired power plants. These include:

Nuclear engineers, i.e., specialists in reactors, ionising radiation, and nuclear chemistry. They account for approximately 13% of the workforce. Because conventional coal power plant personnel lack the required qualifications, virtually all nuclear engineering personnel must be recruited externally, or trained within the coal-fired power plant's existing workforce.

Nuclear reactor operators, i.e., licensed unit operators. At nuclear power plants, they constitute approximately 11% of the workforce. Although similar roles exist at coal-fired power plants, such as

boiler operators, the specific nature and safety requirements make the role of a nuclear reactor operator unique.

Radiological safety technicians and specialists, i.e., individuals qualified in dosimetry. No individuals with the required qualifications are identified among the staff of Poland's national coal-fired power plants.

Facility security personnel (physical security) – a nuclear power plant requires a significantly greater staffing in security. Estimates indicate that approximately 11% of the workforce in a nuclear power plant are security personnel (including armed plant guards). In coal-fired power plants, security, which is usually outsourced, consists of a few guards (less than 1% of the workforce). In this case, training is straight-forward. There are no identified difficulties in finding qualified employees in the market.

Training and development specialists – NPPs place a significant emphasis on continuous staff training (simulators, procedure training). Therefore, approximately 3% of the NPP staff are responsible for training. In a coal-fired power plant, training and development staff constitute less than 1% of the workforce. Retraining is possible for this portion of the employees.

Management engineering staff for maintenance and planning – NPPs require a robust engineering department, repair and maintenance planning, and quality assurance. Positions such as engineering managers, compliance inspectors, and others represent a high proportion of the total workforce at NPPs, accounting for approximately 2-3% of the workforce.

There are many common positions in nuclear and coal-fired power plants that require very similar competencies. These include:

Turbine and auxiliary infrastructure operators – NPPs require operators of non-nuclear systems, such as turbines, generators, and specialists in water and steam management. In NPPs, conventional system maintenance accounts for approximately 10–15% of the workforce. Obtaining the required qualifications is a relatively simple and natural path for operators working in coal-fired power plants. Their experience is very valuable, especially given the shortage of required skills in the market.

Maintenance services, including mechanics and electricians, are professions that are crucial to the operation of both NPPs and CFPPs. For example, in NPPs, industrial mechanics constitute approximately 2.7% of the workforce, while electricians constitute approximately 4.5%. In CFPPs, the shares of these specialists are approximately 3.2% and 6.7%, respectively. Due to the demand for these jobs, there is a high transferability of employees, who will require additional schooling in nuclear procedures and safety culture.

Forepersons and unit managers are familiar positions in coal-fired power plants. In nuclear energy nomenclature, the equivalent terms are shift managers and shift supervisors. These individuals must be familiar with the technological process, and manage shift crews. An experienced foreperson working in a coal-fired power plant can become a shift supervisor at a nuclear power plant after training, for example.

IT and automation specialists are particularly important in modern nuclear power plants, which are heavily computerized (reactor control systems, instrumentation and control systems). Thanks to the ongoing computerisation processes of CFPPs, specialists with the right skills for NPPs are currently being identified in the national market. These specialists (programmers, automation engineers) can transition relatively smoothly to work at NPPs. For example, computer network specialists account for approximately 1% of the workforce at NPPs, and approximately 0.3% at CFPPs.

Administration, occupational health and safety, and finance are the areas of expertise required both nuclear in and coal-fired power. The slight differences in the required number of accountants and auditors are a result of the higher reporting requirements at NPPs. This applies to the need for rigorous preparation of environmental reports, reports submitted to the IAEA, and so on. In general, most of the administrative staff at a coal-fired power plant (HR, accounting, logistics) can continue to work at the new power plant.

The final group of positions are **unique to coal-fired power plants**, meaning they are not required for employment at nuclear power plants. These are roles related to coal management and boiler operation, including:

Boiler and coal management system operators, are not needed at nuclear power plants. These employees must either retrain as operators of other systems or lose their jobs. Although their number in a large CFPP is small (several dozen people), it should be noted that they possess high-level qualifications in thermal energy, which can be widely utilised for the needs of nuclear power plant operations. Tailoring appropriate training for the needs of this group is highly recommended.

Coal handling system operators and fuel warehouse workers, i.e., coal-fired power plant employees whose skills will not be directly used in nuclear power plant operation. These employees account for up to 2% of CFPP employees. The C2N transformation, in its entirety, allows for the skill development of those who work in coal yards and coal dept warehouses, and those who operate conveyor belt and unload cranes. For example, individuals who hold heavy equipment operator licenses can often find work during the demolition and construction phases of a NPP. Some of these people easily be retrained for work at a NPP, for example, operating overhead cranes. The Plan envisage retraining courses organised during the decommissioning period of a CFPP.

Fuel laboratory technicians, who examine the quality of coal fuel at a CFPP, are not required at a NPP. As laboratory technicians often have a chemical background, there is an opportunity for them to be retrained towards gaining competencies for roles in monitoring the environment of a nuclear power plant, or in analysing utility water and other operational fluids at the NPP.

Ash and furnace waste management services, i.e., staff working in CFPPs in ash removal and flue gas cleaning departments (electrostatic precipitators, desulphurisation, gypsum storage). These include both chemists and operators of specialised installations. This group of employees has variety of skills that are not directly applicable to a NPP. Both chemists and mechanics have knowledge that, with the right retraining, can be used in a NPP.

Mapping the skills located in CFPPs and those required in NPPs leads to the conclusion that most CFPP employees will be able to find employment in a new NPP or in its construction, although often in different positions, and after acquiring new qualifications. Despite this positive conclusion, attention should be paid to the HR policies implemented by national energy groups. The predicted decline of coal-fired power generation, reinforced by increasingly bold plans to decommission CFPPs, has resulted in a lack of recruitment within energy companies. This is leading to a gradual increase in the average age of employees working in the coal energy sector. Additionally, given the long periods required to complete all stages of nuclear investment, it can be assumed that only a small portion of the personnel employed in the domestic energy sector will ultimately be transferred to work in operating NPPs. Furthermore, the long-standing decline in the education of specialists with universal aptitudes for coal and nuclear energy, both in secondary, higher and vocational education, requires special attention from national decision-makers. According to many experts, developing a domestic workforce and acquiring the required nuclear competencies is fraught with a high risk of failure. This constitutes a bottleneck in the entire scope of activities aimed at reaching the state's capacity to build and operate the planned nuclear power plants.

The company managing the CFPP slated for C2N transformation must support the process of building out the human resources for the future NPP. It is essential, that the organisation must establish a division to organise its own local activities, and promote national educational programmes. This division should secure funding for young people from the region to participate in education, training programmes, and courses related to nuclear energy. It is recommended that these divisions collaborate with vocational schools and universities, to arrange sponsored studies in the field of nuclear energy or other areas required for the implementation of the overarching nuclear project. It is absolutely necessary that this division would cooperate with entities appointed to coordinate staff development activities for the national nuclear power sector (the Nuclear Competence Centre is set to fulfil this role). Monitoring progress in human resourcing and their competencies would also be an important task for this division. Activities undertaken by this division should be transparent and agreed upon with trade unions and with individual employees subject to assessment and requalification.

To properly manage the competency transformation process, the following **staff preparation procedure** is proposed:

Step 1: Skills and employment structure audit (approx. 5-6 years before the coal-fired power units are decommissioned). A detailed inventory of employee positions and qualifications should be conducted at each power plant with a high potential for C2N transformation. The aim is to create a competency matrix and, as a result, identify those positions in the current CFPP that correspond to positions that will need to be filled in the future NPP. It is important to characterise specific employees in detail, taking into account their age. This will identify groups of employees who: (i) can perform similar work at the NPP (minimal additional training required, e.g., electrician with SEP certification, turbine mechanic, accountant); (ii) can perform work in a different position, which will mean acquiring new skills in a relatively short period of time; (iii) will not find a position at the NPP without complete retraining.

Step 2: Develop career development paths for each job group. An action plan should be prepared for each of the above groups, which should also be differentiated for individual employees. Transparency is needed. Conducting individual interviews and surveys with interested employees may be beneficial. The knowledge gained can be used in the process of planning career path scenarios. Career paths should be phased and include introductory training aimed at raising awareness of challenges, along with training and qualification courses, intensive technical English courses, and internship programs at existing foreign NPPs.

Step 3: Hiring and Redundancy Schedule. For each planned C2N investment, a **roadmap for staff development** should be prepared, showing the years in which new positions will be created at the NPP, and when positions will be eliminated at the CFPP. Synchronisation is required to avoid stages where there is no opportunity to use skills. Periods of potential unemployment should be used for employee participation in courses and internships. Mechanisms supporting the organisation's financing of training activities (which might take the form of paid training leave), should be developed. It is recommended that, given the high demand for nuclear personnel across Europe, the future NPP operator provides for preliminary (e.g., conditional) contracts to be offered to priority employees before they undergo the effort to obtain required qualifications.

Step 4: Implement training and employment at the new power plant. As construction progresses, key employees should be gradually transferred to the new organisational structure. It is recommended that approximately 1–2 years before the planned commissioning, the organisation of the future nuclear power plant be formally structured (even as a division of the company) and recruitment commenced – primarily from employees of the old plant. Employees who have completed training programmes and passed the required exams should be involved in start-up tests, etc. Positions that cannot be filled by the coal-fired power plant's personnel must be filled from external resources.

Communication and public acceptance

As part of the DEsire project, a social diagnosis was completed, aimed at identifying the motivations and emotions that C2N investments may evoke. Interviews and surveys were held to achieve the formulated objectives. The assessment was done with the participation of residents of Opole, a city in close proximity to a major national power plant, which has great potential for a future C2N investment. The conclusions and recommendations presented in this section are also the result of workshops organised as part of the DEsire project, with representatives of entities related to the national energy sector. The aim of the workshops was to identify key stakeholder groups in C2N projects, their roles, and attitudes towards this transformation concept. Detailed results of the assessment, and conclusions drawn during the workshops, are presented in detail in this report [25]. This section is a synthesis of the knowledge acquired during the project.

According to the results of a survey conducted in November 2024 by the Ministry of Energy (then the Ministry of Industry), support for nuclear energy is 92.5%, a record high in the history of monitoring acceptance levels [26]. Despite this, there are noticeable pockets of social tension at the local level, particularly in the vicinity of Choczewo, where preparatory work is currently underway for an investment to build the first nuclear power plant in Poland. This is largely due to the organised and active efforts of opponents of nuclear energy. The emerging and relatively vocal opposition among local communities in the media shows that despite the high level of support for nuclear energy observed in Poland, there is still a need for well-planned communication campaigns. In particular, these should focus on dialogue with communities that will live in the immediate vicinity of nuclear energy investments (and subsequently, the operating nuclear facility). Transparent communication about nuclear energy investment plans, including providing reliable information about the risks and benefits, is fundamental to building strong public acceptance. A well-informed and educated society is resistant to disinformation, which has been especially evident in recent years due to the ongoing war beyond our country's eastern border.

The individual characteristics of CFPP operating regions can foster social acceptance of nuclear investments – for many reasons. This is mainly driven by the notion of regional identity, which is strongly oriented toward the commercial energy sector. The more economically dependent a region is on energy activities (and other business activities indirectly related to energy), the greater the involvement of local decision-making bodies in all activities aimed at dialogue and lobbying for C2N investments. For example, in Bełchatów, the announcement of the cessation of operations of the power plant and open-pit lignite mine, more than a decade in advance, aroused noticeable and understandable anxiety. Such anxiety is a natural trigger for the activation of local government officials and political decision-makers (including those at the central level) from the region. The early and effective organization of social leaders of the Bełchatów region, so clearly visible in their efforts to locate the second national nuclear investment there, can be an excellent example of cooperation across political divides. On the other hand, it is also striking that the greater the diversification of business activities in a region targeted for the C2N pathway, the more difficult it is to reach a local

consensus on nuclear investments. Where there are differing opinions expressed by representatives of significant portions of the community, public debate is often absent, or it tends towards polarisation of opinions publicly communicated by political decision-makers – the opportunity to generate political capital often becomes more important than the desire to develop solutions that genuinely support local communities. An example is the cities within the Silesian-Zagłębie conurbation, where, despite the presence of numerous coal-fired power plants and combined heat and power plants, the topic of nuclear energy is unfortunately often marginalised in terms of discussing transformation directions. The widely held belief that the region has high strength, regardless of the condition of the mining and commercial power sectors, is not conducive to the strong promotion of the repowering idea, which is aimed at maintaining strong and centralised electricity production centres in the region.

To develop a communication policy (intended to build strong support for nuclear energy in the region targeted for investment), the first steps should be an assessment of the current state of knowledge held by the local community. Even when residents live in a region where commercial power is an integral feature of the industrial landscape, it turns out that their knowledge is not necessarily satisfactory. Unfortunately, their understanding is often based on inappropriate sources (e.g., feature films, TV series, computer games) that present nuclear energy in a simplified or distorted manner, which may affect the perception of the technology. The research indicated that proponents of nuclear power plant construction mainly highlighted the potential for energy independence and the beneficial impact on the natural environment, although safety issues were also important. Those neutral towards the nuclear investment indicated a knowledge deficit about the technology and actively engaged in a discussion based on rational arguments. Opponents of nuclear energy had doubts firmly rooted in emotional narratives, citing the Chernobyl disaster and fearing radiation hazards. They raised concerns about the costs of constructing a power plant, and the social consequences of the energy transition. For residents of medium-sized or large urban areas, typically located near large coal-fired power generation systems, they were particularly reluctant to build a nuclear power plant in the immediate vicinity of their homes. This will often also apply to declared supporters of nuclear power. This phenomenon can pose a significant challenge to achieving favourable public support within medium-sized and large urban areas

Regardless of the specific characteristics of the location selected for a nuclear investment, it is essential to initiate a process of continuous communication (based on dialogue) well in advance of the formal investment decision. Organising meetings between credible experts and residents, with the support of local authorities, is the basis for building trust in nuclear energy. Establishing an expert, informational platform on nuclear energy, with secured funding for its activities, will be an effective tool for familiarising residents by increasing their knowledge. The investor should demonstrate high transparency in formulating investment objectives, and maintain constant contact with local leaders who enjoy high recognition and public trust. Proper, substantive preparation of local leaders, who duly represent the local community, will facilitate the formation of lasting, knowledge-based social acceptance. Municipal and district governments should be active partners in the dialogue. It is important for both parties, i.e., the investor and the community, to communicate

their goals, conditions, needs, and expectations. It is advisable to base the educational materials on case studies from regions with similar characteristics – ideally ones that underwent a similar path of social change effected by a C2N transformation. Such case studies can be developed based on experiences identified in France. It will be beneficial to establish interregional cooperation, including the organisation of study visits. Knowledge about the risks posed by the transformation of post-coal regions, supported by real-life examples may also prove valuable. Pointing out all the benefits in terms of taxes, regional development, and wage levels, preferably as precisely as possible, without using generalities, will help to cultivate a high level of acceptance. When communicating with local communities, it is not advisable to avoid topics perceived as difficult, such as those related to radioactive waste management. A transparent approach for the communication process should be taken from the very beginning. This approach should be treated as risk mitigation for the possibility of social resistance emerging at the advanced implementation stage of the investment project. The community should also be involved in activities related to environmental monitoring, including organised site visits to the facility during the construction and operation phases. Another important aspect is to encourage local companies to acquire not only nuclear expertise, but also a wide range of services and skills supporting the entire value chain, so that as much of the work as possible can be carried out by local businesses. Companies typically operating near large power plants and focused on meeting the needs of the coal-fired power industry, often have a solid base of experience and infrastructure that can support the fulfilment of orders for future nuclear power projects. A widespread social activation effort will also include the launch or re-profiling of vocational schools and technical colleges, which often operate in the environs of large commercial power plants and mines (formerly as company schools). Collaboration with academic centres may also prove salient. Organising full-time and postgraduate studies, as well as courses aimed at locally enhancing skills within the C2N investment value chain, will be appropriate for increasing the workforce and shaping a positive social message.

Action plan for the widespread adoption of the C2N path

The economy must be decarbonised, while maintaining its expected international competitiveness. This necessitates the suitable organisation of national activities, along with the adoption of various tools and mechanisms for implementing new – particularly nuclear - technologies. It is critical to involve all stakeholders in these activities. An exceptionally broad group of stakeholders is identified for the C2N pathway, which is a systemic solution enabling the transition of commercial and industrial energy from a coal-based to a nuclear economy. This approach requires thorough reuse of existing infrastructure, and the expertise of national enterprises and communities, who are often locally concentrated near coal-based energy generation systems. To set the right pace in prepping C2N investments, government bodies and the owners of coal-fired power plants and CHP plants must be engaged; in most cases these are state-owned companies. Widespread adoption of the C2N path is of interest to national enterprises, which have spent years refining the skillsets and building up the infrastructure needed to support the commercial energy sector. It is anticipated that so-called cooperative business models in nuclear investments (e.g., the discussion on the Belchatów model, the activities of Industrikraft in Sweden) will grow to greater importance. Therefore, energy-intensive industries and local governments (chiefly those that work for communities in coal-fired regions) are entities that should be interested in the C2N pathway. The pathway can utilise the vast competencies that make-up the legacy of conventional energy. Promotion of this pathway should be the responsibility of chambers of commerce and associations from the machinery industry, energy-intensive industries, and energy and heating companies (e.g., IEPiOE, IGEOŚ, PTEC, TGPE). Natural stakeholders in the C2N pathway would be developers and providers focused on technologies used in nuclear energy. Developing C2N should be of interest to national universities and research institutes. Here, as in vocational schools, educational schemes must be prioritised, to ready the workforce for the national nuclear sector. It is time to found and support initiatives enhancing educational, organisational, and outreach activities, such as the DEsire Energy Transformation Platform, a result of the DEsire project, set-up by an agreement between the three largest universities operating in the Silesian and Zagłębie regions: the Silesian University of Technology, the University of Silesia, and the University of Economics in Katowice.

The full action plan should be deployed as soon as possible, ideally by the end of 2028, so its effects are tangible during the preparation and implementation stages of the second nuclear investment in Poland. According to the draft update of the PPEJ, this will be constructed in a location currently hosting a coal-fired power plant, thus following the C2N concept.

The key areas of activity in the action plan for the widespread adoption of the C2N pathway:

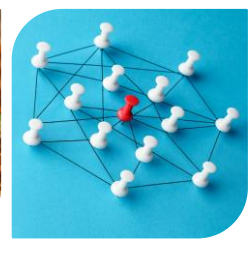
Energy company involvement in identifying the potential for nuclear investments within their generation assets. Since the C2N pathway can be a key part of a just transition (including prevention of social unrest), energy companies should be motivated to take action by the Polish government. The work can be carried out in stages, according to the following scheme: (i) preliminary exploration of the possibility of including generation sources in C2N investments; (ii) conducting feasibility studies for C2N investments in locations with the most favourable conditions; (iii) development of a strategy for managing physical and intellectual assets, aimed at the broadest possible use within C2N investments. We propose that standards for initial site assessments are drafted, in line with the Nuclear Ready concept [22]. Such standardisation will reduce evaluation costs, ultimately leading to an increase in the number of sites assessed..

Incorporating the C2N pathway principles into programs, plans, strategies, and policies created by national ministries. Active inter-ministerial efforts to develop synergies for effectively using coal infrastructure, and employee skills identified in various sectors, to support transformation along the C2N pathway. It is recommended to use good practices identified in other countries and institutions involved in implementing the C2N concept (US DOE, IAEA, EPRI).

Determine legal barriers to the implementation of the C2N pathway, from the onset of intent to the commissioning of nuclear power plant operation. The government and state administrative bodies should be responsible for introducing changes and creating an adequate legal framework for the general economic application of the C2N concept. Appointing appropriate expert teams within state administrative structures, including the National Atomic Energy Agency (PAA), to recognise and propose solutions to eliminate barriers. Eliminating entry barriers for SMRs, as their market share, once economically viable, could materially increase the penetration of the C2N concept.

Securing financial resources for the above activities. Lobbying at the European Commission level, for financing mechanisms for the investment preparation and realisation of C2N. Attempts should be made to include the possibility of financing certain C2N activities based on active mechanisms, such as the Just Transition Fund.

Organisation of cooperation between various stakeholder centres of the C2N pathway, including energy companies, investors, nuclear technology developers, the machine industry and energy-intensive industries, local governments, and educational institutions, to influence the government and state administrative bodies to pursue the activities above. Communities in the regions where C2N investments are to be deployed are paramount stakeholders.



**Are you...
Nuclear Ready?**

Summary

The Plan of decarbonisation of the domestic power industry through modernization with the use of nuclear reactors presents a comprehensive path for transforming the Polish energy sector from a coal-based model to a low- and zero-emissions model, largely based on nuclear sources. It guarantees energy security, regional economic stability, and public acceptance. Execution of this Plan will fill the shortcomings highlighted in the PEP2040 and PPEJ, and provide a concrete solution to the challenges articulated therein: replacing aging coal-fired units with new generating capacity, utilising existing generation infrastructure and leveraging the broad skills and competencies identified within the Polish economy.

One of the Plan's foremost strengths is that it complements socio-economic policy, which, at the current stage of transformation should safeguard the high importance of centralised generation systems. Energy market liberalisation, and its shift towards de-centralisation using weather-dependent sources, should be adapted to the pace of market maturation for technologies (particularly energy storage).

The transformation direction recommended in the Plan is based on the maximum utilisation of existing energy assets. Locating new nuclear units where coal-fired power plants and CHP plants currently operate brings numerous benefits. It avoids costly transmission grid expansion, which will result in time and cost savings. The Plan upholds industrial traditions in regions economically dependent on commercial power generation, thus preventing the collapse of local labour markets and the degradation of local economies. C2N investments align with a 'Just Transition', as they breathe fresh life into regions that have been coal-dependent for decades, offering continuity of employment and preservation of tax revenues for local governments. Thousands of Polish energy sector workers and their skills can add great value to the nuclear sector, which has a high global demand for specialists. The C2N path reconciles climate goals with job protections, and provides a future for the mighty industrial potential of coal-fired regions. The transition from coal to nuclear does not mean other technologies will be abandoned. The Plan underlines that the need to strive for diversification of generation sources: nuclear power plants, renewable energy sources, energy storage facilities, and, during the transition period, natural gas-fired sources.

The plan recommends actions that minimize inactivity of institutional stakeholders responsible for carrying out the partial objectives of the transition program. Preparatory work before the location selection for the 2nd nuclear power plant, (and optimistically for subsequent nuclear investments in the long-term), should be accelerated as far as feasible. Each year of delay increases the risk of a capacity deficit in the coming decade, given the wave of retirements of aging coal-fired units that have been announced. The C2N transformation is technically achievable, and desirable, but requires adaptation to the regulatory, financial and social milieu, so projects can proceed slickly, on schedule and as planned.

With these findings in mind, the Plan formulates strategic and operational recommendations for the main stakeholders of the transition. These are envisaged to guarantee the success of the C2N pathway in the following decades.

Government authorities should set the stable course for the clean transition. The C2N pathway's principles should be embedded into core national strategic documents, so the PPEJ and PEP are up-to-date with definitive plans for nuclear investments in apt locations where CFPPs operate. This Plan recommends that the next PPEJ edition expands on the list of potential locations for nuclear power with sites designated for C2N transition, including those where SMR usage is attractive. Close inter-ministerial cooperation is indispensable to all this. The government should convene dedicated working groups that combine the expertise of various ministries (climate, economy, education, finance) to make optimal use of existing infrastructure, national specialists, and human resources. This collaboration should draw on best international practices, in collaboration with parties such as the IAEA and energy departments (ministries) of other countries that actively support C2N. The government must also clarify and remove legal barriers which hinder C2N investments. Legislative revisions are needed to simplify and expedite procedures – from location and environmental decisions, through the technology licensing process, to obtaining construction and operating permits. To this end, it is recommended that specialist think-tanks be set-up within regulatory bodies (PAA, UDT), to streamline procedural improvements and harmonise requirements with regulators from experienced nuclear nations. The government should assure a consistent and predictable financial framework for project preparation and implementation, including support mechanisms and access to financing instruments which enable the long-term delivery of these projects. A support system for further nuclear investments is required. This includes expanding the list of potential business models for application, and cooperative financing. Early consultation with the European Commission, will ensure state aid enactment occurs before key investment decisions. Furthermore, Poland should actively seek dedicated financial instruments within the EU to support the C2N transformation. Funds from the Just Transition Fund and innovation programmes, among others, could co-finance critical stages (location studies, research, and staff training). Regulatory and political predictability throughout the entire process: a long-term, stable legal framework and administrative decisions (extending beyond political terms of office) will be decisive in gaining investor confidence. The government must ensure that energy policy objectives, including development of nuclear power, remain unchanged and resistant to short-term fluctuations, so that projects with a 20-year horizon are not exposed to uncertainty or course changes. The government should lay out a clear roadmap of actions and systematically adhere to this.

The state's communication and social policy is equally important. Despite high public support for nuclear energy among society, investment plans must be communicated promptly and transparently to individual regions. The government, and relevant authorities, should initiate large-scale information campaigns and dialogue with local communities, particularly where there is high potential for C2N projects. Reliable information about the potential risks and benefits of nuclear energy should be shared; fears dispelled and myths debunked. Well-informed communities,

educated on scientific facts, are far more resilient to disinformation and likely to support investments, regarding these as opportunities instead of threats.

Another important aspect is the preparation of potential investors for the specifics of coal-to-nuclear investments. Energy companies that own CFPPs and the transmission system operator (PSE S.A.) are substantive members of this group. Investors should already begin preparatory steps now, ahead of formal decisions. The Plan recommends the drafting and introducing standards for the initial assessment of "Nuclear Ready" sites. Standardisation of technical, environmental, and social criteria will aid the seamless selection of the most promising sites, and focus investment efforts. Energy companies with coal assets should treat these as natural locations for new nuclear investments. As the decommissioning of these CFPPs is prepared, the site should be safeguarded, technical infrastructure documentation should be archived, and relevant research (e.g., hydrological and geological measurements) should begin for the future construction of a nuclear facility. The speed of action is of the essence here, so investors should consider preparatory work in parallel with administrative procedures, even if this involves some risk. Close cooperation with the transmission system operator should be factored into the earliest stages of the projects. PSE S.A. should become a strategic partner in planning new units. The operator will be responsible for assessing the condition of existing substations and high-voltage lines, planning their modernisation or expansion, and synchronising these investments with the nuclear power unit construction schedule. The Plan recommends that PSE S. A. include C2N projects in its Transmission Grid Development Plan and actively support investors with its technical expertise.

Investors must also address the human resourcing and societal challenges of the clean energy transition. Retaining experienced CFPP staff, and facilitating their smooth segue to becoming NPP staff is a central target, both for social acceptance and efficient facility operation. It is recommended that every C2N investor prepares a detailed capability management plan in partnership with the operator of the existing CFPP. Approximately five years before the planned closure of coal-fired units, the staff's qualifications and employment structure should be audited. The C2N investor, along with local authorities and educational institutions, should design tailored training programs, courses, and internships so maximum staff can skill-up and gain their necessary nuclear certifications in a timely fashion. From the outset, it is worthwhile to motivate critical specialists. Training new staff is absolutely a given, so investors should partner with technical universities and vocational schools to sponsor courses and programs in nuclear energy.

Profound socio-economic transformation is facing regions where large coal-fired power plants are located. Local governments should become active planners and implementors of the C2N pathway, in partnership with the government and investors. Above all, local authorities (provincial, district, and municipal) should endeavour to bring in new nuclear investments to their areas, recognising these as prospects for long-term development. Bełchatów region shows that resolute actions by local leaders can mobilise the community to pay close attention to nuclear investments. Local action can have a tangible impact on central decisions, providing that mandatory nuclear safety assessment criteria are positively verified. Local governments, have the best knowledge of local conditions. They can assist on optimally preparing the infrastructure and logistics for investment, for example, by

incorporating NPP construction plans into local spatial development plans and reserving land for future associated investments (contracting facilities and base, access roads, employee housing estates, waterworks, and wastewater treatment plants). Regional authorities should also seek aid funds, both national (e.g., the National Centre for Research and Development - NCBR, Polish Agency for Enterprise Development - PARP) and EU (Just Transition Fund, Modernisation Fund), to finance employee retraining, the construction of information centres or technical education centres.

The most pressing task at the local level is to increase trust in the clean transition. Local communities, including residents of cities and municipalities, should be participants in the process from the beginning, not passive observers. This can be accomplished through dialogue forged on respect and reliable information. Local advisory councils for the largest planned projects should be instigated (with participation of resident representatives, local government, investors, and government administration), providing a forum to discuss all aspects of the investment. Information campaigns should not only be conducted on the central level by the government, but also on the local level..

Fulfilment of this Plan's principles requires coordinated multilateral commitment from multiple parties. The C2N Path is a systemic challenge, where environmental issues intertwine with social and economic objectives, and highest priority given to nuclear safety. **Trust in science and technology should be a cornerstone of the energy transformation narrative.** The general public expects decision-making to be underpinned by evidence, expert analysis, and global best practices. Nuclear energy is an advanced and well-mastered domain. The experiences of 30+ countries, including Polish neighbours, make it clear that nuclear reactors will safely operate for decades, and supply clean energy. Poland possesses a pool of experts, highly qualified engineering staff, and public support atomic energy is growing. Therefore the country can, and indeed should, step forth as a leader of this coal-to-nuclear revolution in Europe. The C2N pathway offers a one-of-a-kind opportunity to balance our economy with ecology, as it unleashes innovation, generates jobs, modernises infrastructure, and protects the climate. By steadfastly moving forwards with this Plan, Poland will not only fulfil its climate commitments, but also provide for its citizens a state-of-the-art, secure energy system, that stands upon our country's own robust national foundations. Therefore joint action is urged for all stakeholders. The cooperation of the government, the energy sector, the scientific community, local authorities, and society will be of decisive importance here..

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