

## Article

# Nuclear Power in Poland's Energy Transition

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**Abstract:** This article presents an analysis of the future role of nuclear energy in Poland's path to a low-carbon energy transition. The arguments in favor of implementing nuclear power are to be found on three levels: energy security, economic competitiveness and energy efficiency, and lastly, limited environmental impact. In the process of creating this study, the methodology in the field of security sciences was used, including its interdisciplinary approach. Theoretical methods were used, e.g., critical analysis of scientific sources and comparison of statistical data and empirical methods, e.g., document analysis, comparative analysis. The article is based on an analysis of the literature on the subject, applicable legal acts, and government strategies in the field of energy security. The article contains the results of research no. BS.21.6.13 carried out by a research team from the Pomeranian Academy in Słupsk that allowed to indicate the probable directions of transformation of the energy sector in Poland in the next decade.



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**Keywords:** energy security; energy policy; low-carbon energy transition; energy law; nuclear power; nuclear policy; nuclear law; levelised cost of electricity; total cost model; energy sustainability

## 1. Introduction

Poland is one of a few EU countries that directly refer to the principle of sustainable development in their constitutions [1]. However, with regard to the so-called 'energy trilemma', for many decades, Polish energy policy has placed a clear priority on energy security and energy independence over environmentally sensitive production and use of energy [2]. Nonetheless, despite the strong resistance of the energy industry against transition, the Polish energy sector has undergone considerable change over the last couple of years [3]. After more than three decades of transformation, the Polish coal-reliant energy policy gained considerable momentum, in particular due to the decrease in the role of heavy industry [4], as well as the objectives adopted by the European Union within the so-called '2020 Climate and Energy Package' and '2030 Climate Target Plan' [5–7].

In 2007, Poland agreed to the EU's 2020 climate and energy targets to reduce greenhouse emissions, improve energy efficiency, as well as to increase the share of renewables in terms of gross inland energy consumption [8]. In December 2008, Poland accepted a package of binding policies for achieving these targets which have visibly impacted upon Poland's energy policy and domestic legislation [9]. Under the 'Renewable Energy Directive', Poland has committed itself to a legally binding target of 15% share of renewables in terms of gross final energy consumption by 2020 [10]. In November 2009, the Council of Ministers adopted 'Energy Policy of Poland until 2030, which set primary directions of Polish energy policy, both in the short and in the long run, until 2030 [11]. Among top priorities listed in this document were: the improvement of energy efficiency, the

enhancement of security of fuel and energy supplies, the development and promotion of renewable energy sources, the development of competitive fuel and energy markets, and lastly, the diversification of electricity generation structure by introducing nuclear energy. The need for a reduction of environmental impact of the power industry was also emphasized. The energy policy clearly underlined its main goal, which was the country's energy security while observing the principle of sustainable development [12].

Since 2010, Poland has apparently become more reluctant to implement long-term EU's climate policies. In 2011 and 2012, Poland vetoed the Commission's energy roadmap and the low-carbon roadmap for moving to a competitive low carbon economy in 2050 [13]. Although Poland ultimately accepted the 2030 climate and energy framework in October 2014, the decision was driven by pure pragmatism and in exchange for significant reliefs for its energy enterprises [14]. In 2015, Poland vetoed the so-called Doha amendment to the Kyoto Protocol, preventing the EU from ratifying the treaty as a bloc. Ultimately, the Protocol was ratified by Poland in March 2018. The rationale for these actions, undertaken by the Polish government, was a number of serious challenges that Polish energy sector was facing and which, to a large extent, are still valid today. Among the most important ones that should be mentioned are high demand for energy, inadequate fuel and energy generation and transmission infrastructure, significant dependence on external supplies of natural gas, as well as the issue of aging power generation stock. With an energy intensity of the economy that is almost twice as high as the EU average [15] and high dependency on fossil fuels as a starting point for energy transition, Poland's ability to meet its energy security and climate change objectives is much more difficult in comparison to other EU Member States.

In principle, it can be assumed that since 2016 Poland's energy system has been undergoing a gradual phase of reorientation, particularly due to Poland's membership of the EU and the necessity of meeting obligations deriving from climate and energy targets. Poland has been a signatory to the Paris Agreement since 2016 [16], thus contributing to the efforts undertaken by the international community to mitigate climate changes. In December 2018, Poland hosted the UN climate conference (COP24), which resulted in so-called 'Katowice climate package' that contains common and detailed rules, procedures and guidelines that operationalise the Paris Agreement [17]. In this package, a particular attention has been subjected to the principles of fairness and solidarity in respect of energy transformation resulting from the Paris Agreement.

Although the change may not be as smooth as in the case of other EU Member States, Polish energy policy and its long-term targets envisage a gradual shift away from fossil energy sources. In this respect, the main driving forces behind Polish energy transition are political and legal, as combined into a set of measures ranging from cutting greenhouse gas emissions to investing in cutting-edge research and innovation, to preserving natural environment.

From a political standpoint, ultimately, it is the EU that has the biggest influence on Polish energy policy. A significant impact on shaping the Polish energy strategy has the current EU climate and energy policy, including its long-term vision of striving for EU climate neutrality by 2050. In December 2020, the European Council approved a binding EU target to reduce net greenhouse gas emissions by 2030 by at least 55% compared to 1990 levels [18]. Consequently, in February 2021, the European Commission adopted its new EU strategy on adaptation to climate change, which sets out how the EU can adapt to the unavoidable impacts of climate change and become climate resilient by 2050.

As for the legal dimension, the obligation to shape energy policy in a more sustainable and secure manner has visibly influenced the domestic law. The main legal instruments implementing the national transitional process are defined in the administrative and competition law. In principle, Polish energy strategy and its legal framework are very much influenced by the EU's legislation. In 2019, the so-called 'Clean energy for all Europeans package' was completed. The package is a set of eight legislative acts related to regulatory mechanisms with respect to the energy performance of buildings, renewable

energy, energy efficiency, governance, and electricity market design [19]. It also indicates how to operationalize the EU's 2030 climate and energy targets; however, the long-term goal of the package is to contribute to the implementation of the Energy Union, as well as the construction of the EU's single energy market.

Nevertheless, further changes to fundamental EU legislation concerning energy sector shall be expected inasmuch as EU's energy and climate policy goes beyond the perspective of 2030. For example, in March 2020 the European Commission proposed the first European Climate Law with aim to set a legally binding target of net zero greenhouse gas emissions by 2050 [20]. The Climate Law, as a part of the so-called 'European Green Deal' [21], includes mechanisms to monitor the progress and undertake actions if needed. Moreover, it refers to existing solutions related to national energy and climate plans, as well as reports by the European Environment Agency.

Although Poland supports the ambitious goal to achieve climate neutrality by the EU by 2050, following the dynamically accelerating climate and energy trends will be a huge challenge for this country. Due to the difficult starting point of the Polish transformation and its socio-economic aspects, Poland emphasizes the need for a fair (just) transition that entails a specific national derogation. Such transition should take into account national conditions, actual starting points, the social context of the transformation and counteracting the uneven distribution of costs between countries, as well as the need to guarantee energy security and the independence in shaping the national energy mix.

In principle, from the perspective of the EU's climate policy objectives, the main challenge with respect to Poland's energy transition is decarbonisation. Poland has no explicit carbon tax (a specific CO<sub>2</sub>-related vehicle tax) in place and a number of Polish coal mines that are unable to compete with imports have obtained sizeable public subsidies. The defence of the coal industry is driven by several factors, among which the most important are energy security and energy independence underpinned by socio-economic factors. Other significant challenges pertain to aging energy generation capacity and the slow development of energy interconnectors, which undermines the security of energy supplies and a deeper integration with neighbouring electricity markets. From a Polish stakeholders' perspective, an ambitious EU climate policy could impair energy security and lead to less affordable energy. In order to move forward, it is important to take into account different rationales and drivers behind national energy policies. Polish concerns could be resolved by introducing a common energy market in Europe, which would significantly boost Polish energy security and facilitate the energy transition in Poland.

## 2. Materials and Methods

The article is based on an analysis of the literature on the subject, applicable legal acts, government strategies in the field of energy security and data from research on the topic: The future of Poland's energy security, carried out by a research team from the Pomeranian Academy in Słupsk.

In the frame of research theoretical methods were used, e.g., critical analysis of scientific sources and comparison of statistical data and empirical methods, e.g., document analysis, comparative analysis. The project was carried out in accordance with the approved research plan and in accordance with the regulations in the field of ethics of scientific research at the Pomeranian University in Słupsk [22].

## 3. Empirical Foundations. Structure of Primary Energy Production and Consumption in Poland

In order to understand the difficult and complex position of Polish energy sector in respect of the EU's climate goals, it is necessary to analyse country's current energy mix. The production and consumption of primary energy in Poland heavily relies on fossil fuels, principally on hard coal and lignite. Poland is Europe's largest hard coal producer, and the vast majority of electricity in Poland is produced from solid fuels.

In 2019, the share of fossil fuels reached, depending on available data, from approximately 78% up to 82% of the total energy production in Poland (incl. 71–74% from coal fuels) and

around 85% of the structure of the generation of heat (incl. 71% from coal fuels) [23–25]. As for the total primary energy production, hard coal remained the most important energy carrier with a share of 56 (up to 59%), while lignite amounted to a 15% share of the domestic energy generation. The share of natural gas amounted to 5.5% and crude oil to 1.5%. Other energy carriers, mostly renewable, accounted for 18% in the year 2019.

The domination of coal fuels is even more visible in reference to electricity production: 72.1% (up to 75%) of the gross national electricity generation, which in total amounted to 163.989 GWh in 2019 [26,27]. The total installed capacity as of the end of the year amounted to 46.799 MW. The share of renewable energy sources (RES) in the structure of indigenous electricity production accounted for approximately 15.5% in 2019. In the structure of use of RES for electricity production, in 2009 the first position belonged to onshore wind power plants, which produced in total 15.107 GWh (59% of RES share). Electricity generation by units dedicated solely to the incineration of biomass and installations that generate electricity through the process of biomass co-incineration with other fossil fuels persisted at high level reaching 25% of the proportion of renewables. Hydropower plants, which until 2007 were the main source of green energy in Poland, were capable of delivering only 1.2% of the generation capacity in 2019 (1.958 GWh). The share of natural gas and other fuels amounted to 12.4%.

In 2019, total global energy consumption in Poland amounted to 4361.7 PJ, with a stable domination of solid fuels with a total share of 89.4%. Consumption of hard coal amounted to 37.5% and lignite to 9.1%. The share of crude oil reached 26.6%, whereas natural gas accounted for 16.2% and other energy carriers 10.6% of total consumption (with approximately 9% RES share). According to the most recent data published by the Central Statistical Office of Poland, the overall share of renewable energy in terms of gross final energy consumption in 2019 amounted to 12.16%: with 14.35% in the electricity sector, 15.98% in heating and cooling and 6.12% in the transport sector [28].

#### 4. The Way Forward. Current Governmental Plans for Energy Transition in Poland

In March 2021, Poland's Council of Ministers approved the 'Energy Policy of Poland until 2040 (EPP2040), which provides a framework for country's transition to a zero-carbon economy and constitutes a national contribution to the implementation of the EU's climate and energy policy [29]. The policy creates an axis for the adoption of EU energy-related measures, deriving from the EU's 2030 climate and energy targets and the European Green Deal, as well as meets the economic needs arising from the weakening of the economy during the COVID-19 pandemic. It contains strategic decisions and development directions regarding the selection of technologies for building a low-emission energy system. It also contributes to the implementation of the Paris Agreement by taking into account the need for carry out the transformation in a fair and solidary manner. EPP2040 is one of nine integrated sectoral strategies resulting from 'Strategy for Responsible Development', and it is compatible with recently 'National Energy and Climate Plan for the years 2021–2030 [30,31].

EPP2040 indicates three pillars on which it is based, namely:

- A just and inclusive energy transition (I pillar)—which means providing new opportunities for development to regions and communities most negatively affected by the low-carbon energy transition, while creating new jobs and building new industries that contribute to the transformation of the energy sector;
- A zero-emission energy system (II pillar)— as a long-term direction of the energy transition in Poland. As assumed in the EPP2040, this could be possible through the implementation of nuclear energy and offshore wind energy, as well as increasing the role of distributed and civic energy. The temporary use of energy technologies based, among others, on gaseous fuels is deemed as necessary to ensure energy security before turning to nuclear power as a stable and reliable source of baseload electricity generation;

- A good air quality (III pillar)—which could be achieved through development of district heating, transformation of individual sources (heat pumps, electric heating) through low-emission technologies, electrification of transport (aiming at zero-emission public transport by 2030 in cities over 100,000 residents), and promotion of passive and zero-emission houses, with ambitious goal of moving away from burning coal in households (in cities by 2030 and in rural areas by 2040). According to the document, the energy transformation will be founded on modernisation and innovation, sustainable economic growth, increased efficiency and competitiveness. Consequently, among top priorities, the government's energy policy goals are:
- A maximum 56% share of coal-fired power generation of electricity in 2030, with estimated base value of 77% in 2018;
- A minimum 23% share of renewable energy sources (RES) in gross final energy consumption in 2030, with estimated base value of 11.3% in 2018—in electricity at least 32% net (mainly wind and PV—up to 27 GW in 2040), 28% in heating (increase by 1.1 pp per year) and 14% in transport;
- An introduction of nuclear energy to Polish energy mix in 2033—with expectancy to launch the first unit of 1–1.6 GW by 2033 and implement subsequent five units every next 2–3 years (in total 6 units with approximately 6–9 GW of installed nuclear capacity by 2043);
- A reduction of CO<sub>2</sub> emissions by 30% until 2030 (in relation to 1990)—in particular through the modernization of generation capacity and diversification of the energy generation structure;
- The improvement in energy efficiency by 23% by 2030 (compared to the PRIMES 2007 projection).

The above-mentioned indicators were adopted as a global measure of achieving the EPP2040 target. The government estimates that the cost of capital expenditure in relation to proposed energy transformation may reach approximately PLN 1600 billion (EUR 353.32 billion) in the years 2021–2040. Investments in the fuel and energy sectors will involve approximately PLN 867–890 billion (EUR 1914–1965 billion), including PLN 320–342 billion (EUR 70.6–75.5 billion) only in the electricity generation sector. Moreover, approximately 80% of the projected outlays in the electricity generation sector will be allocated to zero-emission capacities, i.e., renewable and nuclear energy. The cost of transition in other sectors, including industry, households, services, transport and agriculture, is estimated by the Ministry of Climate and Environment up to PLN 745 billion (EUR 1645 billion).

EPP2040s pillars underpin eight specific objectives, along with numerous activities for their implementation and strategic projects. According to the policy, recalled objectives cover the entire energy supply chain, from obtaining raw materials, through energy production and supply (transmission and distribution), to the method of its use and sale. The adopted directions of energy policy are largely correlated and well reflect the current challenges of the Polish energy sector (Table 1).

**Table 1.** EPP2040s specific objectives and associated strategic projects.

Ordinal Number	Strategic Objective	Strategic Projects
1.	Optimal use of own energy sources.	Transformation of coal regions.
2.	Development of electricity generation and network infrastructure.	Capacity market. Implementation of smart power grids.
3.	Diversification of supplies and expansion of the network infrastructure of natural gas, crude oil and liquid fuels.	Construction of the Baltic Pipe. Construction of the second line of the Pomeranian Pipeline (by 2023).
4.	Development of energy markets.	Implementation of the Action Plan aimed at increasing cross-border electricity transmission capacity. Gas hub.
5.	Implementation of nuclear power.	Polish Nuclear Power Programme.
6.	Development of renewable energy sources.	Implementation of offshore wind energy (up to 11 GW in 2040).
7.	Development of district heating and cogeneration.	Development of district heating.
8.	Improvement of energy efficiency.	Promotion of the improvement of energy efficiency.

As indicated in EPP2040, the statutory goal of the state's energy policy is *“energy security, while ensuring the competitiveness of the economy, energy efficiency and reducing the impact of the energy sector on the environment, while the optimal use of own energy resources”*.

In order to decline carbon intensities, Poland's electricity sector has to face two main challenges: ensuring the replacement of old capacity and providing incentives for diversification of the energy mix away from coal [32]. In particular, Poland has to address the issue of aging power generation stock, among which nearly half of generating capacity is more than thirty years old and 75% of coal capacity is over 25 years old [33]. According to estimates presented in EPP2040, approximately 26.5 GW of generation capacity will be decommissioned by 2040, which is more than 50% of the present installed capacity in the National Power System.

At the same time, the results of conducted analyses indicate a relatively large change in the structure of electricity generation in Poland by 2040. The maximum capacity of generation sources may increase from approximately 46 GW in 2018 (37.3 GW in 2015) to approximately 59 GW in 2030 (an increase by approximately 58%) and up to 72 GW in 2040, which means almost doubling the capacity in this period (93%). The change in the fuel structure of the installed capacity is particularly evident after 2030. It is mainly due to the phasing out of exhausted coal-fired units that will be replaced by new hard coal-fired units (4.4 GW by 2025) characterized by high efficiency, the development of renewable energy sources, the implementation of nuclear power programme and a significant increase in the capacity of gas units.

EPP 2040 expects that the power sector will be entirely restructured by 2040 with fundamental changes to the generation mix. A very important element of the Polish energy policy is the introduction of nuclear power. In terms of the future Polish energy mix, nuclear power plants could ensure the stability of energy generation with zero emissions of air pollutants, enabling Poland to meet its environmental obligations resulting from the EU climate policy.

The primary objective behind the implementation of nuclear power is the need to provide appropriate energy security for Poland, particularly because of the anticipated shutdowns in the National Power System and an increase in demand for electricity in the

next decades. In the years 2030–2035, nuclear power should replace a high volume of the decommissioned coal-fired capacities that provide a baseload for the National Power System. According to data presented in EPP2040, by 2035 nuclear power should generate as much as 9% net electricity of the total production structure and about 16% in 2040. It is estimated that in 2035 nuclear capacity may generate even more than 20 TWh, which is nearly twice as much energy as will be obtained in the same period from photovoltaics, with nearly 4.5 times less installed nuclear capacity.

According to EPP2040, another argument in favour of implementing nuclear power is that it generates a very low environmental and system costs, which makes it a very attractive technology for an optimal (in terms of social costs) energy mix. Poland's actions related to moving away from conventional energy sources consider nuclear power as an economically viable source of energy production in most long-term scenarios and analyses. This is particularly the case due to stricter EU emission standards and increasing CO<sub>2</sub> prices under the EU Emissions Trading system (EU ETS), which make lignite-fired power plants increasingly expensive. Moreover, Polish coal-reliant energy sector has to adjust its power generation capacity to stricter environmental requirements as set forth in the EU legislation, notably in the so-called 'Industrial Emissions Directive' [34]. Therefore, the development of nuclear power would enable Poland to remarkably decrease emissions of CO<sub>2</sub> and of pollutants such as SO<sub>2</sub>, NO<sub>x</sub> and dusts.

## 5. Discussion

### 5.1. The Outlook for Nuclear Power in Poland's Energy Transition

The idea of implementing this new source of power is delineated in a separate government strategic document devoted entirely to nuclear power—the Polish Nuclear Power Programme [35]. It describes the main goal and specific goals, in the form of State's tasks, and provides a comprehensive justification for this decision.

The main governmental target as envisaged in the Polish nuclear power programme is the construction of nuclear power plants with a total installed capacity of 6–9 GWe based on advanced, but proven, large-scale pressurized water reactors (PWR).

#### 5.1.1. Reactor Technology

One of the main factors that affect the amount of capital expenditure and the level of risk involved in construction is the maturity of technology and experience in the construction and operation of units of a particular type. The first version of the Programme (2014) was technologically neutral. However, since its adoption, significant progress has been made in implementing certain types of reactors. In the last years, the global nuclear power market has been dominated by advanced large-scale PWRs with capacities of 1000–1650 MWe net (since 2016 following PWR reactors have been commissioned: APR1400: Barakah-1 in United Arab Emirates (2020), Shin Kori-4 (2019) and Shin Kori 3 (2016) in South Korea; EPR: Taishan-2 (2020) and Taishan-1 (2018) in China; AP1000: Haiyang-2 (2019) and Haiyang-1 (2018) in China; Hualong One: Kanupp-2 (2021) in Pakistan and Fuqing-5 (2020) in China; VVER: Belarusian-1 (Astravyets) (2020) in Belarus and Leningrad-2-2 (2020), Leningrad-2-1 (2018), Novovoronezh-2-2 (2019), Novovoronezh-2-1 (2016) in Russia.). This is also confirmed by numerous plans for the construction of new units of this type and a relatively small number of planned projects with boiling water reactors (BWR) and heavy water reactors. Pressurized water reactors in recent years were built or are being built in Europe, among others in Finland, France, Great Britain, Slovakia, Belarus, Russia and Hungary, and in other parts of the world such as USA, South Korea, United Arab Emirates, Turkey, China, Pakistan, India, Brazil, Bangladesh and Iran. In Europe, there are currently no active projects with BWR, and almost all those under construction are based on the PWR type. Plans for construction of heavy-water blocks exist in Europe only in the case of Romania, where the construction of blocks 3 and 4 at Cernavodă NPP was suspended in 1990. There is a will to resume the construction soon and preparatory work in this regard is underway [36]. The Programme names also a few reasons for this: (1) the

largest, among all reactor technologies, experience in construction and operation (the most common reactor type in the world—currently 303 out of 444 operational reactors, 68% of the world's power reactor fleet), (2) no negative safety experience (not a single failure with major releases into the environment), (3) common knowledge of the PWR technology by nuclear regulatory control bodies (important in knowledge transfer), (4) a smaller area of radiation impact in the event of a possible failure of in relation to BWR and PHWR, (5) a larger number of entities offering PWRs than BWRs and heavy-water reactors, which ensures the competitiveness of bids and reduces costs, (6) lower operating costs of PWR units against BWR.

The government further claims that experience acquired in the course of site and environmental surveys shows that the joint consideration of different technologies would unreasonably complicate the process of nuclear technology selection, the administrative process, and it would increase the costs of these activities, also with regard to public expenditure [37]. Therefore, efforts should focus on the most proven designs, namely large-scale pressurised light-water reactors. An early limitation of the technology choice to this group will significantly simplify and shorten these processes and reduce costs. The recommended choice of the PWR technology applies, also for the reasons described above, to reactors available in the market with a capacity of 1000–1650 MWe net. For the Polish power sector, the priority is to replace high-emission coal-fired capacity with zero-emission generation as soon as possible and to avoid a gap in the system that could occur in 2030. Large, proven nuclear reactors guarantee fast and reliable capacity growth effects while providing for rapid and effective decarbonisation.

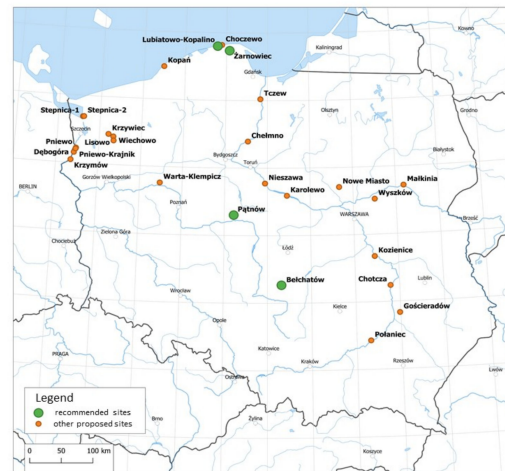
For many reasons, the government programme does not provide for relying on the technologies of smaller reactors which are being currently developed (so called SMRs—small, modular reactors). The main argument is that they do not exist yet, and their commercial availability as a proven technology is to be expected around 2040. Thus, it will not be possible to consider them as an alternative around 2026 when the construction of the first nuclear unit in Poland should start. It can also be read as a part of a broader idea of not planning the future based on non-existent solutions, which may be promising but do not exist in practice and whose development is still uncertain. This does not however stop private entrepreneurs from investing in such technologies. One of them has even started the regulatory dialogue with the national nuclear authority (PAA President) [38]. The Programme is binding only for the government itself including all its subordinated entities. Polish law is technologically neutral and thus allows the construction of any nuclear installation that proves compliance with safety standards.

#### 5.1.2. Sites

Government documents do not directly indicate where the nuclear power plants will be located. However, the programme includes a list of 27 potential sites for such installations, dividing them into recommended and other locations. All the sites are the same as those specified in the 2014 Programme. With no changes in this regard, the type and scale of potential environmental impact remain the same; therefore, a new strategic environmental impact assessment is not required. The most favourable sites are located on the eastern coast: Lubiatowo-Kopalino and Żarnowiec. For those two, the work on environmental and siting studies is most advanced. The advantages of these sites include a significant electricity demand; the lack of large, dispatchable generation sources in the area; access to unlimited amount of cooling water and the possibility of transporting large-size loads by sea. Other recommended sites are those currently used by existing baseload lignite-fired power plants Bełchatów and Pątnów. Their main advantages are developed transmission, transport and other important infrastructure and central location. Placing a new power plant in such a place will also help to achieve one of the main goals of the current energy policy of the state—a fair transformation of the energy sector (“just transition”). New power plants would allow jobs to be maintained after existing plants in operation will retire. Given the fact that works regarding site and environmental surveys



are most advanced on the potential coastal sites, the first site will be selected from among them. In Figure 1 is shown the potential sites of nuclear power plants in Poland.



**Figure 1.** The potential sites of nuclear power plants in Poland. Source: <https://www.naturalearthdata.com/> (accessed on 1 April 2021), the institution's own data.

The choice of an optimal site for the construction of a nuclear power plant requires an analysis of many factors. They include the following: (1) environmental factors—including the identification of the geological structure of the substrate, population density and land use, meteorological and hydrological conditions, including the adequacy of water resources for cooling purposes, constraints on the construction and operation of power plants due to environmental conditions, including legal requirements in the field of environmental protection, (2) technological factors—including the possibility of outgoing power from power plants—integration with the power system, access to transport routes (road, rail, sea and air transport have been taken into account), (3) economic factors—including the deficit of generation capacity in a given region, the possibility of filling gaps after closed mining and energy complexes; (4) social factors—local acceptance for nuclear power plant construction.

### 5.1.3. Business Model

As the 2020 Programme indicates, different models are used in the world for the implementation of nuclear projects, depending in the policy of the country concerned, the design of the local energy market and the type of investor. New projects are implemented mostly on the basis of such models (or, actually, electricity sales modes) as (1) long-term power purchase agreements—PPAs (e.g., in the USA, United Arab Emirates, Turkey), (2) contracts for difference—CfD (e.g., in the UK, planned in Romania, and considered in the Czech Republic), (3) tariff model the so called Regulated Asset Base—RAB (e.g., in the UK), (4) co-operative models (e.g., Mankala in Finland and Exeltium in France). The document does not indicate any particular business model to be used in the implementation of the nuclear programme. However, it clearly sets out some assumptions for it. They include (1) one reactor technology for all NPPs, (2) one strategic co-investor linked to the technology provider, (3) acquisition of 100% shares in an existing special purpose vehicle implementing the project (joint ownership of several state-owned energy and raw materials companies—it has already taken place in March 2021), (4), retaining at least a 51% stake in the SPV (after one strategic co-investor is selected).

The selection of one reactor technology for all NPPs will reduce costs of construction and operation owing to economies of scale. Repeatability of projects (same reactor type, same general contractor) will allow for a large contract with low unit price for specific NPP projects and more effective use of experience gained while building individual units. Large multiple contracts will further allow for price discounts and thus lower prices of

equipment and spare parts. Training of crews, other personnel and regulatory staff will also cost less. With one standardized technology, the participation of domestic industry and enterprises can grow faster, and construction of units can be quicker both owing to the learning effect. One technology gives also possibility for the nuclear regulatory authority and other control bodies to use their resources in a much more efficient way. In the case of an eventual further expansion of the PNP Programme (after 2050), a large number of units of the same type will provide rationale for the possible location of fuel fabrication plants in Poland, which falls in line with the energy security component as a part of the justification of the Programme.

An early selection of a single business partner (strategic co-investor) will facilitate the organisation of low-cost NPP project financing. A foreign investor will contribute their experience in the construction and/or operation of NPPs and increase the credibility of the project, which will make it possible to acquire attractive export loans and other sources of capital. Such approach will help to ensure strategic partnership at a political and economic level and significantly accelerate the process of preparing nuclear projects. The retention by the Polish government of control over the special purpose vehicle will provide direct control over the decision-making process of PNP Programme and will enable effective ownership supervision over the implementing company investments. It will limit risks affecting the level of financial costs of the project, which will consequently lower investment capital cost and ultimately reduce price of electricity. This is part of the strategy of ensuring energy security and will make it possible to guarantee that NPPs will bring benefits to the whole economy and the whole society, and not only investors.

#### 5.1.4. Long Term Policy Reasons for Nuclear Power in Poland's Energy Mix. Strengthening Energy Security

The implementation of nuclear power in Poland will significantly contribute to energy security and will enable ageing high-emission baseload coal units to be replaced with new, zero-emission units. In particular, nuclear power will contribute to increasing the diversification of both the fuel base and the directions of supply of primary energy carriers.

##### Diversification of the Fuel Base in the Electric Power Sector

The construction and operation of the NPP will contribute to the diversification of energy generation sources and, more broadly, to the diversification of the fuel base (through the introduction of nuclear fuel). It is expected that around the year 2045, the NPP share in the energy mix will be approximately 20%, while its share in system baseload generation will be significantly higher.

Nuclear fuel has the key advantage of having the highest energy density among all other fuels. In conjunction with the possibility of deliveries from many geographic directions and many different routes (sea, rail, road, air), this creates the possibility of reliable supply under any conditions. What should also be mentioned is the unique, compared to other energy sources, possibility of storing additional stocks of fresh nuclear fuel on the premises of a power plant or uranium stocks in the fuel cycle plants, which guarantees continuity of electricity supply even in situations of international political and economic instability and in extreme weather conditions.

The cost of the entire fuel cycle represents 10–15% of the total cost of electricity generation. An increase in the nuclear fuel price by 50% causes an increase in the cost of electricity production at an NPP by approximately 6%. This proportion is inverse to gas, where fuel cost represents 70–80% of total energy costs, and therefore, all major fluctuations of gas prices in the global market are significantly reflected in the costs of energy production in gas plants.

##### Diversification of the Directions of Supply of Primary Energy Carriers

Nuclear fuel will also allow the diversification of the directions of supply of primary energy carriers by purchasing it from different states (including NATO and EU member states) mainly from other politically stable countries. In addition, as a member of the

European Atomic Energy Community, Poland will benefit from support and security of fuel supply within purchase coordination mechanisms. This provides real choice opportunities—uranium and the fuel cycle services market is competitive and not dependent on one supplier or service provider [39].

#### Replacement of Aging Baseload Generating Assets

In recent years, balancing the demand and electricity generation has increasingly been at risk due to aging generating assets. In addition, in line with the EU's increasingly ambitious climate policy, old coal or lignite-fired generating units must be replaced with new, zero-emission, stable energy sources. Forecasts by the transmission system operator indicate that most outages will take place in 2030–2040. The government assumes that in that period the first nuclear power units will go online, which will provide baseload power supply for the national power system. The implementation of nuclear power will enable the achievement of the climate neutrality objective in compliance with the provisions of the Paris Agreement [40], will have a positive effect on the economy (no high costs of purchase of CO<sub>2</sub> emission allowances, no high fuel costs). In the EU context, zero-emission electricity generation from nuclear fuel allows ambitious goals of greenhouse gas emission reduction to be achieved whilst avoiding emission costs under the EU Emissions Trading System (EU-ETS).

#### 5.1.5. Fighting Climate Change and Protecting the Environment

##### The role of Nuclear Power in Preventing Climate Change

According to the report compiled by the Intergovernmental Panel on Climate Change (IPCC), nuclear power is a very important element of combating climate change [41]. Three of four model scenarios presented in the report provide for an increase of installed capacity of nuclear sources, and every fourth represents the status quo, i.e., the construction of new power plants in place of the decommissioned ones. Identical conclusions arise from the report by the International Energy Agency “Nuclear Power in a Clean Energy System” [42], according to which abandoning the extension of the service life of existing nuclear power plants and investment in new nuclear capacity in developed economies would mean an additional 4 billion tonnes of CO<sub>2</sub> emissions by 2040. According to the Polish government, nuclear power, as a dispatchable baseload source, will allow RES to be deployed on a mass scale in a stable manner, setting the direction of energy transition and helping to achieve the climate neutrality objective. Without nuclear power, it is impossible to maximise the use of RES and to achieve an optimal reduction of emissions. The experience of countries such as Germany, but also the USA or China, shows that without zero-emission sources for baseload generation, huge investment in RES capacity expansion does not lead to the desired emission reduction effects [43]. On the other hand, examples of large industrialised and highly developed countries such as France, Sweden, Switzerland and regions such as the Canadian province of Ontario prove that nuclear power contributes to the effective, fast, deep and durable decarbonisation of the power sector. In all those cases, emissions have been reduced dramatically to a level much below 100 kg CO<sub>2</sub>/MWh based mainly on nuclear power (France) or on a combination of nuclear power and large-scale hydro power (Sweden, Switzerland, Ontario).

Seeking to achieve the objective of the Paris Agreement, in December 2019, the EU adopted the EU-wide objective of reaching complete climate neutrality by 2050. In this context, the EC started work on increasing the greenhouse gas emission reduction target for 2030 from 40% to at least 50%. The weight of these plans is highlighted by the establishment of the European Green Deal (EGD), which will replace the Europe 2020 Strategy as the main strategic document for the EU. The political commitment contained in the EGD Communication is to be transformed into a legal obligation after the adoption by the European Parliament and the Council of a legislative proposal on the European Climate Law, presented by the EC on 4 March 2020. These considerations, in the context of Polish energy transition, necessitate the inclusion of zero-emission nuclear power in the energy mix as the basis of the country's sustainable power system.

## Protection of the Environment

The environmental advantages of nuclear power mainly include: no direct CO<sub>2</sub> emissions during operation (over the past 50 years, approximately 55–60 Gt of CO<sub>2</sub> has been avoided), as well as no emissions of other substances harmful for the environment and human health: NO<sub>x</sub>, SO<sub>2</sub>, CO, particulate matter (PM), mercury and other heavy metals and polycyclic aromatic hydrocarbons (PAHs). Nuclear power also means very low consumption of concrete and steel per unit of produced electricity [44], saving valuable raw materials: rare earth elements and silver used in RES technologies [45], the lowest area footprint per unit of generated electricity. Nuclear energy has the lowest ratio of 0.1 m<sup>2</sup>/MWh, compared to 0.2 m<sup>2</sup>/MWh for coal and gas, 1.0 m<sup>2</sup>/MWh for wind power and 10 m<sup>2</sup>/MWh photovoltaic sources [46] and even up to 80–100 years of efficient operation, e.g., Turkey Point in USA, units 3&4, Peach Bottom in USA, units 2&3. Moreover, NRC received application to extend operation up to 80 years for: Surry-1&2, North Anna-1&2 and Oconee-1,2,3. Nuclear power is also an important element of biodiversity protection, as confirmed by many renowned environmental protection experts [47]. Bearing in mind the seriousness of climatic situation as well as expected exclusion of biomass from the list of low-emission sources, and also growing social opposition to large RES projects, observed in some EU countries, nuclear power may become an important factor limiting negative impacts of some projects on birds, bats, insects etc.

A less highlighted advantage is the possibility to operate an NPP in cogeneration mode. A nuclear combined heat and power plant is the only zero-emission technology of electricity and heat cogeneration, which is of significance especially for countries with numerous district heating systems. Operational experience exists in Switzerland, the Czech Republic, Hungary and Slovakia. Conceptual works have been carried out in Finland, France, the UK and Poland (Żarnowiec NPP) [48–50]. In addition, nuclear fuel can be recycled and reused in the reactor (if deciding on closed fuel cycle), which fits into the principles of the circular economy and sustainable development.

An additional technical aspect of operation, which distinguishes nuclear power plants from other sources, is radioactive waste and spent nuclear fuel safely managed. It should be noted that the nuclear power sector, as the only one among the electricity generation technologies, follows a systemic approach to these issues and ensures isolation of waste from the environment and the population over the entire life cycle and after the end of service life. Moreover, only in this case, funds are accumulated for waste disposal and plant decommissioning. The related costs are included in the cost of electricity. In the case of other energy sources, the issue of waste from the whole life cycle has not, so far, been in focus of interest, nor has it become an object of a systemic approach in either the technical and organisational dimension (disposal or recycling methods) or financial dimension (waste and decommissioning fund).

### 5.1.6. Economics

The cost of electricity for consumers is of key significance for the economy and society owing to its impact on the final price of services, competitiveness of the national industry and the society's well-being. A nuclear power plant, as a stable generating source with a long service life, generates a very low environmental and system cost, which may contribute to suppressing the increase of electricity costs for consumers, taking into account the full range of costs associated with production of electricity. This is confirmed by an analysis carried out by the government which showed that (1) according to the total electricity cost account, provided that appropriate development conditions are ensured, nuclear power plants are among the lowest-cost generating units in the 2050 perspective; (2) in the 2045 perspective, the optimum volume of nuclear capacity should be approximately 7.7 GW net, which means the energy sector's share in the mix (generation) of 27%; the extended analysis perspective indicates the profitability of construction of NPP of approximately 10 GW net by 2050; (3) nuclear power plants contribute to reducing the demand for natural gas in the electric power sector, minimising the capital outflow related to fuel

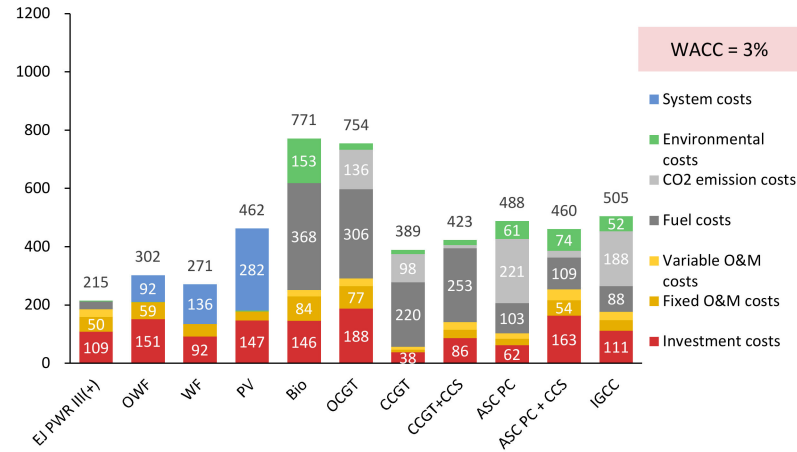
import and the sensitivity of electricity prices to gas price fluctuations; (4) system costs are growing with the increasing share of weather-dependent sources in electricity production, significantly increasing the total electricity generation cost in the system; dispatchable sources such as nuclear power plants allow the generation of such costs to be reduced, ensuring operational security of the power system; (5) the total levelised cost of electricity in 2020 is 80 EUR/MWh. In 2045, the cost will be the lowest in the scenario in which the NPP is developed by the way of free optimisation (83.5 EUR/MWh) and the highest in the scenario without the NPP (87 EUR/MWh). The extended model perspective demonstrates a further decline in the total cost with continued development of nuclear power (76 EUR/MWh in 2050) and an increase in divergence from scenarios excluding NPP (84 EUR/MWh in 2050).

Most of the NPPs currently in operation, with returned capital, bear the costs of 17–27 EUR/MWh including balancing costs. The other components of the cost of electricity supply guarantee (i.e., other system costs, such as network development, system balancing and redundancy costs), owing to high availability, operational stability and ability to follow demand are negligible for nuclear sources. Other dispatchable sources (coal, gas) are characterised by system costs at a similar level, but they bear high costs of fuel and greenhouse gas emission costs (EU-ETS system). For their part, RES are characterised by medium or low investor costs (LCOE) but many times higher system costs. Solar (photovoltaic) and wind farms, both onshore and offshore, require stable and flexible reserve capacity of gas units, hydro power plants or other dispatchable sources. For technological and cost reasons, the capability to store surplus energy from RES in the short and medium term will remain insufficient having regard to the needs of the Polish power system, as is also the case with the DSR/DSM services potential.

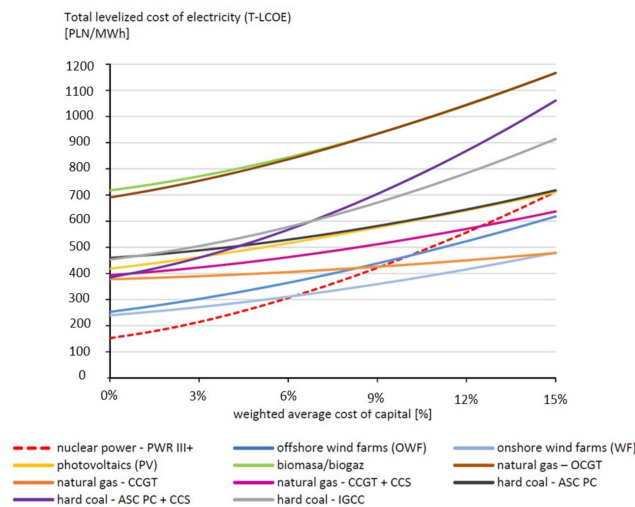
For the purposes of public debate, the competitiveness of individual generating technologies is determined very often by means of the Levelised Cost of Electricity (LCOE). The LCOE methodology does not take into account all costs associated with electricity generation, focusing exclusively on the investor's perspective. Energy companies in most EU member states treat investment in new generating sources as purely financial investments that offer a quick return and low risk, without taking into account their strategic significance for the state and for the economy [51]. Producers using priority technologies (e.g., high-efficiency cogeneration or RES) are released from a number of obligations (e.g., in terms of provision of regulatory reserves) or have special privileges (e.g., guarantee/priority of electricity off-take regardless of the cost) as opposed to others market participants. This leads to lower levels of investment risks (e.g., related to the lack of the possibility of selling energy), thus reducing the cost of capital, increasing the availability of loans and ultimately improving their competitiveness against other sources. The preferential conditions of certain technologies negatively affect other energy market participants. The economic assessment of projects based on LCOE reflects these dependencies only through differentiation of individual technology WACC levels, which can lead to confusing conclusions in terms of the real competitiveness of the compared solutions strongly dependent on applicable regulatory conditions. At the same time, transmission and distribution system operators (and thus—the total energy consumers) must provide integration of all generating sources services, even though the value of these services can vary significantly depending on used technologies (in particular in the field of uncontrollable sources). Standard LCOE methodology does not differentiate projects in this area, assuming full socialization of system costs, which again can lead to confusing conclusions for policymakers [52].

In creating the national energy strategy, the government, having regard to the long-term development of the country and responsibility for the whole state, society and the economy, cannot assume a short-term perspective of power sector investors seeking the maximization of profits [53]. The government's priority is to maintain energy security of the country understood as ensuring the continuity of electricity supply at a minimum cost for the final consumer, taking into account safety, technical (including system) and environmental requirements. In this context, nuclear power plants are generating units

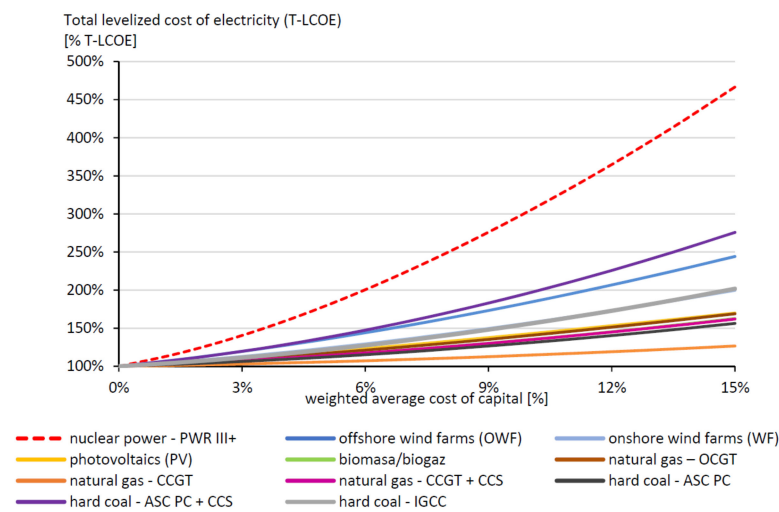
that may reduce the real total cost of electricity generation. Figure 2 present the operating costs of energy sources in Poland and the relationship between the cost of capital and the price of electricity from nuclear power plants (Figures 3 and 4).



**Figure 2.** The low cost of capital makes nuclear power plants the cheapest source of electricity. Decomposition of the total levelised cost of electricity (T-LCOE). WACC = 3%; power generation technologies commissioned in 2035; 30% penetration of the given variable RES technology in the system.

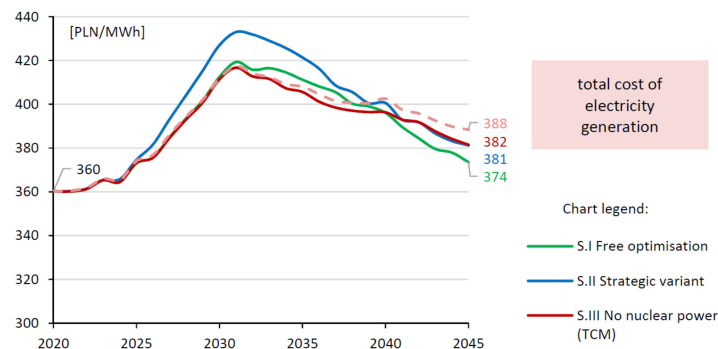


**Figure 3.** The lower the cost of capital, the lower the price of electricity from nuclear power plants. Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035. Variable: weighted average cost of capital (WACC). Constant: 30% penetration of the given variable RES technology the system.



**Figure 4.** The dependence between the lower cost of capital and the price of electricity from nuclear power plants. Estimation the sensitivity of the total levelised cost of electricity (T-LCOE) in 2035. Variable: weighted average cost of capital (WACC). Constant: 30% penetration of the given variable RES technology the system.

Figure 5 present the average total cost of generating electricity from nuclear power and compares the costs of generating electricity without a nuclear power plant.



**Figure 5.** Nuclear power in the longer term reduces the average total cost of electricity generation compared to variants without NPP (free optimisation scenario—7,7 GWe nuclear power plants until 2045, strategic variant—6,6 GWe nuclear power plants until 2045).

## 5.2. Implementing the Nuclear Energy: The Role of the State

The Polish Nuclear Power Programme provides for five task-goals areas: human resources development, infrastructure development, support for domestic industry, strengthening nuclear regulatory authority, public communication.

### 5.2.1. Human Resources Development

Providing highly educated and well-trained staff capable of actively co-creating a unique safety culture is one of the most important tasks in preparing for the construction and operation of a nuclear power plant. In view of the need to ensure the high competence and efficiency of nuclear power sector workers, proper planning, training and management of staff is essential. The main prerequisite for preparing personnel is the fact that Poland currently does not have sufficient human resources prepared specifically for the purposes of nuclear power. With the decision to include nuclear power in the national energy mix, Poland must plan in advance the number and structure of personnel that will be needed at each stage of the construction and operation of the nuclear power plant. This is necessary in order to implement education and training programmes in the national education system

in sufficient time and to ensure that the relevant workforce is provided in time for the future nuclear power plant. Recent experience with the deployment of nuclear power in the United Arab Emirates indicates that insufficient staffing may lead to a delay in the launch of the NPP. It should also be noted that liability for untimely HR preparation for UAE NPPs is borne by the government and the plant operator / investor, not the technology vendor.

The construction of one unit requires a total of 3–4 thousand construction and assembly workers representing a wide range of professions and educational levels—from workers duly trained for work on the construction of a nuclear facility, to welder-fitters, mechanics, crane operators, drivers of construction vehicles, electricians, automation surveyors, electrical fitters, pipeline fitters, steel fixers and concreters to engineers, architects and representatives of many other professions. 80–90% of personnel are people with technical, vocational education and those trained to carry out the above-mentioned work. According to the IAEA methodology, the number of personnel for the operation of a single-unit power plant can be estimated at 500–700 people (depending on capacity, etc.), of whom 200–300 are technicians and 300–400 other specialists. The staffing for a two-unit power plant is around 1000 people. Therefore, in order to identify needs and create an optimal mechanism for the preparation of human resources for the purposes of implementation of the NPPP, the following tasks are required to be performed: (1) assessment of the national human resources potential; (2) identification of the needs in terms of the number and professional qualifications of employees, necessary in the various phases of the implementation of the nuclear project, the role of the technology provider in the development of personnel for the nuclear power sector, the training system and international cooperation; (3) comparison of staffing needs with current employment and education and identification of actions to fill gaps detected in this area; (4) establishment of a cooperation mechanism for building human capital for nuclear power [54].

The document setting out the tasks and the time schedule for their implementation will be the *Plan for the Development of Human Resources for Nuclear Power*, taking into account the staffing needs of the entities involved in the implementation of projects and the operation of power plants and their ability to satisfy those needs at home and abroad, the recruitment system, and career paths. Each public body implementing the nuclear programme should also prepare its own human resource development plan in line with IAEA recommendations.

### 5.2.2. Infrastructure Development

The development area intended for the construction of the NPP is subject to special preparation. Accompanying investment projects are generally not part of the power plant itself; moreover, they are not located on its territory but are necessary for its construction and proper and safe operation. The work carried out in the development area for the entire NPP construction project reflects the scope of construction and installation work carried out during the construction of a large industrial facility. The uniqueness of the project is in the length of the construction period and the extent of the scope of work and its complexity. In addition, it is necessary to comply with strict quality standards and construction procedures as well as international guidelines and recommendations. In particular, new sections of roads, railway lines, a marine structure for the unloading of oversize elements, water and sewerage networks, including wastewater treatment plants, and the upgrading of existing infrastructure will be carried out. The prepared infrastructure will serve not only the NPP, but it will also satisfy local needs and thus make a lasting contribution to the development of the region.

The NPPP determines three key areas of infrastructure development: changes in the national power grid (development of transmission and distribution networks, power evacuation from power plants), development of transport infrastructure (road and rail transport, maritime logistics infrastructure, air transport infrastructure), other infrastructure investments (water supply network, accommodation and housing, telecommunications and teletechnical).



### 5.2.3. Support for Domestic Industry

As in similar projects elsewhere, the Polish government aims at rational maximisation of the participation of domestic entities in the construction, operation and maintenance of nuclear power plants. This should not only translate into their direct commercial success and development of whole new industries, but it will also benefit the economy at large. The Polish may benefit mainly from the technology and knowledge transfer (e.g., experience in the implementation of mega projects) and the implementation of a large number of high value-added projects. The scope of involvement will depend on the size of the nuclear programme itself, previously undertaken adjustment measures, and the investor's arrangements with the technology provider and the generation contractor. Apart from technological, organisational or competence advantages, the domestic enterprises participating in the NPP construction in Poland, based on the experience and contacts gained, will find it easier to join the global chains of supply of the nuclear sector and in related sectors.

An important role in this regard is played by the fact that for many years now, Polish industry has been providing services and supplied products for the nuclear power sector abroad, mainly in the EU, but also in other parts of the world. In the recent 10 years, almost 70 domestic enterprises have participated in international nuclear competitions as subcontractors. Moreover, another group of almost 200 Polish enterprises has been identified, which, subject to minor adjusting measures, which can be completed within a relatively short time, may start operating in this sector [55].

The preparation of the domestic industry for cooperation with the nuclear sector is a time-consuming process, and if such measures are taken at a possibly early stage, the PNP Programme will be more effective and less expensive. The expenditure incurred will be returned through the development of Polish enterprises; hence, it is an investment in the development of the Polish economy and the re-industrialisation of the country. The existing support programmes for the Polish industry are insufficient in the context of relations with the nuclear sector. Based on proven examples of other countries implementing nuclear programmes (e.g., United Kingdom, Finland), all measures promoting Polish enterprises should be coordinated at government level. Future measures should focus on several main areas: (1) supporting domestic enterprises in the acquisition and implementation of expensive quality certification; (2) information and training activities concerning codes and standards applicable in this industry; (3) promoting and supporting domestic enterprises on the global stage in order to acquire foreign contracts; (4) facilitating the nuclear technology transfer to domestic enterprises, supporting cluster initiatives or other initiatives bringing together interested enterprises. The basic planning tool which allows the proper coordination of actions in the above area will be the Programme of Support for Domestic Industry's Cooperation with the Nuclear Power Sector. The programme will contain information on specific actions and a time schedule for their execution.

### 5.2.4. Strengthening the Nuclear Regulatory Authority

The President of the National Atomic Energy Agency (PAA) is an independent regulatory authority whose role is to ensure that the use of ionising radiation and nuclear energy does not cause a risk to human health and life and to the environment. In the course of PNP Programme, the primary responsibility of the President of PAA will be to exercise supervision and enforce compliance with security and safety requirements and standards for nuclear power plants and other nuclear facilities. For the efficient performance of his responsibilities, the President of PAA must have relevant authority guaranteed by law, independence in taking decisions on nuclear safety, adequate financial and organisational resources and competent expert personnel of the office supporting him (PAA). The ability of PAA to efficiently perform its nuclear regulatory control tasks depends mainly on the possession of highly qualified personnel. Regulatory oversight over project implementation with regard the design, construction and operation of a nuclear power plant is a new challenge for the President of PAA, which requires the reinforcement of the existing PAA staff

by employing personnel specialised in many technical areas, such as power engineering, electrical engineering, automation, mechanics, civil engineering, materials engineering, physics, chemistry, geology, and skills in using calculation tools for the deterministic and probabilistic safety analysis.

A significant part of analyses and expert reports in the area of nuclear technology and individual technical fields will have to be outsourced to third parties. Owing to the extensive scope and complexity of technical issues, the nuclear regulatory body is unable to perform on its own all analytical work as part of the assessment of documentation submitted by the investor for the purposes of design, construction and operation of the nuclear plant. For many specialist issues, necessary analysis will require more personnel to be involved than available from PAA. Moreover, certain analyses and expert reports will be performed on a one-time basis for the purposes of a specific project stage; therefore, it is more economically reasonable to outsource such work than to maintain employment and train additional staff.

In order to ensure the proper performance of tasks for the purposes of the PNPP, PAA will purchase appropriate hardware and software for safety analyses and assessment of documentation submitted by the investor. Moreover, the national radiation system will be expanded, including programmes supporting decision-making in crisis situations. The monitoring system must allow the nuclear regulatory body to independently assess the radiation situation around the nuclear power plant and its impact on the environment and population. For this purpose, the PAA President will conduct cyclical measurements covering all components of the environment, which will allow verification of the results of radiation monitoring performed by the facility operator. A dosimetry team will also be set up within PAA, equipped with appropriate gear for providing support in conducting dosimetric measurements in the event of a radiological emergency.

#### 5.2.5. Public Communication

Public support for nuclear power, as for many other objectively safe technologies, grows along with the increasing level of knowledge about it. The role of social education and information is key in the process of implementation of the PNPP. It is important to provide society with up-to-date, objective and reliable knowledge of energy and nuclear power, based on scientific grounds. This will contribute to the improvement of the education level and increasing citizens' awareness of the technology. Stable and conscious social support for nuclear power is one of the key conditions for the implementation of the PNPP. The main information and education tasks of the government will consist in: (1) increasing the awareness of the public about nuclear power energy and nuclear power generation; (2) transferring knowledge on the rules of operation and safety of nuclear power plants, other nuclear facilities and on the rules for the safely managed of radioactive waste; (3) informing the public about economic and political benefits of the development of nuclear power; (4) keeping the public informed about individual benefits of the development of nuclear power, i.e., new jobs, development of the region in which the power plant will be situated, stabilisation of electricity prices; (5) responding to social needs with regard to access to information, in particular on the safety of the installations, replying to questions from citizens, and keeping them informed about the current radiation situation in Poland and in the world.

The detailed scope of activities and the tools for their implementation will be defined in the Communication Strategy of the PNPP. The Strategy will indicate ways of building awareness of the existence of the PNPP, its importance and benefits of implementation. It will define goals and detailed tasks and tools for their completion. The Strategy will include specific educational and information activities along with their thematic scope, schedule and entities that will be responsible for their implementation. The Strategy will take into account the educational and information role of non-governmental organizations, universities and research institutes that may play a supporting role. The government declares that full transparency will be the key and main principle governing all activities.

### 5.3. Political and Legal Instruments Introducing Nuclear Power in Poland

Successful implementation of the nuclear programme needs the intermediate goals to be met first. Based on government documents, there are three intermediate objectives on the way to nuclear power implementation: public acceptance, reduction of investment risks, retention of political control over the selection of the investor and operator. The introduction of nuclear power in Poland is governed by political and legal instruments. In order to provide a solid substantive basis for the successful nuclear programme, both types of instrument have to be correlated. The introduction of nuclear power in Poland is governed by political and legal instruments. In order to provide a solid substantive basis for the successful nuclear programme, both types of instruments have to be correlated. A significant role in achieving each of them was passed for legal actions, in particular legislation. The government proposed a number of changes in Polish legislation subsequently adopted by the parliament. Those changes are a good example of using law (legislation) as an instrument to implement state policy in a socially and economically sensitive area. In this case, a holistic approach was applied, not limited to single changes. The entire spectrum of issues has been revised in several key identified areas, including introducing of solutions previously unknown to the Polish legal order. The relatively low cost of introducing changes is a significant asset of the law as an instrument of policy implementation. On the other hand, its disadvantage is the fact that changes in the law do not themselves fulfil the assumed political goals. They only provide conditions for their achievement, among others stimulating the behaviour of individual entities, or creating more favourable rules of the game than before. Laws are also not created in a vacuum. The desired effect of certain law provisions cannot be achieved without real implementation. Laws themselves, even the most perfect, will not build nuclear power plants. In order to achieve the goals they are to serve, it is also necessary to apply them properly and demonstrate consistently the credibility of stakeholders in particular the government and the investor and operator [56,57].

Plans to build Poland's first nuclear power plant date back to the seventies and eighties; however, after the political transition in 1989 the construction of two Soviet-designed VVER 440 units in Żarnowiec was eventually abandoned. The turning point came with the resolution of the Council of Ministers of 13 January 2009, in which the Council expressed the need for the preparation and implementation of the nuclear power programme in Poland [58]. Due to the necessity to incur significant financial outlays for the development of regulatory, organizational, educational, scientific and research infrastructure, it was decided by the Polish government that the investor of the first nuclear power plants should be a company with a direct or indirect majority stake of the State Treasury. By virtue of the aforementioned resolution, the largest power engineering company in the country and one of the largest in Central and Eastern Europe, namely PGE Polska Grupa Energetyczna S.A., was entrusted by the Polish government with a mission to develop nuclear power generation in Polish energy mix.

In 2009, the Council of Ministers adopted a document entitled 'Energy Policy of Poland until 2030. Among the primary directions of energy policy, the Polish government indicated the diversification of electricity generation structures by introducing nuclear energy. In January 2010, the National Court Register entered in its records a new company: PGE EJ 1 sp. z o.o. with the registered office in Warsaw. PGE EJ 1 Sp. z o.o. is a company directly responsible for development of the investment process and site investigation, as well as obtaining all necessary licenses and permits required for the construction of the first Polish nuclear power plant. It is also responsible for the selection of technology for the future nuclear power plant and will in time become the operator of the plant.

On 28 January 2014, the Council of Ministers adopted the Polish Nuclear Power Programme, which envisaged the construction of two nuclear power plants by 2035, with a total installed capacity of 3000 MW each [59]. Although according to the project schedule, the first nuclear power plant should start operation by 2030, the completion of the first nuclear power plant was delayed, mainly as a result of a lack of political motivation, until 2018.

On 9 October 2020, the Council of Ministers updated the government's long-term Polish Nuclear Power Programme and its new schedule. The main objective of the Programme is to build and commission nuclear power plants in Poland with a total installed capacity of approximately 6 to 9 GWe based on Generation III (+) water pressure nuclear reactors. According to the updated schedule the first unit should be commissioned by 2033. On 2 March 2021, Poland's Council of Ministers approved the 'Energy Policy of Poland until 2040 (EPP2040), with one of the top priorities to introduce a nuclear energy to Polish energy mix. On 26 March 2021 a sales agreement for 100% of the interest in the share capital of PGE EJ 1 Sp. z o.o. was signed between shareholders and the State Treasury represented by the President of the Council of Ministers and acting via the Government Plenipotentiary for Strategic Energy Infrastructure.

Among strategic governmental documents, which are related to the introduction of nuclear power programme in Poland, one should also point out the 'National Plan for Safely Managed Radioactive Waste and Spent Nuclear Fuel' and 'Strategy and Policy for the Development of Nuclear Safety and Radiation Protection'.

The objective of the 'National Plan for Safely Managed Radioactive Waste and Spent Nuclear Fuel' is to ensure the development and implementation of a nationwide, coherent, integrated and sustainable management system for all categories of radioactive waste generated in the country. This document covers various types of activities related to the safe management of all categories of radioactive waste generated in Poland, including the financing of storage, the closure process and monitoring of the closed repository. It should be noted that in the context of achieving the objectives related to the implementation of nuclear power, both EPP2040 and PNPP refer to this document.

As for 'Strategy and Policy for the Development of Nuclear Safety and Radiation Protection', its main purpose is to ensure that the issue of radiation hazards resulting from the operation of nuclear facilities is treated with due attention from the government and regulatory bodies. Currently, the document is being prepared by the President of National Atomic Energy Agency, who has been authorized to do so by the minister responsible for climate affairs. The need to develop and adopt this type of strategy results from one of the basic safety requirements defined by the International Atomic Energy Agency in a document relating to the regulatory framework for safety [60].

With regard to the legal framework, the basic act governing the nuclear investment process in Poland is the Act of 29 June 2011 on the preparation and implementation of investments in nuclear power facilities and associated investments [61]. The investment law provides for a dedicated framework for the implementation of nuclear power investments and establishes a privileged path for nuclear projects in terms of spatial development and construction process.

The second major component of the regulatory framework in the field of nuclear power is the nuclear safety and radiation protection system, which is primarily regulated by the Act of 29 November 2000—Atomic Law [62]. The most important issues regulated by the provisions of the Atomic Law concern the regulation of activities related to exposure to ionizing radiation, the duties of heads of organizational units performing such activities and the powers of the President of the National Atomic Energy Agency and other bodies to exercise control and supervision over this type of activity. The Atomic Law is supplemented by the secondary legislation, including specific requirements for the lifecycle of nuclear installations (design, siting, construction, operation and decommissioning) and successively issued by PAA's President non-binding organisational and technical recommendations.

Since its adoption, the Atomic Law has been substantially amended several times, as part of the country's continuous efforts to align with IAEA standards and Euratom legislation. In the field of nuclear safety and radiological protection, Polish law is duly adapted to supranational requirements and standards, as it was confirmed by the IAEA's Integrated Nuclear Regulatory Review (IRRS) verification missions in 2013 and 2017. The Atomic Law and the secondary legislation issued on its basis relate to the entire life cycle of

nuclear facilities, i.e., the stages of design, location, construction, commissioning, operation and decommissioning of a nuclear facility.

Legal requirements in the field of nuclear safety and radiological protection are subject to continuous improvement in connection with the advances in nuclear technology, operational and regulatory experiences, progress in the field of international standards and research on nuclear safety and radiological protection.

## 6. Conclusions

All over the world, electricity consumption continues to increase. As a result, further dynamic development of the power sector is inevitable. However, planning the energy policy should take into account the context of climate change and the tightening regulatory policy in this regard in the world, and in particular in the European Union. The use of fossil fuels to produce electricity increases the emission of greenhouse gases and other harmful substances, negatively affecting climate, but also local environment. Responsibility for future generations stimulates the development of carbon dioxide-free energy sources. In Poland, the energy transformation towards low-carbon energy is a necessity—the overwhelming majority of electricity is generated in coal-fired power plants, which are the most emissive and also increasingly older. Willing to act responsibly, but also to meet global and EU requirements in the field of climate and environmental protection, Poland decided to switch the economy including energy sector to clean generation sources, basing it on two main pillars—renewable energy sources and emission-free nuclear energy.

The main objective in this regard as described in strategic documents of the Polish government is construction and commissioning of nuclear power plants with a total installed capacity from approximately 6 to approximately 9 GWe based on proven, large-scale, Generation III (+) pressurised water reactors. The rationale for the implementation of nuclear power rests on three pillars: energy security, climate and the environment, and economy. In terms of energy security, the addition of nuclear power plants to the energy mix will mean its reinforcement mainly through the diversification of the fuel base in the Polish electric power sector, the diversification of the directions of supply of primary energy carriers and replacement of the ageing fleet of high-emission baseload coal units with stable and scalable zero-emission units immune to regulatory policies tightening climate requirements. In the environmental context, nuclear power means a dramatic step reduction of greenhouse gas emissions into the atmosphere from the electric power sector as well as low environmental external costs. In the economic context, nuclear power plants can suppress the increase of energy costs for consumers and even reduce them, having regard to the full account for the final consumer. This results from the fact that they are the most inexpensive sources of energy, taking into account the full cost account (investor, system, network, environmental, health, other external costs) and the factor of long operation after the depreciation period. It applies to both individual and business recipients, and in particular secures development of energy-intensive enterprises (e.g., steel industry, chemical). Nuclear power, due to even over 80 years of the installation operation, is also an important investment, thanks to which intergenerational solidarity is achieved.

The assumed investment model provides for the implementation of the project with the use of a single technology, which will produce benefits including economies of scale, a single strategic co-investor linked to the technology provider, and maintaining the State Treasury's control of the implementation of this undertaking. Only large and proven pressurised water reactors with a unit capacity above 1000 MWe are considered, as they are backed by extensive operational experience and ensure excellent safety characteristics.

The main activities of the government administration are summarised in five basic tasks prerequisite for the achievement of the programme's objective. These are: development of human resources, infrastructure development, support for domestic industry, strengthening the nuclear regulatory control system and social communication and information.

Polish plans to build nuclear power plants in the context of the necessary energy transformation towards a low-carbon economy should be considered a rational choice. The

need to replace aging, high-emission coal power plants with zero-emission units makes the choice of nuclear energy even more natural. This will allow to increase the share of RES without worrying about the stability of the system and without the necessity of large-scale combustion of natural gas, which is still a high-emission fuel. Effective implementation of nuclear energy will require a great deal of determination on the part of the Polish state and its decision-makers. Building a series of nuclear power reactors in a newcomer country is a technological, logistical and political challenge for decades. In the event of success, this will determine the appearance of a large part of the Polish electricity generation sector many years ahead.

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