Polish Nuclear Power Programme

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Introduction

The objective of the *Polish Nuclear Power Programme* (*PNP Programme*) is construction and commissioning in Poland nuclear power plants with a total installed nuclear capacity from approx. 6 to approx. 9 GWe based on proven, large-scale, Generation III (+) pressurised water reactors.

The rationale for the implementation of nuclear power has not changed since the adoption of the first version of the *PNP Programme* in 2014.[1] It 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, replacement of the ageing fleet of high-emission baseload coal units with dispatchable and scalable zero-emission units immune to regulatory policies tightening climate requirements.

In the environmental context, nuclear power means adramatic step reduction of greenhouse gas emissions into the atmosphere from the electric power sector as well as low environmental external costs. Examples of large industrialised and highly-developed countries and regions such as France, Sweden and the Canadian province of Ontario prove that nuclear power contributes to the effective, fast and deep decarbonisation of the electric power sector. In all those cases, emission have been reduced dramatically to alevel much below 100 kg CO_2/MWh based mainly on nuclear power (France) or on acombination of nuclear power and large-scale hydro power (Sweden, Ontario).

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 asingle technology, which will produce benefits including economies of scale, asingle strategic co-investor linked to the technology provider, and maintaining the State Treasury's control of the implementation of the *Programme*. Only large and proven pressurised water reactors with a unit capacity above 1,000 MWe are considered, as they are backed by extensive operational experience and ensure excellent safety characteristics.

The nuclear power plant sites selected are identical with the locations specified in the 2014 *PNP Programme.* As there are changes in this respect, the type and scale of environmental impact remain the same; therefore, anew strategic environmental impact assessment is not required[2]. Coastal locations and central locations in which large baseload power plants are currently located are particularly attractive. Having regard to the progress of project siting work and other considerations, the location of the first nuclear power plant (NPP) in Poland will be selected from among coastal locations.

The main activities of the government administration are summarised in 5 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.

Nuclear safety is the priority at every implementation stage of the *PNP Programme.* This issue is ranked so high that, in compliance with the Polish legislation, a separate strategic document has been dedicated to this priority, titled Nuclear Safety and Radiological Protection Strategy, to be adopted by the Council of Ministers on proposal from the minister responsible for climate. Therefore, this document does not contain achapter dedicated separately to nuclear safety issues. This also applies to the handling of radioactive waste and spent nuclear fuel. This issue is also dealt with in a separate strategic governmental document *National Plan for Handling Radioactive Waste and Spent Nuclear Fuel*[3].

[1] Resolution No. 15/2014 of the Council of Ministers of 28 January 2014 on the multi-annual programme referred to as the Polish Nuclear Power Programme (Polish Monitor [M.P.], item 502).

[2] Exemption from carrying out a strategic environmental impact assessment has been obtained: https://www.gov.pl/web/klimat/in-formacja-o-odstapieniu-od-przeprowadzenia-strategicznej-oceny– oddzialywania-na-srodowisko2.

[3] National Plan for Handling Radioactive Waste and Spent Nuclear Fuel adopted by Resolution No. 195 of the Council of Ministers of 16 October 2015 on the "*National Plan for Handling Radioactive Waste and Spent Nuclear Fuel*" (Monitor Polski [M.P.], item 1092). See also the report on the implementation of the document – Announcement of the Minster of Energy of 8 February 2019 on the publication of the report on the implementation of the National Plan for Handling Radioactive Waste and Spent Nuclear Fuel for the years 2015-17 (Monitor Polski [M.P.], item 238).

Objective of the Polish Nuclear Power Programme

THE OBJECTIVE OF THE POLISH NUCLEAR POWER PROGRAMME IS TO BUILD 6 – 9 GWe OF INSTALLED NUCLEAR CAPACITY BASED ON LARGE, PROVEN PRESSURISED WATER REACTORS.

1.1 Rationale

1.1.1. Energy security

The implementation of nuclear power in Poland will significantly contribute to raising the state's energy security level and will enable ageing high-emission baseload coal units to be replaced with new, zero-emission units.[4] In particular, nuclear power will contribute to increasing the diversification of both the fuel base in the electric power sector 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 of the Polish electric power sector and the energy sector in general (through the introduction of nuclear fuel). It is expected that around the year 2045 the NPP share in the energy mix will be approx. 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 (coal, gas, biomass, fuel oil, hydrogen). The ratio of energy contained in nuclear fuel to its volume and mass is incomparably more favorable than for other fuels. In conjunction with the possibility of deliveries from many geographic directions and many different routes (sea, rail, road, in special situations even air), this creates the possibility of reliable supply under any conditions.

It should also be mentioned that, in relation to other energy sources, or uranium stocks at the power plant, which guarantees

[4] Committee on Energy Problems of the Polish Academy of Sciences; „Polish energy in the horizon 2050; Selected technological issues", Gliwice, Warsaw 2018.

What should also be mentioned is the unique, compared to other energy sources, possibility of storing additional stocks of ready nuclear fuel on the premises of apower 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 proven immunity of nuclear power plants to weather conditions, including hurricane winds, frosty and snowy winters, and torrential rain and flood, are another advantage of this technology.[5]

Another positive feature of nuclear power in terms of energy security (but also in economic terms) is a low share of the cost of this fuel in the cost of energy production.

> The cost of the entire fuel cycle represents 10-15% of the total cost of electric energy generation at an NPP. For example, an increase in the nuclear fuel price by 50% causes an increase in the cost of energy production at an NPP by approx. 6%. This proportion is inverse to gas, where 70-80% of energy production costs are the costs of fuel, and therefore all major fluctuations of gas prices in the global market are reflected in the costs of energy production in gas units.

Frequent changes in generation costs, in particular their uncontrolled increases and consequently changes in energy prices for consumers are unfavourable for the economy, as they prevent long-term investment planning by enterprises and impede economic development. The implementation of nuclear power will have astabilising effect on electricity prices levels in the domestic market over atimeframe of at least 60 years.

[5] https://www.nei.org/news/2019/heat-waves-hurricanes-intensify-nuclear-plants;
https://www.nei.org/news/2018/hurricane-michael-nuclear-industry-response.

Uranium production from unconventional deposits and construction of fuel cycle plants in Poland cannot be ruled out in the future. The practice of other countries shows that the choice of an appropriate business partner and technology provider many facilitate the materialisation of such plans.

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 NATO member states or from other politically stable countries with a well-established market economy with which Poland has good relations. In addition, as a member of the EU and European Atomic Energy Community, Poland will benefit from support and security of fuel supply within EU 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, while reducing, with Euratom practices, of dependence on potential monopolistic actions by a specific fuel producer.

Replacement of aging baseload generating assets

In recent years, balancing the demand and electricity generation is becoming increasingly 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 and dispatchable energy sources. Forecasts by the transmission system operator indicate that most outages will take place in 2030-2040. The *PNP Programme* assumes that in that particular period the first nuclear power units will be commissioned, which will provide baseload power supply for the national power system. The construction of nuclear power units will enable the achievement of the climate neutrality objective in compliance with the provisions of the Paris Agreement[6] (CO_2 emissions), will have a positive effect on the economy (no high costs of purchase of CO_2 emission allowances, no high fuel costs) and will Poland's enhance energy security through the diversification of energy sources and reduction of dependence on imports of energy carriers. In the EU context, zero-emission energy generation based on 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).

[6] Paris Agreement – UN Framework Convention on Climate Change, drawn up in New York on 9 May 1992, adopted in Paris on 12 December 2015. (Journal of Laws of 2017, item 36).

1.1.2. The environment and climate

The role of nuclear power in preventing climate changes

According to the report compiled by the Intergovernmental Panel on Climate Change (IPCC) nuclear power is a very important element of combating climate change[7]. 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"[8], 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 additional 4 billion tonnes of CO_2 emission by 2040. Nuclear power, as a dispatchable baseload source, will allow renewable energy sources 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 renewable energy sources (RES) and to achieve an optimal reduction of emissions. Experience of countries such as Germany, but also the USA or China, shows that without using zero-emission sources for baseload generation, huge investment in RES capacity expansion does not lead to desired emission reduction effects[9]. On the other hand, examples of large industrialised and highly-developed countries such as France, Sweden and regions such as the Canadian province of Ontario prove that nuclear power contributes to the effective, fast and deep decarbonisation of the electric power sector. In all those cases, emission have been reduced dramatically to a level much below 100 kg CO_2/MWh based mainly on nuclear power (France) or on a combination of nuclear power and large-scale hydro power (Sweden, Ontario).

[7] Summary for policymakers, Global Warming of 1.5°C, an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, 2018.
[8] IEA, "Nuclear Power in a Clean Energy System", Paris 2019.
[9] N. A. Sepulveda, J. D. Jenkins, F. J. de Sisternes, R. K. Lester, The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation. July 2018; DOI: 10.1016/j.joule.2018.08.006.

European context

The Energy Policy of Poland must take into account new of energy policy defined at the EU level. Poland, as an EU Member State, actively participates in the creation of a common energy policy, and implements its main objectives under the specific domestic conditions, having regard to maintaining the competitiveness of the national economy, protection of consumers' interests, and its energy resources.

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)[10] 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[11].

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.

Clean environment through diversity

The Polish power system will follow the path of decarbonisation of the sector, including through the gradual reduction of the share of fossil fuels. The energy generation technologies used will form an efficient configuration that ensures not only the reduction of the negative environmental impact but also security of supply and acceptable electricity prices.

The environmental advantages of nuclear power mainly include: no direct CO_2 emissions during operation (over the past 50 years, approx. 55-60 Gt of CO_2 has been avoided), as well as no emissions of other substances harmful for the environment and human health: NOx, SO_2, CO, particulate matter (PM), mercury and other heavy metals and polycyclic aromatic hydrocarbons (PAHs).

> The high degree of safety of NPP operation is ensured by safety procedures developed over the years and the number of technical systems ensuring such safety. As aresult, nuclear power has the lowest accident and fatality rate among all electricity generation technologies over the entire life cycle, including nuclear fuel production[12].

Overall, also owing to zero emissions in nuclear power generation, 1.84 million premature deaths were avoided during the period between 1970 and 2009[13]. Nuclear power also means very low consumption of concrete and steel per unit of produced electricity[14], saving valuable raw materials: rare earth elements and silver used in RES technologies[15], the lowest area footprint per unit of generated electricity[16] and even up to 80-100 years of efficient operation[17]. Nuclear power is also an important element of biodiversity protection, as confirmed by many renowned environmental protection experts[18]. 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 renewable energy projects, observed in Western Europe, nuclear power may in the future be important factor limiting negative impacts of some projects on birds of prey, bats, insects etc. through the possibility of resignation from implementation of energy generation projects showing negative impact on nature, in favor of building new nuclear power plants[19]. Aless highlighted, while environmentally significant, 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[20]. In addition, nuclear fuel can

[10] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "The European Green Deal", COM(2019) 640 final

[11] Proposal for a Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law), COM(2020) 80 final.

[12] „Not without your approval: a way forward for nuclear technology in Australia", House of Representatives Standing Committee on Energy and Environment, Canberra 2019; Table 1.4: Mortality rate per PWh (PetaWatt – million billion watt-hours) of electricity generated, citing K. Emanuel, Massachusetts Institute of Technology.

[13] P. A. Kharecha, J. E. Hansen, Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power, Environmental Science & Technology 2013 47 (9), 4889-4895 DOI: 10.1021/es3051197

[14] P. F. Peterson, H. Zhao, R. Petroski, Metal And Concrete Inputs For Several Nuclear Power Plants, University of California, Berkeley 2005.

[15] IAEA, Nuclear Power for sustainable development, 2017, p. 5.

[16] Nuclear energy has the lowest ratio of 0.1 m²/MWh, compared to 0.2 m²/MWh for coal and gas, 1.0 m²/MWh for wind power and 10 m²/MWh photovoltaic sources . See U. Fritsche et. al, Energy and land use – Global land outlook working paper, United Nations Convention to Combat Desertification, International Renewable Energy Agency, 2017, 10.13140/RG.2.2.24905.44648, Table 2.

[17] 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.

[18] B. W. Brook, C. J. A. Bradshaw, Key role for nuclear energy in global biodiversity conservation, Conservation Biology, Vol. 29, No. 3, 2015.

[19] A. Gasparatos and others, Renewable energy and biodiversity: Implications for transitioning to a Green Economy, Renewable and Sustainable Energy Reviews, April 2017, 70: 161-184.

[20] 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).

be recycled and reused in the reactor (closed fuel cycle), which fits into the principles of the circular economy and sustainable development.

It should, of course, be kept in mind that nuclear power requires special care of operational safety. Large light water reactors built nowadays are characterised by high safety parameters taking into account experiences and lessons learned from the Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011) nuclear accidents. They provide security in the event of various internal events, malfunctions or damage of systems or devices, personnel errors and extreme external events or threats. In particular, they are equipped with containment structure resistant to emergency situations and extreme man-made threats, such as a large passenger plane crash or explosions from terrorist attacks, as well as various extreme natural threats. As a result, significant radiation effects even of severe (very unlikely) meltdowns of the reactor core would be limited to the near surrounding of the power plant, and also limited in time. Modern reactors have both passive and active safety systems that in case of any failure ensure the reactor core cooling or during a severe accident could cool down the molten core and containment, even in the event of loss of emergency power supply (they use universal and reliable laws of physics, e.g. gravity, convection or differential pressure).

An additional technical aspect of operation, which distinguishes nuclear power plants from other sources, is radioactive waste and spent nuclear fuel handling. Waste and spent fuel require storage and stockpiling under controlled conditions in isolation from the environment for a long period. Spent fuel in the first few years after discharging from reactor will be stored and cooled in the reactor fuel pools, and for the next several decades safely stored in a spent fuel storage facility at the power plant site. During 60 years of nuclear power operation, a significant progress has been achieved in waste management technologies and appropriate procedures have been developed. High-level waste and spent fuel can partially be processed and recycled, and their residues in compressed form will ultimately be stored in deep geological formations, with the option to reuse the spent fuel as a material for the production of MOX fuel (a mixture of uranium and plutonium oxide) being already in use in II/III Generation reactors or as a material for the production of nuclear fuel for fast reactors[21]. Currently, a large proportion of radioactive waste comes from outside the energy sector, mainly from the health sector, in particular from diagnostics and oncological therapies. This means that the national waste infrastructure, including radioactive waste storage facilities, must exist irrespective of the implementation of nuclear power. Poland has more than 60 years' experience in safe handling of radioactive waste and spent nuclear fuel from research reactors, including the use of the National Radioactive Waste Storage Facility at Różan.

It should be noted that the nuclear power sector, as the only one among the electricity generation technologies, follows asystemic 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. Also 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 (decommissioning fund).

1.1.3. Economics

The cost of electricity for consumers is of key significance for the economy and society owing to its impact on the process of services, competitiveness of the national industry and population welfare.

A nuclear power plant, as a stable generating source with a long service life, generates avery 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 Office of the Government Plenipotentiary for Strategic Energy Infrastructure and PSE S.A., commissioned by the Ministry of Climate. The analysis showed that:

[21] The most advanced deep geological repository projects are under construction in Finland, Sweden, France and the USA; for more on the subject, see: NEA OECD, *Management and Disposal of High-Level Radioactive Waste: Global Progress and Solutions*, Paris 2020 [http://www.oecd-nea.org/rwm/pubs/2020/7532-DGR.pdf].

- 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;
- in the 2045 perspective, the optimum volume of nuclear capacity should be approx. 7.7 GWe 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 approx. 10 GWe net by 2050;
- 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.
- 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.
- the total levelised cost of electricity in 2020 is 360 PLN/MWh. In 2045, the cost will be the lowest in the scenario in which the NPP is developed by way of free optimisation (374 PLN/MWh), and the highest in the scenario without the NPP (388 PLN/MWh). The extended model perspective demonstrates a further decline in the total cost with continued development of nuclear power (340 PLN/MWh in 2050), and an increase in divergence from scenarios excluding NPP (376 PLN / MWh in 2050).

Most of the NPPs currently in operation, with returned capital, are characterised by costs of 80-120 PLN/MWh[22], and the costs include not only investor costs but also 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 in 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.

Producers using priority technologies (e.g. high-efficiency cogeneration or renewable sources) 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 take-up regardless of the cost) as opposed to other 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. At the same time, 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

[22] Based on, inter alia, Nuclear Costs in Context, NEI, September 2019 (USA), https://www.tvo.fi/en/index/investors/keyfigures.html (Finland, TVO, historical minimum in 2019 – energy production cost 16.83 EUR / MWh), Electric Power Statistics Information System http://epsis.kpx.or.kr/epsisnew/ (South Korea), http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx (Sweden), Annual reports of Rosenergoatom (Russia), Kernkraftwerk Goesgen Geschäftsbericht 2016 (Switzerland), Information obtained by MK from NPP operators in other countries.

socialization of system costs, which again can lead to confusing conclusions for policymakers.

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 maximisation of profits. The government's priority is to maintain energy security of the country understood as ensuring the continuity of electricity supply at aminimum costs 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. However, this will not happen automatically, as specific conditions must be met.**

Most importantly, it is necessary to ensure acceptable costs of construction and operation and the selection/establishment of an appropriate business model, including the financing structure.

NPP costs are strongly dependent on government policy. The state (government) has astrong influence on project risk and reliability, and hence on the cost of capital (risk bonus). The determination of the nuclear power development objective and its consistent fulfilment allows the project risk to be significantly reduced, and consequently contributes to reducing the cost of capital.

The government also has an influence, albeit smaller, on the costs of contract with the EPC contractor (Engineering, Procurement, Construction – formula for complete execution, including design, delivery, construction, commissioning, handover to operation) by selecting a contractor with an appropriate experience and competence, definition of a clear allocation of risk between the project parties (regulatory and political risk on the part of the state), choice of foreign business partners with experience in NPP construction and/or operation and the use of an appropriate scale of contract (the more power units of the same type, the lower their unit cost). Ultimately, the above actions will enable low cost of electricity generation to be achieved at the planned NPPs.

In order to ensure that low costs of electricity from the NPP translate into low costs of electricity for the economy, it is necessary to have an appropriate business model. The model should take into account the interests of electricity consumers and avoid the risk of excessive profits for investors, which can be witnessed in the case of some new power projects in the world, implemented largely as purely financial investments (profiting mainly banks and investors, while the selling price of electricity is much higher than the actual cost of electricity generation). Such a model must meet a number of requirements, including compliance with the EU law and strategic documents, in particular with regard to the set development directions of the EU electricity market looking forward to 2050 and beyond (it should be kept in mind that nuclear units will be commissioned in 2033-2043 and can operate for up to 80-100 years). The details of the economic analyses discussed here are contained in Appendix 5.

1.2. Financial model

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:

- Long-term Power Purchase Agreements (PPAs) e.g. in the USA, United Arab Emirates, Turkey,
- Contracts for Difference (CfD), e.g. in the UK, planned in Romania, and considered in the Czech Republic,
- Tariff model RAB (the Regulated Asset Base) e.g. in the UK,
- Co-operative models (e.g. Mankala in Finland and Exeltium in France).

1.2. The business model for Polish NPPs envisaged in the *PNP Programme* provides for:

- selecting one common reactor technology for all NPPs,
- selecting one strategic co-investor linked to the technology provider,
- acquisition by the State Treasury a 100% share in the SPV implementing nuclear power projects in Poland (PGE EJ1 Sp. z o. o.),
- finally, after one strategic co-investor is selected, linked to the technology provider, retaining at least a 51% stake in the SPV.

The selection of one reactor technology for all nuclear power plants planned in the *PNP Programme* means lower costs of construction and operation owing to economies of scale:

repeatability of projects – NPP of the same type, the same general contractor, a large contract with a low unit price for specific NPP projects, more effective use of experience (so-called lesson learned) gained while building individual units,

lower prices of apparatus, equipment and spare parts – large multiple contracts, price discounts,

lower costs of training for crews and personnel of repair firms,

increasing participation of Polish enterprises with the construction of further units, continuous and increasing cooperation with the general contractor,

more technology transfer to the Polish economy and quicker NPP construction – both owing to the learning effect among firms and focusing the competence and involvement of nuclear regulatory and technical control bodies on a single technology,

in the case of a 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 nuclear fuel fabrication plants in Poland, which falls in line with the energy security component described before.

An early selection of a single business partner (strategic co-investor) will facilitate the organisation of low-cost NPP project financing. Aforeign investor will contribute its 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 apolitical 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 in nuclear power. It will limit as well risks affecting the level of financial costs of the nuclear project, which will consequently lower investment capital cost and ultimately reduce price of electricity for society. This corresponds with 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.

1.3. 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. Since the adoption of the *PNP Programme* by the Council of Ministers in 2014, a significant progress has been made in implementing certain types (models) of reactors[23], and additionally extensive experience has been obtained as regards the selection of the site for the first nuclear power plant.

Proven designs

In the recent dozen or so years, the global nuclear power market has been dominated by large-scale pressurised water reactors with capacities of 1000 – 1650 MWe net. 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 and heavy water reactors[24]. In Europe there are currently no active projects with BWR (Boiling Water Reactor), and almost all those under construction are based on the PWR type (Pressurized Water Reactor). There are many reasons for this state affairs, the main ones including:

[23] During this period the first reactors of following types have been commissioned: EPR: Taishan-1 (13/12/2018); AP-1000: Haiyang-1 (22/10/2018), Haiyang-2 (09/01/2019), Sanmen-1 (21/09/2018), Sanmen-2 (05/11/2018) in China and other reactors APR1400: Shin Kori 3 (20/12/2016) and Shin Kori 4 (29/08/2019) in South Korea. Soon APR1400 reactors will generate electricity in the UAE (Barakah-1 was connected to the grid on August 19, 2020).

[24] Pressurized water reactors in recent years were built or are being built in Europe, among others in: Finland, France, Great Britain, nSlovakia, Belarus, Russia, Hungary (planned construction is in the final stage of preparations). In other parts of the world in: USA, South Korea, United Arab Emirates, Turkey, China, Pakistan, India, Brazil, Bangladesh, Iran. Plans for construction of heavy-water blocks occurs in Europe only in 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.

- the largest, among all reactor technologies, experience in construction and operation (the most common reactor type in the world),
- no negative safety experience (not a single failure with major releases into the environment),
- common knowledge of the PWR technology by nuclear regulatory control bodies (with few exceptions, e.g. Canada, Argentina, Romania),
- a smaller area of radiation impact in the event of a possible failure of NPP with PWR reactors in relation to NPP with BWR and NPP with PHWR,
- a larger number of entities offering PWRs than BWRs and heavy-water reactors, which ensures the competitiveness of bids and reduces costs,
- lower operating costs of PWR units against BWR.

The experience acquired in the course of site and environmental surveys shows that the joint consideration of PWR, BWR and PHWR facilities 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. 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. Such a solution was used, e.g. in the Czech Republic for the project involving the construction of new units at the Temelin NPP and the latest unit No. 5 at the Dukovany NPP.

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 MW 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 just after 2030. Large, proven nuclear reactors guarantee fast and reliable capacity growth effects in the PPS and rapid and effective decarbonisation following the example of France, Sweden and the Canadian province of Ontario.

Designs under development

Other design types include those currently in the development stage, called small modular reactors (SMRs) which are slated for commercial deployment ca. 2040. To date, no construction contracts have been concluded; there is also no design documentation or execution documentation (plans and specifications that could be subjected to verification). Thus, at the present stage, it is not possible to estimate, in a sound and reliable manner, future costs of such facilities. The philosophy adopted in many cases by designers, of both an integrated design and an "add-on" design that allows further reactors (modules) to be added every few years, indicates possible operational problems and high costs of repair (which is admitted by the designers themselves). The technical characteristics of SMRs shows that they do not surpass large reactors in any way, and in some areas are much inferior, e.g. in terms of thermodynamic efficiency, which means generating agreater amount of radioactive waste per megawatt-hour of produced electricity. "Modularity" of the NPP with SMRs also means that the entire technological part of the power plant would be produced and assembled at the facilities of the designer and only a few companies strongly associated with it. In this case, the participation of local companies in the construction, operation and repair of the NPP will be very limited, as the manufacturer will have no interest in selling licences for the production of modules, which will be its only source of revenue from NPP construction.

Waiting about 20 years for the operational experience with SMRs (if built anywhere in the world [25]) will prevent Poland from restoration of decommissioned capacity, achieving the EU's climate and energy policy objectives, and will lead to a further increase in electricity costs, with all the economic and social consequences described earlier. Investment decisions on the construction of the NPP must be taken as soon as possible. It should also be emphasized the small electric power of SMR units, which is not desirable from the point of view of the objectives of the *PNP Programme*, as it would lead to an unnecessary increase in the number of nuclear facilities in the country to meet the assumed electricity production targets. Aderivative of small scale of these reactors, is also avery high unit cost of the installed capacity (already at the stage of manufacturers' declarations it is higher than actually obtained in investments with large reactors), which further emphasizes the futility of using such technologies to achieve the objectives of the *PNP Programme*.

At the same time, the government will monitor the progress in SMR development in the world. If these projects are implemented and experience of construction and operation arises, then the use of SMRs in district heating should be considered, alongside co-generating NPP.

[25] There are not taken into account SMRs operating as technology demonstrators, built in non-OECD countries and/or for non-standard applications, e.g. a floating NPP.

In addition to small pressurised water reactors, high temperature reactors (HTR) should be mentioned, which, while not providing an alternative to large-scale light-water nuclear units, could be used mainly as asource of process heat. A research project in this area is being carried out at the National Centre for Nuclear Research (NCBJ) and is worth continuing. If the project is successful and the HTR technology is successful in the world in the long term, it will be reasonable to consider its deployment in Poland for the purposes of industry. However, this will not happen before 2040.

1.4. Sites

The choice of an optimum site for the construction of anuclear power plant requires an analysis of many factors[26]. They include:

- 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,
- 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),
- economic factors – including the deficit of generation capacity in a given region, the possibility of filling gaps after closed mining and energy complexes;
- social factors – local acceptance for nuclear power plant construction.

Possible sites

The possible sites for construction of nuclear power plants are the same as those specified in the 2014 *PNP Programme*. As there are no changes in this respect, the type and scale of potential environmental impact remain the same; therefore, a new strategic environmental impact assessment is not required.

The diagram below shows the key actions performed so far in the process leading to the selection of the nuclear power plant sites:

2009 identification 27 potential NPP sites – minister in charge of energy in coordination with local governments ➩ **2010** classification of 27 potential NPP sites ➩ **2010–2011** public consultations on an EIA forecast drawn up for the PNP Programme (with a description of the potential sites ➩ **2011–2013** cross-border consultations of the draft PNP Programme ➩ **od 2017** siting and environmental studies (since 2016 – seismic monitoring)

The most favourable sites are as follows:

Coastal sites – Lubiatowo-Kopalino and Żarnowiec, for which the work on environmental and siting studies is most advanced. The advantages of these sites include a significant electricity demand and the lack of large, dispatchable generation sources in the area, access to cooling water, the possibility of transporting large-size loads by sea;

[26] Currently, location studies in progress are carrying out in accordance with the Act of 29 November 2000 – Atomic Law (Journal of Laws of 2019, item 1792 as amended) and with implementing measures, including the Regulation of the Council of Ministers of 10 August 2012 on the detailed scope of site assessment for the location of anuclear facility, cases excluding the possibility of considering a site to be in compliance with the requirements for the location of a nuclear facility, and on the requirements for a site location report for a nuclear facility (Journal of Laws of 2012, item 1025).

Sites currently used by baseload power plants, including Bełchatów and Pątnów due to the developed transmission, transport and other infrastructure, the location in the centre of Poland and the fact that the NPP construction in these areas after retiring the power plants in operation will allow jobs to be maintained.

Other potential sites (in alphabetical order): Chełmno, Choczewo, Chotcza, Dębogóra, Gościeradów, Karolewo, Kopań, Kozienice, Krzymów, Krzywiec, Lisowo, Małkinia, Nieszawa, Nowe Miasto, Pniewo, Pniewo-Krajnik, Połaniec, Stepnica-1, Stepnica-2, Tczew, Warta-Klempicz, Wiechowo, Wyszków.

Having regard to the progress of work and other considerations, the site of the first nuclear power plant (NPP) in Poland will be selected from among coastal sites.

The potential sites of nuclear power plants

Prepared by: Nuclear Energy Department, Ministry of Climate

Sources: https://www.naturalearthdata.com/, the organisation's own data

Tasks

2.1. Development of human resources for the purposes of nuclear power

The main task in the development of human resources is to prepare qualified personnel for the construction and operation of nuclear power plants, and fulfilling the tasks of the nuclear regulatory body.

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.

Poland participates in programmes for the modelling of human resources for the nuclear power sector using the *Stella Architect* tool in cooperation with the International Atomic Energy Agency (IAEA). This tool has been developed on the basis of best global practices and implemented nuclear projects. One of the modules, the *Nuclear Power Human Resource Model* , allows a model of human resources development to be created, adapted to Polish requirements and the specific selected technology. It should be emphasised that the construction of nuclear power plants and associated facilities involves the creation of thousands of well-paid jobs on and around the construction site. 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, 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 twin-unit power plant is around 1000 people.[27]

Therefore, in order to identify needs and create an optimal mechanism for the preparation of human resources for the purposes of implementation of the *PNP Programme*, the following tasks are required to be performed:

1. Assessment of the national human resources potential, in particular:
   - defining the preparedness of human resources for nuclear power of the main stakeholders of the *PNP Programme* and the preparedness of the education and science sectors for nuclear power education. The preparation must cover, in particular, full-time studies in nuclear power and nuclear specialisation in various fields of study: material engineering, mechanical engineering, electrical engineering, electronic engineering, automation, construction, and environmental protection. Technical and vocational education will also be an important component of the human resources education system,
   - updating the content of textbooks and the core curriculum in non-technical and non-vocational primary and secondary schools for the delivery of knowledge on nuclear power,
   - identification of the possibility of using the existing nuclear infrastructure in Poland for education and training of personnel (with particular regard to the MARIA research reactor at the National Centre for Nuclear Research in Świerk and the installation of the Radioactive Waste Management Plant in Otwock and Różan – radioactive waste storage facilities);
2. Identification of the needs in terms of the number and professional qualifications of employees,

[27] IAEA, Workforce Planning for New Nuclear Power Programmes, IAEA Nuclear Energy Series, No. NG-T-3.10, Vienna 2011.

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. The role of the institutions implementing the nuclear project should be to stimulate universities to take coordinated steps towards opening new fields of study related to nuclear power and the development of existing ones. It is necessary to develop appropriate programmes and additions and to perform a quantitative estimation of the needs in order to be able to plan the recruitment of students who can join the human resources of the nuclear power plant in the future.

4. Establishment of a cooperation mechanism for building human capital for nuclear power, who will deal, among other things, with amending the legislation to provide for new nuclear professions and supporting the Polish research facilities in preparing an offer of higher education courses, postgraduate studies and specialised training in nuclear power.

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[28]. In 2016, the *Framework Plan for the Development of Human Resources for the Purposes of Nuclear Power*[29] was developed, which sets forth the objectives and tasks in the period preceding the preparation of the final plan.

The final *Plan* will be based on precise knowledge of the dimension and dynamics of the nuclear project in Poland, selected technology, as well as the level and type of human resources and educational/training capabilities. At the present stage of the nuclear project, based on IAEA studies, typical staffing data can be defined in an averaged manner for the organisation dealing with the construction, putting into service and operation of nuclear power plants[30].

[28] Ibid.
[29] Accepted by the Minister of Energy on 30 June 2016.
[30] IAEA, Commissioning of Nuclear Power Plants: Training and Human Resource Considerations, IAEA Nuclear Energy Series NG-T-2.2, Vienna 2008.

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.

The work described in the following sub-chapters includes the adaptation or construction and reconstruction of existing transmission, transport and other infrastructure necessary for the construction and operation of the NPP.

For example, 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 Act of 29 June 2011 on the preparation and implementation of nuclear power facilities and accompanying investment projects ("Investment Act") allows for the smooth carrying out of work which will be given the accompanying investment status.[31]

The infrastructure development model adopted will be based on best practices. Proper coordination of activities and close cooperation of all participants will allow the monitoring of the individual tasks assigned with the allocation of responsibilities for construction, upgrading and maintenance. Where necessary, the solutions adopted will be subject to verification and continuous improvement.

A number of planning instruments have already been prepared to carry out infrastructural projects and further ones are under development. As part of the preparatory work for the construction of the nuclear power plant, the *National Infrastructure Coordination Plan* was established in 2015. The document contains a summary of the existing infrastructure to be

[31] Journal of Laws of 2018, item 1537, as amended.

used for the purposes of the NPP, a list of necessary modifications or extensions, and an action plan to start cooperation with external actors. The *Spatial and Ownership Analysis* (2015) and the *Analysis of the Access Road Route to the Location* (2016) were also drawn up. Arrangements were made for the provisions of the *Spatial Development Plan for the Pomeranian Voivodeship 2030* due to the most likely location of the first NPP by the sea. Infrastructural needs are also reflected in the *Territorial Contract for the Pomeranian Voivodeship*[32].

In the second half of 2020, detailed studies will be ready: the *Transport Study*, the *Water Supply and Wastewater Disposal Study* and the *High Voltage Corridor Study*. In addition, the planned NPP infrastructure elements in the maritime areas and in the coastal strip have been included in the draft *Maritime Spatial Plan for Internal Sea Waters, the Territorial Sea and the Exclusive Economic Zone at a scale of 1:200 000*[33]. In the second half of 2021, a *Functional Area of Nuclear Power Development* study will be ready, which will detail the *Spatial Development Plan for the Pomeranian Voivodeship 2030*.

2.2.1. Required changes in the Polish power system (PPS)

Main considerations

In order to ensure reliable operation of the NPPs, it is necessary to connect it to the PPS in such a way as to guarantee the safe evacuation of power into the country and supply its auxiliaries in states of normal operation of the network and in post-fault states.

Due to their capacity, the NPPs will be connected to the national transmission network (NTN) comprising 400 and 220 kV lines and substations. The connection of the NPP will require investment and adjustment measures on the part of the transmission system operator (TSO) at a scale dependent on the location. The NTN is a well-developed structure in the south of the country, while in the northern part it has been undergoing intensive expansion for several years. It should therefore be borne in mind that locations in the north of the country or away from points of electricity consumption and the existing transmission infrastructure are likely to require the construction of new NTN elements. It should also be assumed that power supply to NPP auxiliaries will be supported by a local 110 kV distribution network.

[32] Resolution No. 234 of the Council of Ministers of 14 November 2014 on the approval of the Territorial Contract for the Pomorskie Voivodeship (Monitor Polski [M.P.], item 1144) as amended by Resolution No. 77 of the Council of Ministers of 19 May 2017 on the approval of the amendment to the Territorial Contract for the Pomorskie Voivodeship (Monitor Polski [M.P.], item 540).
[33] https://www.umgdy.gov.pl/?p=30680.

PPS development activities

The TSO role in Poland is played by Polskie Sieci Elektroenergetyczne S.A. (PSE). The NPP connection should be built by the investor in coordination with PSE and the local distribution system operator (DSO). PSE and the relevant DSO should be responsible for the expansion of the national transmission network and the distribution network for the NPP connection. The evacuation of power from the nuclear power plant situated at one of the coastal locations is consistent with the development directions specified in the *Development Plan for meeting the current and future electricity demand* (PRSP) *for 2021-2030* [34] agreed with the President of the Energy Regulatory Office on 28 May 2020.

At the preparatory work stage, depending on the NPP technology, capacity and location, the basic features and key parameters of the connection system should be determined, including:

- the distance between the point of connection and the NPP site and the configuration of the electrical substation to which the power plant is connected,
- the required number of line circuits evacuating power from the NPP,
- the connection method and the resulting NPP auxiliary power supply system,
- transmission and distribution network operational reliability criteria affecting the operation of the NPP, including the method of satisfying them.

The final scope of expansion of the NTN for the NPP connection will be defined following the investor's submission of an application for connection conditions (specifying, among other details, the final NPP site location and its capacity).

The preparation and implementation of grid projects for the purposes of evacuation of large capacity volumes requires a period of at least several years (under the current general legislation, approx. 7-10 years). In justified cases, it will be possible to apply special provisions supporting the effective and timely implementation of the project.

The running of grid projects for nuclear power has been facilitated by the Investment Act. In addition, the Act

[34] https://www.pse.pl/-/plan-rozwoju-systemu-przesylowego-do-2030-roku-zatwierdzony-przez-ure.

on strategic transmission network projects has been in force for several years,[35] providing asignificant support to the investment process.

In addition, attention should be drawn to Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure[36]. In the event that power is evacuated from the NPP over lines with the PCI ("Project of Common Interest") status[37] (which is possible due to the TEN-E South–North corridor), additional privileges such as fast-track issuing of building permits for such transmission infrastructure can be leveraged.

It should also be emphasised that the process of NPP connection to the PPS will be based on Commission Regulation 2016/631 establishing a network code[38].

Activities to date

Preliminary analyses carried out so far by the investor and PSE have confirmed the feasibility of connecting the NPPs to the transmission network at the locations under consideration. PSE has already completed some of the investment projects in the north under an approved development plan, and the completion of the remaining ones is scheduled before the end of 2030. The new network infrastructure will be used, among other purposes, to evacuate power from RES and to enable cross-border connections to operate. The rapid rate of RES development, in particular onshore and offshore wind power plants, the connection of which is planned earlier than the NPP, will result in the use of the transmission capacity of the network infrastructure currently under construction. Therefore, additional network investments will be required for the connection of the NPP and full evacuation of power from it.

Location aspects

The NPP can be built at several locations. Siting the NPP in coastal locations and on the sites of decommissioned large baseload power plants is advantageous from the point of view of the PPS operation conditions. The number of NPP locations advantageous for the PPS is limited, and therefore the possibility of reserving selected locations for the purposes of nuclear power will be considered.

It should also be pointed out that the development of offshore wind power is also envisaged in the area of the first recommended NPP site location. Power evacuation both from the nuclear power plant and from offshore sources to be implemented and fully feasible in accordance with PRSP.

Power evacuation from both sources will be implemented by siting both points of connection at a distance from each other.

2.2.2. Transport infrastructure

Transport infrastructure components necessary for the construction and operation of the nuclear power plant include road, railway, sea (including ports), and air transport investment projects. They will allow the transport of all kind of building materials, construction machinery and equipment, and personnel to the NPP site.

In the most probable NPP locations in northern Poland, investment needs have been identified for the different types of transport infrastructure.

The **road transport infrastructure** requires, among other things, the construction of a main transport road with voivodeship road (DW) parameters from the S6 expressway (Strzeblino junction) do DW No. 213, access roads from DW 213 to the NPP itself, and providing a good link to airfields and helipads. The tasks will include both the construction and modification or upgrade of infrastructure (widening/reinforcement of roads, repair/construction of civil engineering structures).

The **rail transport infrastructure** (goods and passenger) requires work on the Gdynia Chylonia – Słupsk section of railway line No. 202, [39] reinstatement of the existing or construction of a new section of the electrified railway line [40] (e.g. complete reconstruction of the Wejherowo-Garczegorze section of inactive railway line No 230, including the construction of a siding to the NPP site or dismantled railway line No 230A from Rybno Kaszubskie to the former NPP Żarnowiec railway station). In addition, work will include the reinforcement of embankments and alteration/construction of civil engineering structures, construction of anew railway siding, expansion of local railway stations and passenger stops.

The **marine logistic infrastructure** will enable a large quantity of materials and large-size and high-tonnage

[35] The Act of 24 July 2015 on the preparation and implementation of strategic transmission network projects (Journal of Laws of 2020, item 191, as amended).

[36] Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009 (OJ L115 of 25.04.2013, p. 39).

[37] EU energy infrastructure Projects of Common Interest.

[38] Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators (OJ L 112 of 27.04.2016)

[39] The project is included in the National Railway Programme and in the Territorial Contract for the Pomeranian Voivodeship.

[40] Railway electrification is an example of a zero-emission transport solution.

equipment components to be delivered to the NPP construction site. Its great advantage is the lack of the limitations occurring in overland transport. It will be necessary to build a new, dedicated marine structure for offloading operations, together with a technical road in its immediate vicinity for connection with the NPP site. Sea transport for the purposes of NPP construction and operation will involve the use of the existing ports at Gdańsk and Gdynia, serving as intermediate ports. After transhipment to smaller vessels, materials and equipment will go to anewly built marine structure nearby the NPP.

The **air transport infrastructure** will include the construction of a helipad in the immediate vicinity of the NPP or upgrades of existing helipads in the Pomeranian voivodeship for the purposes of transport of materials and equipment, and emergency medical services. The transport of materials and equipment to the NPP construction site will be performed from existing airfields by road or rail.

2.2.3. Other accompanying investment projects

Other infrastructure elements necessary for the construction and operation of the NPP will include investment in a water supply network, sewerage network, telecommunication and ICT networks, accommodation facilities, power supply to the construction site by a 110 kV line.

In the most probable NPP locations in northern Poland, investment needs have been identified for a number of major infrastructure elements.

Water supply network will ensure water supply to the NPP construction site for domestic purposes. It includes water intakes and a water treatment station. **Sewerage network** will guarantee the removal and treatment of wastewater from the construction site. This includes the construction of a new wastewater treatment plant with a sewerage network and treated wastewater discharge into a receiving water body. The infrastructure will also serve local needs.

Site accommodation facilities will provide living quarters to employees during the NPP construction and can be later used by personnel during the operation of the NPP. Apart of permanent structures, container accommodation facilities are envisaged in the immediate vicinity of the NPP for the purposes of temporary workforce employed on site. The facilities will be equipped with water, sanitary drainage, power supply, gas, telecommunications, district heating, health services, etc.

Telecommunication and ICT networks will enable wired and wireless communication during the construction and operation of the NPP and for crisis management purposes. Stable and secure power supply at the NPP construction stage and in emergency situations will be ensured by the construction of a 110 kV line and 110/15 kV electrical substation.

For the commencement of construction, it is also necessary to ensure medical and emergency facilities, public transport, expansion of the national system for the detection of radioactive contamination, expansion of the national safety infrastructure, including alarm communications and crisis management.

In addition, office facilities, municipal (including construction) waste disposal and management facilities will be needed, and it will be necessary to ensure the availability of fuels (diesel oil, heating oil, petrol) and industrial gases (nitrogen, oxygen, acetylene, etc.) and other elements important for the NPP, such as: EUPOS active geodetic network, closed areas excluded from common use, dosimetry laboratories for the calibration of measurement instruments.

2.3. Supporting domestic industry in preparations to participate in the construction and operation of nuclear power plants

In the process of preparing for the construction and during the construction, operation and decommissioning of nuclear power plants, it is necessary to aim at a rational maximisation of the participation of domestic entities.

This will translate not only 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.

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[41].

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 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 will focus on several main areas:

- supporting domestic enterprises in the acquisition and implementation of expensive quality certification,
- information and training activities concerning codes and standards applicable in this industry,
- promoting and supporting domestic enterprises on the global stage in order to acquire foreign contracts,
- facilitating the nuclear technology transfer to domestic enterprises,
- supporting cluster initiatives or other initiatives bringing together interested enterprises.

The above list is not exhaustive and it arises from analyses carried out so far by the minister for energy concerning the potential involvement of domestic industry in the nuclear project.

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.

Until the programme in question is developed and approved, the minister in charge of energy will take stimulating measures, mainly of a training, informational and promotional nature at international level. Technical training seminars will also be arranged and targeted business missions to countries in which promotion of Polish products is possible.

In the future, the nuclear technology provider and the general contractor will assess the feasibility and define a path for improving the competence of Polish enterprises. In coordination with the minister in charge of energy, they will also define a specific list of products and services which can be commissioned to domestic enterprises. Moreover, tools will be specified and a path for improving the competence of Polish enterprises with a view to increasing their share in the implementation of the project in the case of successive construction of more than one reactor in the same technology. Such analyses will form an integral part of

[41] The catalog of Polish nuclear companies "Polish Industry for Nuclear Energy 2019" https://www.gov.pl/web/polski-atom/przemysl3

the contract with the selected entity. The role of the minister in charge of energy will be to ensure that the share of Polish industry is as large as possible, subject to the priority of efficient project execution.

2.4. Strengthening nuclear regulatory control

2.4.1. The role and responsibilities of the President of the National Atomic Energy Agency

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.

The President of PAA will perform his functions at each stage of the nuclear facility life cycle, starting from the environmental assessment and siting stage, to design, construction and operation, to decommissioning. His responsibility will be to check and confirm that the investor meets the requirements of nuclear safety and radiological protection. To this end, the President of PAA will evaluate the documentation submitted and perform necessary safety analyses. The President of PAA and nuclear regulatory inspectors will also carry out inspections of the nuclear facility during its construction, start-up and operation.

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 resource, and competent expert personnel of the office supporting him (PAA).

2.4.2. Staffing reinforcement

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 anuclear 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 safety analysis, including deterministic and probabilistic analyses.

The efficient performance of tasks by nuclear regulatory control personnel requires many years of competence building. It is an international practice to employ in nuclear supervision positions experienced staff from the nuclear power industry. In the situation of unavailability of human resources in the domestic market, as is the case with Poland, at least several years' preparation of staff for work as nuclear regulatory inspector or nuclear regulatory analyst. PAA will prepare and implement a personnel training scheme in nuclear technology and the methodology and criteria of regulatory assessment, as well as inspections of nuclear facilities. The training will be carried out largely in cooperation with foreign nuclear regulatory control authorities. From the moment of selection of the nuclear technology provider, information and experience exchange with the nuclear supervision authorities of the provider's country will be enhanced. Owing to a long period of attaining the ability to perform regulatory control tasks independently and efficiently and alack of experienced specialists in the country, it is necessary to employ about 80-90% of the proposed staff at least three years before receiving the application for the building permit for the first nuclear power plant. This several years' period will be used for intensive preparation of the PAA staff to perform the tasks related to the process of issuing permits and supervision of the construction and operation of the nuclear power plant.

The need for staffing reinforcement involves mainly the need to ensure appropriate financial resources for PAA. The nuclear power plant project implementation period will see a high demand for the scarce domestic specialist workforce. The situation will involve the risk of personnel outflow to the private sector offering attractive remuneration. This should be viewed as a threat from the point of view of the efficiency of nuclear regulatory control activities, therefore preventive measures must be taken, largely based on the elimination of wage disparities between PAA and the commercial nuclear sector. An analysis of remuneration of personnel of nuclear supervision authorities in selected European countries, performing nuclear programmes with characteristics similar to Poland's shows that the average remuneration there is approx. 50 to 150% higher than the current remuneration at PAA. Having regard to the above, for positions that require specialist knowledge and unique competences, competitive employment conditions will be ensured compared to the market, which will enable experts to be hired and retained.

2.4.3. Technical support organisation system

PAA will be responsible for the assessment of compliance with safety and security requirements and the issuing of relevant permits and opinions. The President of PAA and PAA staff will bear the final responsibility for the correct performance regulatory assessment and the control of activities related to the construction, start-up, operation and decommissioning of a nuclear facility.

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 control 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.

The practice of using expert support organisations is common to all nuclear regulators. In line with IAEA recommendations, the nuclear reactor should use services of this type of independent technical organisations performing analytical work supporting the regulatory control decision-making process. The organisations have specialists and software as well as laboratory equipment in narrow fields of knowledge. Expert reports, studies and analyses performed by expert organisations will be used by PAA in assessing nuclear power plant safety at each stage of investment process.

Financing will be ensured for PAA for the purposes of cooperation with and outsourcing of services to expert support organisations. The costs incurred for this purpose will be partly returned to the government budget by the investor. According to the provisions of the Atomic Law, the costs of reasonable activities executed in the course of the assessment of the permit application by laboratories and expert organisations are incurred by the organisational unit submitting the permit application. In addition, the costs of laboratory testing and other activities indicated in the course of inspection by nuclear regulatory control bodies, as well as opinions issued by the laboratories and expert organisations, and also experts and laboratories indicated by the President of the Agency will be incurred by the organisation unit inspected.

2.4.4. Equipment and infrastructural resources of PAA

In order to ensure the proper performance of tasks for the purposes of the *PNP Programme*, 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.

With the acquisition of new personnel and purchase of equipment, PAA's needs in terms of office facilities will double and it will be necessary to ensure that it has its own headquarters, which PAA currently does not have. The headquarters will have to meet the requirements of information security, 24-hour emergency service, as well as other necessary conditions related to the performance of tasks to ensure nuclear safety and radiological protection of the country. In addition, prior to the commencement of construction, at each nuclear power plant site, a local office will be set up for nuclear regulatory inspectors supervising the progress of the project on an ongoing basis.

2.5. Social communication and information

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 *PNP Programme*[42]. 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 *PNP Programme*.

[42] ASM Centrum Badań i Analiz Rynku Sp. z o.o., Final Report on a public opinion survey on the development of nuclear energy in Poland, carried out for the Ministry of Energy, December 2017.

In Poland, 57% of respondents support the construction of a nuclear power plant[43].

An even greater support for the implementation of the project is declared by residents of the municipalities of the potential sites of the first nuclear power plant, where 71% of the respondents are for the power plant project[44].

At the same time, it should be emphasised that this subject is difficult in technical terms, spans multiple aspects, arouses extreme associations and social emotions, and is sometimes used by interest groups at home and abroad for political purposes as a public disinformation tool.

Prejudices on nuclear power are often determined by a lack of information and are based on arbitrary or incomplete data. The lack of knowledge on the main causes of the nuclear accidents in Three Mile Island in 1979, Chernobyl in 1986 and Fukushima in 2011 as well as the decision to abandon the construction of a nuclear power plant in Poland leads to negative associations and myths related mainly to such issues as the belief in harmful impact of the power plant on the surrounding environment and human and animal lives, and concern about the risk of a serious failure.

Having regard to the above, the main information and education tasks of the government will consist in:

- increasing the awareness of the public about nuclear power energy and nuclear power generation, showing a comprehensive range of related issues,
- transferring knowledge on the rules of operation and safety of nuclear power plants and other nuclear facilities, the rules for the safe handling of radioactive waste, informing the public about economic and political benefits of the development of nuclear power, i.e. the improvement of energy security and economic development,
- 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,
- responding to social needs with regard to access to information, in particular on the safety of the facilities operated, implementation of the nuclear programme in Poland, 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 PNP Programme*. The *Strategy* will indicate ways of building awareness of the existence of the *PNP Programme*, 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 Communication Strategy of the PNP Programme will take into account the educational and information role of non-governmental organizations, universities and research institutes that may play a supporting role.

Under the *PNP Programme,* the key communication roles are played by: **the minister in charge of energy with the supporting office** (Article 108a (3) of the Atomic Law) and the **National Atomic Energy Agency (PAA)** with regard to information on the issues of nuclear safety and radiological protection. Moreover, keeping the public informed on the operational safety and security of facilities is the responsibility of operators and investors of nuclear facilities and radioactive waste storage facilities. What will play a major role in this regard are Local Information Centres to be run by the investor of the nuclear power facility in accordance with the requirements of the Atomic Law (Article 39m).

Ensuring a high level of knowledge and maintaining a stable level of public acceptance for nuclear power will be possible through regular activities based on competent, clear and interesting communication. The main principle governing the activities of all entities will be full transparency.

[43] IMAS International survey on a representative sample of 2028 Poles aged 18-64, carried out using the CAWI technique between 31.07-12.08.2020, for the Ministry of Climate.
[44] PSB, Report on the survey "Poles' attitudes on nuclear power" commissioned by PGE EJ1 Sp. z o.o., December 2019.

Appendices

Appendix 1. Project implementation schedule

HPP construction schedule	
2021	– selection of technology for NPP1 and NPP2
2022	– obtaining the environmental and location decisions for NPP1 (approval of NPP1 location site choice) – signing the contract with the technology provider and the main EPC contractor
2023	– commencement of preliminary and preparatory work at NPP1 site – signing the connection agreement with the TSO for NPP1 – commencement of work on the selection of site location for NPP2
2025	– issuance of the building permit for NPP1 by PAA President
2026	– obtaining the building permit and commencement of NPP1 construction
2028	– obtaining the environmental and location decisions for NPP2 (approval of NPP2 location site choice)
2029	– commencement of preliminary and preparatory work at NPP2 site – signing the connection agreement with the TSO for NPP2
2031	– issuance of the building permit for NPP2 by PAA President
2032	– issuance of the start-up permit by PAA President, nuclear start-up and synchronisation of the first reactor at NPP1 – obtaining the building permit and commencement of NPP1 construction
2033	– issuance of the operation permit by PAA President and commissioning of the first reactor at NPP1
2034	– issuance of the start-up permit by PAA President, nuclear start-up and synchronisation of the second reactor at NPP2
2035	– issuance of the operation permit by PAA President and commissioning of the second reactor at NPP1
2036	– issuance of the start-up permit by PAA President, nuclear start-up and synchronisation of the third reactor at NPP2
2037	– issuance of the operation permit by PAA President and commissioning of the third reactor at NPP1
2038	– issuance of the start-up permit by PAA President, nuclear start-up and synchronisation of the first reactor at NPP2
2039	– issuance of the operation permit by PAA President and commissioning of the first reactor at NPP2
2040	– issuance of the start-up permit by PAA President, nuclear start-up and synchronisation of the second reactor at NPP2
2041	– issuance of the operation permit by PAA President and commissioning of the second reactor at NPP2
2042	– issuance of the start-up permit by PAA President, uclear start-up and synchronisation of the third reactor at NPP2
2043	– issuance of the operation permit by PAA President and commissioning of the third reactor at NPP2

Appendix 2. Tasks to be performed under the *PNP Programme*

a) Minister in charge of energy

Task	No.	Sub-task / Implementation years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
1. Supporting the participation of domestic industry	1.1	**Development of the *Domestic industry support programme* – Q1 2021**													
	1.2	Supporting domestic enterprises in the acquisition and implementation of quality certification													
	1.3	Information and training activities – organisation of 3-4 training programmes annually													
	1.4	Promoting and supporting domestic enterprises on the global stage – arranging 1-2 profiled foreign missions annually													
	1.5	Facilitating the nuclear technology transfer to domestic enterprises – reimbursement of costs													
	1.6	Supporting cluster or other initiatives aimed at bringing together interested enterprises – reimbursement of costs													

Task	No.	Sub-task / Implementation years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
2. Educational and information activities	2.1	Activities preceding the preparation of a communication strategy and a nationwide education and information campaign (including in-depth opinion polling, analysis of media reports)													
	2.2	Current education and information activities													
	2.3	**Adoption of the *PNP Programme Communication Strategy***													
	2.4	Nationwide education and information campaign addressed to all citizens													
	2.5	Expanded training programme for teachers in voivodeship cities and nuclear energy and nuclear power lessons for primary and secondary schools													
	2.6	Participation in conferences, fairs and science picnics													
	2.7	**Adoption of the *Plan for the Development of Human Resources for the Purposes of the PNP Programme***													

Task	No.	Sub-task / Implementation years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
2. Educational and information activities	2.8	Supporting activities at schools of higher education – establishment of dedicated courses of study and post-graduate courses at technical universities and colleges													
	2.9	Education and information campaign – activities dedicated to maintaining social acceptance													
	2.10	Conducting supporting information and education activities (in printed press, the media, online)													
3. Expert reports, analyses	3.1	Performing analyses related to the implementation and updating of the *PNP Programme*													

b) National Atomic Energy Agency (PAA) – strengthening the nuclear regulatory authority

Task	No.	Sub-task / Implementation years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
4. Strengthening the staff and building PAA's competences	4.1	Recruitment of PAA employees													
	4.2	Cooperation and exchange of experiences with the nuclear regulatory authority of the country of the technology supplier													
	4.3	Compilation of a personal and professional development plan for employees													
	4.4	Participation of PAA employees in specialist domestic and foreign trainings - building PAA's competences													
	4.5	Preparation of documentation supporting the process of issuing permits and conducting inspections													
	4.6	Cooperation with national authorities in the coordination system of control and supervision													

Task	No.	Sub-task / Implementation years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
5. Adaptation of the PAA's equipment and infrastructure facilities to the tasks resulting from the *PNP Programme*	5.1	Adaptation of infrastructure facilities to the PAA's needs													
	5.2	Purchase, implementation and maintenance of IT systems for project, document and control management													
	5.3	Adaptation of technical equipment for the needs of analysis and control													
	5.4	Purchase, implementation and maintenance of software for the purpose of conducting safety analyzes													
	5.5	Purchase of the necessary national and international technical standards and participation in training courses related to their application													
	5.6	Development of the country's radiation monitoring system and programs supporting the decision-making process in crisis situations													
6. Technical and expert support system for PAA	6.1	Conducting the authorization process of laboratories and expert organizations													
	6.2	Commissioning expert opinions to authorized laboratories and expert organizations, as well as other entities in the area not requiring authorization													
7. Licensing and supervision of the PAA President	7.1	Analyzes and assessments necessary for issuing administrative acts of the PAA President and other authorities													
	7.2	Licensing of operating personnel for a nuclear power plant													
	7.3	Inspections of suppliers of systems, structural elements and equipment crucial for nuclear safety													
	7.4	Supervision control conducted at the construction site													

Appendix 3. Expenditures related to the implementation of the *PNP Programme*

Expenditures incurred and planned in 2020-2033, related to the implementation of the *PNP Programme* (in PLN ,000s)
State budget funds under the multiannual *PNP Programme*

Item	Organisation	Expediture up to 2033	Including expenditure in 2020–2033			
			2020	2021	2022	2023
	1	2	3	4	5	6
1.	Office supporting the minister in charge of energy	**188.000**	1.000	900	23.500	25.500
	of which: a) Supporting the participation of Polish industry in the *PNP Programme*	57.700	100	100	8.000	10.000
	b) Information and education activities	111.300	900	800	15.000	15.000
	c) Development of human resources for the purposes of nuclear power	13.000				
	d) Performing analyses connected to the implementation and updating of the *PNP Programme* and related documents	6.000			500	500
2.	National Atomic Energy Agency (PAA) – strengthening nuclear regulatory control	**400.350**	961	1.563	19.318	35.498
	of which: a) Strengthening the staff and building PAA's competences	222.596			7.437	12.410
	b) Adaptation of the PAA's hardware facilities and infrastructure to the tasks stemming from the *PNP Programme*	87.326	961	1.514	5.011	12.738
	c) System of technical and expert support for PAA	86.049		49	6.500	10.000
	d) Performing of control and other tasks accompanying the implementation of PAA's tasks stemming from the *PNP Programme*	4.379			370	350
TOTAL: items 1 and 2		**588.350**	**1.961**	**2.463**	**42.818**	**60.998**

Item	Organisation	Including expenditure in 2020–2033				
		2024	2025	2026	2027	2028
		7	8	9	10	11
1.	Office supporting the minister in charge of energy	28.500	30.500	17.500	12.500	10.500
	of which:					
	a) Supporting the participation of Polish industry in the *PNP Programme*	13.000	15.000	2.000	2.000	1.500
	b) Information and education activities	14.000	14.000	14.000	9.000	7.500
	c) Development of human resources for the purposes of nuclear power	1.000	1.000	1.000	1.000	1.000
	d) Performing analyses relating to the implementation and updating of the *PNP Programme* and related documented	500	500	500	500	500
2.	National Atomic Energy Agency (PAA) – strengthening nuclear regulatory control	31.428	31.136	34.188	29.981	32.398
	of which:					
	a) Strengthening the staff and building PAA's competences	13.487	15.534	16.921	18.357	19.591
	b) Adaptation of the PAA's hardware facilities and infrastructure to the tasks stemming from the *PNP Programme*	6.591	5.232	6.897	5.754	6.937
	c) System of technical and expert support for PAA	11.000	10.000	10.000	5.500	5.500
	d) Performing of control and other tasks accompanying the implementation of PAA's tasks stemming from the *PNP Programme*	350	370	370	370	370
TOTAL: items 1 and 2		**59.928**	**61.636**	**51.688**	**42.481**	**42.898**

Item	Organisation	Including expenditure in 2020–2033				
		2029	2030	2031	2032	2033
		12	13	14	15	16
1.	Office supporting the minister in charge of energy	10.500	10.100	6.000	5.500	5.500
	of which: a) Supporting the participation of Polish industry in the *PNP Programme*	1.500	1.500	1.000	1.000	1.000
	b) Information and education activities	7.500	7.100	2.500	2.000	2.000
	c) Development of human resources for the purposes of nuclear power	1.000	1.000	2.000	2.000	2.000
	d) Performing analyses relating to the implementation and updating of the *PNP Programme* and related documented	500	500	500	500	500
2.	National Atomic Energy Agency (PAA) – strengthening nuclear regulatory control	33.484	34.421	37.954	37.704	40.316
	of which: a) Strengthening the staff and building PAA's competences	21.100	21.924	23.944	24.706	27.185
	b) Adaptation of the PAA's hardware facilities and infrastructure to the tasks stemming from the *PNP Programme*	6.535	6.627	8.140	7.128	7.261
	c) System of technical and expert support for PAA	5.500	5.500	5.500	5.500	5.500
	d) Performing of control and other tasks accompanying the implementation of PAA's tasks stemming from the *PNP Programme*	349	370	370	370	370
TOTAL: items 1 and 2		**43.984**	**44.521**	**43.954**	**43.204**	**45.816**

Appendix 4. *PNP Programme* monitoring system and implementation metrics

The *PNP Programme* will be monitored at the level of the objective, tasks, activities and directions of intervention. The implementation metrics of individual activities will also be monitored. The Minister in charge of energy monitors the implementation of the *PNP Programme* and is responsible for preparing a report on the implementation of the *PNP Programme* every two years and submitting it to the Council of Ministers, in accordance with the requirements of the Act – Atomic Law (Article 108e).

Metric	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Development of human resources													
Preparation and implementation of the *Plan for the Development of Human Resources for the Purposes of Nuclear Power* (%)	10	20	50	55	60	65	70	75	80	85	90	95	100
Infrastructure development													
Preparation of accompanying projects (% share)	–	22	38	56	72	88	90	92	92	94	96	98	100
Supporting domestic industry in preparations to participate in the construction and operation of nuclear power plants													
Involvement of domestic industry (cumulative % share in total project value)	–	–	–	–	5	10	12	15	20	25	30	35	40
Number of information and training projects	2	4	4	4	4	4	4	4	4	4	4	4	4
Number of foreign missions or business forums in the country	1	2	2	2	2	2	2	2	2	2	2	2	2
Number of nuclear certifications obtained by Polish enterprises	–	10	12	12	10	8	6	6	4	4	4	4	4
Strengthening nuclear regulatory control – the National Atomic Energy Agency (PAA)													
Employment of nuclear surveillance specialists (% of the target number [LD] employees for the purposes of the PNP Programme, where [LD] = 110 people)	25	56	75	78	83	88	88	93	93	96	98	100	100
Training for the implementation of employed specialists (total number of training man-days per year)	540	1080	1480	1560	1620	1740	1740	1840	1840	1880	1920	1960	1960
Expansion of the network of early warning stations of radioactive contamination (% of the target number [LD] of operating early warning stations of radioactive contamination, where [LD] = 145 stations)	26	26	31	38	45	52	59	66	72	79	86	93	100
Social communication and information													
Preparation and implementation of the nuclear power programme communication strategy (%)	1	14	30	45	55	65	70	75	80	85	90	95	100

Appendix 5. Comparative analysis of the cost of electricity generation in nuclear, coal and gas power plants, and renewable energy sources

1. Summary and key conclusions of the study

The analysis was developed in two stages in March and May 2020 for the Ministry of Climate and the Office of the Government Plenipotentiary for Strategic Energy Infrastructure with substantive and analytical support from Polskie Sieci Elektroenergetyczne. The study was performed with the use of the total cost methodology which allows additional costs associated with electricity generation to be taken into account, which are not included in a standard assessment of power investment projects. The analysis contains variant optimisation of the total cost of electricity generation in the Polish power system (PPS), presenting the impact of nuclear power development on the design and cost of the energy mix. In addition, a sensitivity analysis of the total cost of electricity generation was performed for individual energy technologies.

The studies led to 5 key conclusions:

- 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;
- in the 2045 perspective, the optimum volume of nuclear capacity will be approx. 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 approx. 10 GW net by 2050;
- nuclear power plants contribute to reducing the demand for natural gas in the electric power sector, minimising the capital outflow related to fuel import, as well as the sensitivity of electricity price to a natural gas price;
- system costs grow as the share of weather-dependent energy sources in electricity production increases, significantly rising 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.
- the total levelised cost of electricity in 2020 is 360 PLN/MWh. In 2045, the cost will be the lowest in the scenario in which the NPP is developed by way of free optimisation (374 PLN/MWh), and the highest in the scenario without the NPP (388 PLN/MWh). The extended model perspective demonstrates a further decline in the total cost with continued development of nuclear power (340 PLN/MWh in 2050) as well as an increase of discrepancy (spread) of costs between free optimisation and non-nuclear scenarios (376 PLN/MWh in 2050).

2. Total cost methodology

The role of the state is to ensure energy security, defined as the ability to maintain 100% continuity of energy supply at a minimum cost to final consumers, taking into account system (technical) and environmental requirements. For this purpose, the government determines a long-term, economically beneficial energy strategy, setting out the directions of the sector's development.

In determining the strategy, the government uses tools including the total cost methodology (TCM) which differs significantly from the investor's economic account. The overarching objective of the TCM is to minimise the total cost incurred by the economy and society for power generation, taking into account indirect operating costs of the power sector. Side effects of electricity production, such as emissions or system imbalance, cause third parties to bear a part of the operating costs of the power plant, which are not included in the energy cost at the investment decision-making stage. The side effects form a group of external costs which include system costs (capacity reserve, networks, balancing), environmental costs (health, ecosystem), and macroeconomic costs (security, import-export balance, employment).

The total cost methodology assigns external costs directly to their source, tending towards fair cost distribution between investors, final consumers and other participants of the electricity market. The energy mix, optimised for total cost, allows efficient use of available resources, which translates into the improvement of price competitiveness of Polish enterprises in the international and domestic market and allows the electricity price for households to be reduced. Real reduction of costs requires appropriate regulatory changes adjusting the electricity market to the methodological assumptions. The investor's account commonly in use is targeted at the maximisation of the investor's individual profits. In such a model, external costs of electricity generation are not taken into account as the investor's cost and are carried through to other market participants and final consumers. This leads to the creation of an energy (capacity) mix which may be suboptimal in terms of the cost to society.

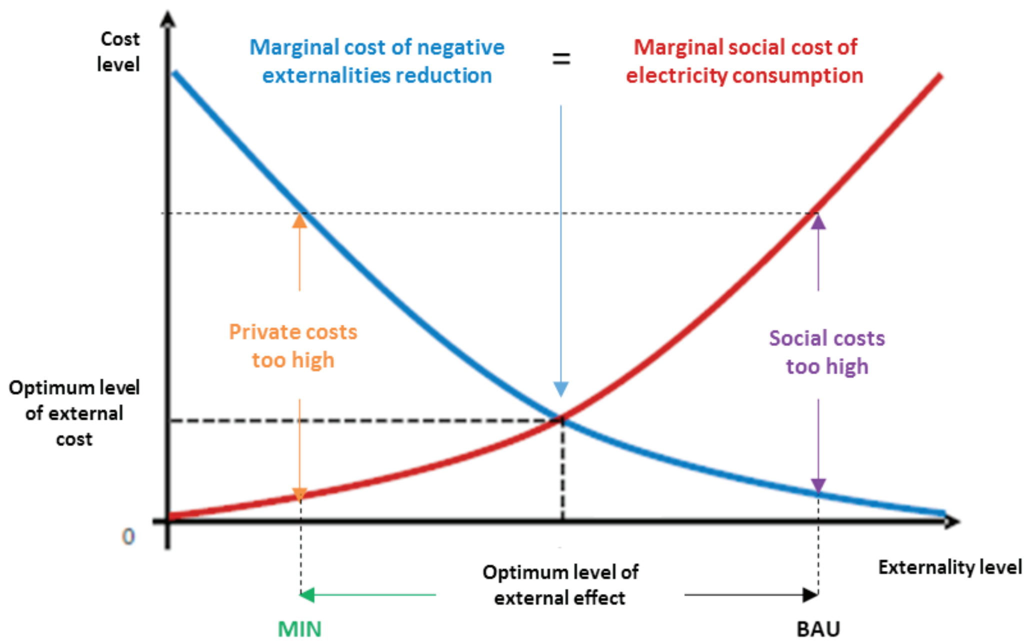


Figure 1. Mechanics of external cost optimisation in the total cost methodology – illustrative drawing; MIN - minimum technically possible limitation of the external effect, BAU - Business as Usual, system designing disregarding external costs

The role of the state is to develop a strategy that reconciles the interests of final consumers with the interests of power sector investors. Owing to incomplete representation of costs in the currently functioning electricity market, regulatory measures are needed for a rational reduction of external costs. The government administration aims at creating optimal market mechanisms that will enable investors to make the investments provided for in the strategy and to receive a reasonable return on invested capital while respecting the environment and other market participants (system aspects). The final effect of the application of the total cost methodology is obtaining a minimum electricity price at which the final consumer buying electricity pays back capital expenditure and operating costs of the power sector, without having to incur technically and economically unjustified external costs.

System costs

The power system operates as a system of communicating vessels in which generation, transmission, distribution and consumption of electricity interdependent. The factors of special importance, which determine the way the system is managed, are the operating parameters of the available and future generation base. The diversification of technologies in terms of operational flexibility, stability and predictability, the average utilisation of capacity, failure rates, or the ability to choose a convenient site location has a direct influence on the cost of system functioning as a whole. The greater the deviation of the characteristics of the generating source from parameters that allow the system to operate securely, the higher the costs generated in its other components.

The lowest system costs are generated by dispatchable sources, which are characterised by the capability to produce electricity on demand in accordance with the consumers' demand profile, a high annual capacity factor and the possibility to be built at convenient network nodes, close to electricity demand centres.

System maintenance costs increase significantly for uncontrollable sources such as wind and solar technologies. Operational unpredictability and lack of certainty of supply, location constraints resulting from wind and solar conditions, asynchronous operation reducing available system inertia, and low concentration of capacity are factors that hinder the secure and cost-effective system management.

This results in significant system costs which are disregarded by investors in the economic assessment of uncontrollable sources. The costs include:

- costs of reserve maintenance and change of system load profile (profile cost),
- transmission and distribution infrastructure development costs,
- system balancing and flexibility costs.

Profile costs related to a permanent change in the effectiveness of generation asset utilisation are the biggest cost component. The development of uncontrollable technologies, which have priority of access to the grid, is limited by the number of hours available to dispatchable technologies responsible for the secure operation of the system. The ongoing reduction of the operating time makes it difficult to obtain a return on investment in dispatchable sources, increasing uncertainty as to the full depreciation of assets. This translates into the growing risk of stranded costs emerging in the sector in consequence of early closures of existing generating units. The growing investment uncertainty, correlated with the increasing share of uncontrollable RES in electricity production, leads to a steady growth of the weighted average cost of capital (WACC) of new dispatchable power units. This leads to a delaying of or making no investment decisions on the planned dispatchable energy sources. Finally, the increase risk level, translating into an increase in the costs of financing dispatchable power plants, necessary to secure unstable RES generation, increases the total cost of electricity production in the power system. In the total cost methodology, owing to the invariability of the WACC for the individual technologies over the entire forecast period, profile costs representing the value of the change in the effectiveness of asset utilisation, have been assigned in whole to uncontrollable RES which are the source of profitability disruption for the other system participants.

Environmental costs

A rational reduction of the negative impact of the energy sector on the environment and health of citizens requires the identification, valuation and then inclusion of all environmental costs in optimising the national power strategy. The identification of negative environmental effects associated with electricity production has been carried out for the full production cycle including the extraction of energy resources, transport, conversion, and final electricity consumption. The studies[45] used in the analysis have enabled an approximate assessment of the impact of the power sector on human health, the ecosystem, and the volume of agricultural crops.

The model analysis starts with defining the amount of toxic emissions, such as particulate matter ($PM_{2.5}$, PM_{10}), sulphur oxides (SO_x), nitrogen oxides (NO_x) or heavy metals, and energy emitted in the form of noxious noise, heat or radiation. Mathematical models are used to determine the radius of dispersal of harmful agents around the power plant and the intensity of negative environmental impacts in the area under study. Based on the functions determining the impact of the concentration of specific effects on the quality of air, potable water, soil and agricultural crops, the increase in probability of occurrence of diseases and degradation of surrounding ecosystems is determined. The coefficients obtained allow a unit-based valuation of emission impact on health and the environment to be carried out. The cost indicators calculated this way are used as a component criterion of the economic optimisation of the sector.

[45] NEEDS (2004-2008) - New Energy Externalities Developments for Sustainability http://www.needs-project.org/; European Commission (1990-2005), External Costs of Energy - http://www.externe.info/

3. Description of variants and presentation the results of the optimisation of the total cost of electricity generation in the Polish power system

The economic analysis for the purposes of the *PNP Programme* has been carried out with the use of the PPS total cost model developed by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure in substantive and analytical cooperation with Polskie Sieci Elektroenergetyczne. The optimisation model of Polish power system was developed in Energy Exemplar's PLEXOS, which is widely used by PSE and ENTSO-E for analyses of generation adequacy and for the development needs of the grid. Apart from private (investor's) costs, the total cost model takes into account in the optimisation criterion a directional valuation of system and environmental costs based on available literature knowledge (see sub-chapter 5). The results of this analysis should be regarded as only for analytical purposes and not as creating any alternative scenarios to the forecasts in Energy Policy of Poland up to 2040 (PEP2040) document. Conducted simulations are aimed to verify economic viability of nuclear power development in Poland from perspective of the state and national economy as a whole. Four scenarios have been prepared for the purposes of the analysis, which allow to assess an impact of nuclear power on economic effectiveness of Polish Power System:

Scenario I - Free optimisation
– optimisation in the **total cost model**

- capacity mix is defined through economic optimization od PPS taking into account system costs and environmental costs,
- the aim of this scenario is to find the most cos effective capacity mix of PPS and to verify the need for development of nuclear power (the optimizer decides independently whether to build nuclear units or not),

Scenario II - Strategic variant
– optimisation in the **total cost model**

- nuclear power development in line with government's schedule, reactors' lifetime is 60 years,
- offshore wind development in line with government's schedule stipulated in the Offshore Wind Power Promotion Act,
- distance law for onshore wind power upheld in force, as of September 2020,
- existing generating units decommissioning schedule in line with draft PEP2040 (as of September 2020),
- other decisions on the choice of energy sources based on economic grounds, including system costs and environmental costs.

Scenario III - No nuclear power (TCM)
– optimisation in the **total cost model**

- forced lack of nuclear power development,
- other decisions on the choice of energy sources based on economic grounds, including system costs and environmental costs,
- the aim of this scenario is to illustrate how the decision of not to build nuclear power plants will affect the power system and the total cost of electricity.

Scenario IV – No nuclear power (IM)
– optimisation in the **investor model**

- comparative variant relative to the total cost model,
- forced lack of nuclear power development,
- other decisions on the choice of energy sources based on economic grounds not including external costs,
- the aim of this scenario is to illustrate how the decision of not to build nuclear power plants will affect the power system and the total cost of electricity.

As the optimisation basis, the forecast electricity demand has been used as well as data on the planned outages of existing generating capacity in accordance with the *Development Plan for meeting the current and future electricity demand for 2021-2030 (PRSP'20)*, with necessary extrapolations. The perspective of scenarios is 2045, but calculations performed indicate a similar results for costs and energy mix up to 2050.

Owing to the need to ensure energy security of the Polish power system, and stable electricity supply to consumers, the assumption of domestic generation self-sufficiency was adopted. Since Polish government cannot take any responsibility for actual availability of foreign capacity, the forecasted energy mix is based on zero import-export balance of electricity. This assumption is necessary in order to precisely plan the investments needed to maintain PPS self-sufficiency in case of import unavailability.

The obligatory assumption under each scenario is the achievement of the sectoral RES target for the power sector in 2030, i.e. 33.32% RES share in net electricity production.

According to the nuclear investor's schedule, first reactor should be connected to the grid in 2033. In both "nuclear" scenarios this date is manually set an earliest moment when first nuclear unit can come online. Construction duration was set to 6 years and design operational lifetime to 60 years The maximum expansion rate is 1 nuclear reactor every 2 years[46]. The calculations take into account the costs of NPP decommissioning and radioactive waste disposal, but they **do not include the costs of demolition and waste disposal for the other energy sources.**

Taking into account the investors' announcements[47] and the rising trend of CO_2 allowances[48], all scenarios provide for the conversion of the Ostrołęka power unit to gas fuel[49] as well as construction of 2 new CCGT units in Dolna Odra power plant[50].

The CCS and IGCC are included in the optimisation, but they have not arisen in any scenario owing to excessively high capital expenditure and a high cost of capital resulting from a lack commercial maturity of the technologies.

Energy storage facilities and hydrogen technologies are not taken into account in the optimisation owing to their excessively high costs in the mid and long-term (despite the forecasted costs reduction for these technologies). In the case of a technological breakthrough which allows for mass and system-scale use of energy storage or a commercialization of micro-storage, some of the peaking gas power plants (OCGT), built in subsequent years, may be replaced in the mix by energy storage facilities. However, it should be noted that maintaining a self-sufficiency of PPS without dispatchable energy sources will require a significant overinvestment in RES capacity above energy demand in order to secure the electricity supply during extended (several days) period of no RES output. Dispatchable power plants (nuclear and gas), RES and energy storage are complementary technologies, which in right proportions will ensure a secure, economic and low-emission operation of the PPS.

System costs and environmental costs are accounted for as additional variable costs per MWh for each type of energy source. The amount of system costs generated by non-dispatchable energy sources changes dynamically depending on the share of these sources in energy mix. Initial development of weather-dependent sources with its share of 10-20% in generation means a limited system costs (25-35 PLN/MWh). After passing a 30% penetration totally for all non-dispatchable sources, a negative effects of unstable generation become stronger (ca. 60 PLN/MWh) leading to a non-linear increase of system costs generated by a weather-dependent sources (ca. 110 PLN/MWh at 50% penetration) and a total operation cost of PPS[51]. The inclusion of system costs in this analysis is not meant to discredit a RES development. These sources are needed for climate and environmental protection as well as for diversification of energy mix and for a decrease of fossil fuels dependency. The total cost methodology only indicates for a need to rationalize its development in order to maintain a secure operation of the system and to ensure a stable and socially acceptable electricity prices to the consumers.

The other technical and economic assumptions used in the modelling, including projections of decrease of investment costs and O&M costs for all technologies in the period of 2020-2050 are described in sub-chapter 5.

The power sector modelling results are of an analytical nature and they are not counterfactual scenarios to the forecasts presented in the *draft Energy Policy of Poland to 2040 (PEP2040).* The variant analysis of the energy mix was aimed to verify the economic viability of nuclear power development in Poland from the point of view of the state and the whole economy. The viability was confirmed in Scenario I (free optimisation), the main assumption of which was the

[46] A conservative assumption; in practice, the pace of reactor construction may be up to 1 reactor per year with an appropriate optimisation of work and utilisation of construction teams and machines.

[47] On 2 June 2020, PKN Orlen, Energa and Enea signed an agreement on the terms and conditions for the construction of the Ostrołęka C power unit. The agreement provides for the continuation of the project at Ostrołęka, with the technology to be changed from the coal-based one being implemented so far to the fuel gas-based technology.

[48] Center for Climate and Energy Analysis, The National Centre for Emissions Management (KOBiZE): Change of emission reduction targets and allowance prices resulting from the communication „The European Green Deal".

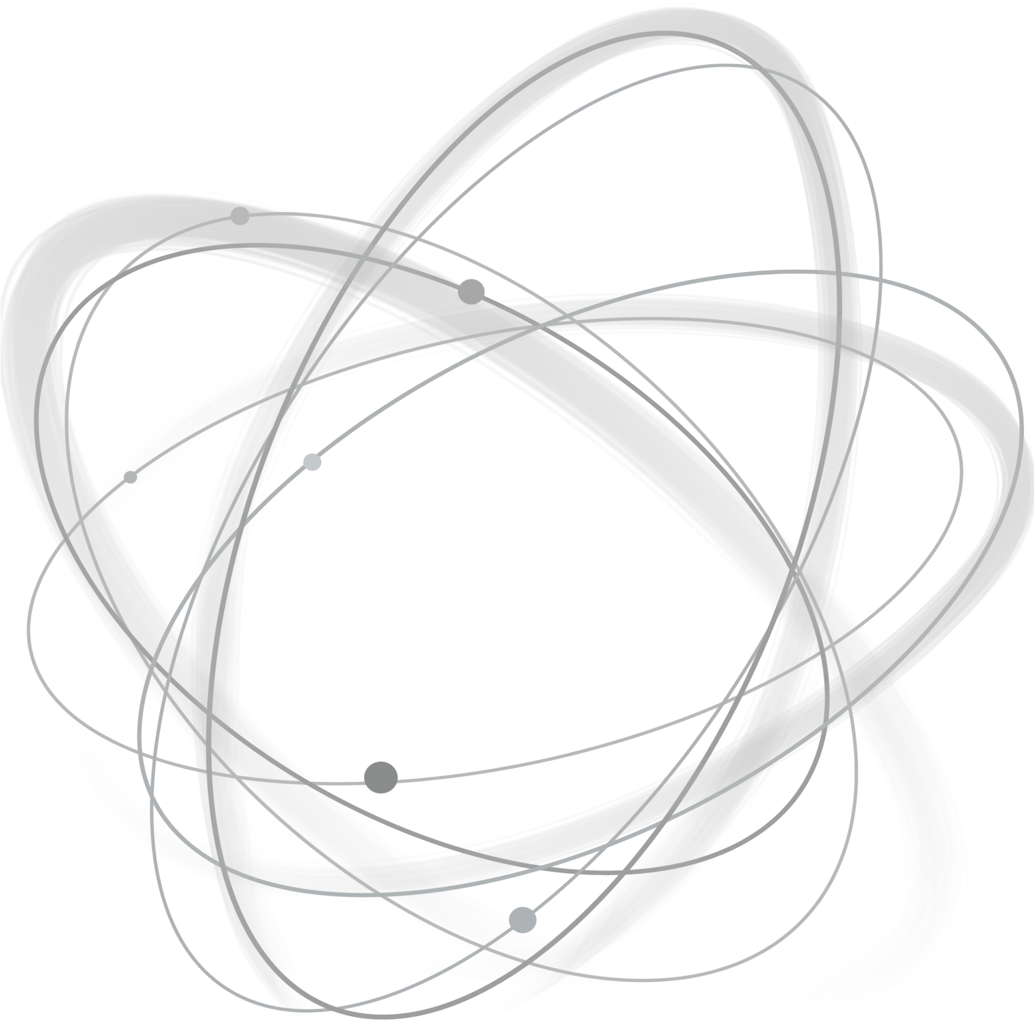
[49] On September 3, 2020, PKN Orlen and PGNiG signed the letter of intention to analyze the possibilities of joint investment implementation. The companies announced that the CCGT construction project in Ostrołęka provides for the construction of a CCGT unit by the end of 2024 with a designed nominal power of approx. 750 MWe net.

[50] On January 30, 2020 at Dolna Odra Power Plant, belonging to PGE Górnictwo i Energetyka Konwencjonalna, a part of PGE Capital Group a contract for the construction of two new gas-fired units with total power amounting to approx. 1400 MWe was signed - official announcement from pgegiek.pl.

[51] OECD-NEA The Cost of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, p. 120-127: https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf

free formation of the mix based on total cost model algorithms, including system costs and environmental costs. The optimizer opted for the construction of the first nuclear power unit of 1.1 GW in 2036, expanding the nuclear sector to 7 reactors in 2045, and ending with 9 nuclear units of a total capacity of 9.9 GW in 2050 (extended model perspective). While making this decision the optimiser takes also into account a liftime of a given power plant which is out of the time scope of scenario, simulating energy demand and system balance from the last year of scenario (no end of the world effect). The results of free optimization indicate that nuclear power plants are economically viable and will secure a stability of electricity prices far beyond the time scope of the scenario – a design lifetime of first nuclear unit will end around 2095.

The construction of the first nuclear reactor in 2035 results from a minimization of total costs carried for an entire period of forecast, not taking into account strategic government's decisions and legal constraints for any technology. The only criteria is the economic effectiveness of the entire power system. Taking into account that differences between results of free optimization and a government's nuclear development schedule are minor, the commissioning of first nuclear unit in 2033 is fully justified.
The result of free optimisation confirms the economic viability and rationality of the development of 6-9 GW of installed capacity in nuclear power plants as the strategic direction of PEP2040.



3.1. Scenario I – Free optimisation, total cost model

In the free optimisation scenario (S.I), the first NPP unit is commissioned in 2035. The next units are commissioned every 2 years, expending the generation base to 7 NPP units with a total capacity of 7.7 GW in 2045. The extended model perspective shows that by 2050 there will finally be 9 nuclear reactors with a total capacity of 9.9 GWe. The NPP share in electricity production in 2035 is 4%, in 2040 is 12% and it increases to 27% in 2045 and 32% in 2050. Maintaining stable baseload supply limits, in comparison to other scenarios, the development of gas power plants (CCGT) – additional 5.2 GWe relative to 2020. Peaking sources (OCGT) are built due to the system balancing needs, up to the total of 7.1 GWe in 2045. Owing to high capital expenditure and system costs included in the model, the first offshore wind farm is commissioned in 2046 (beyond the basic model perspective). Onshore wind farms develop dynamically to the level of 12-13 GWe of installed capacity, and photovoltaics to 20 GWe. Further investment in those technologies is limited by growing system costs excessing economic benefits for the system resulting from projected decrease in the cost of those technologies

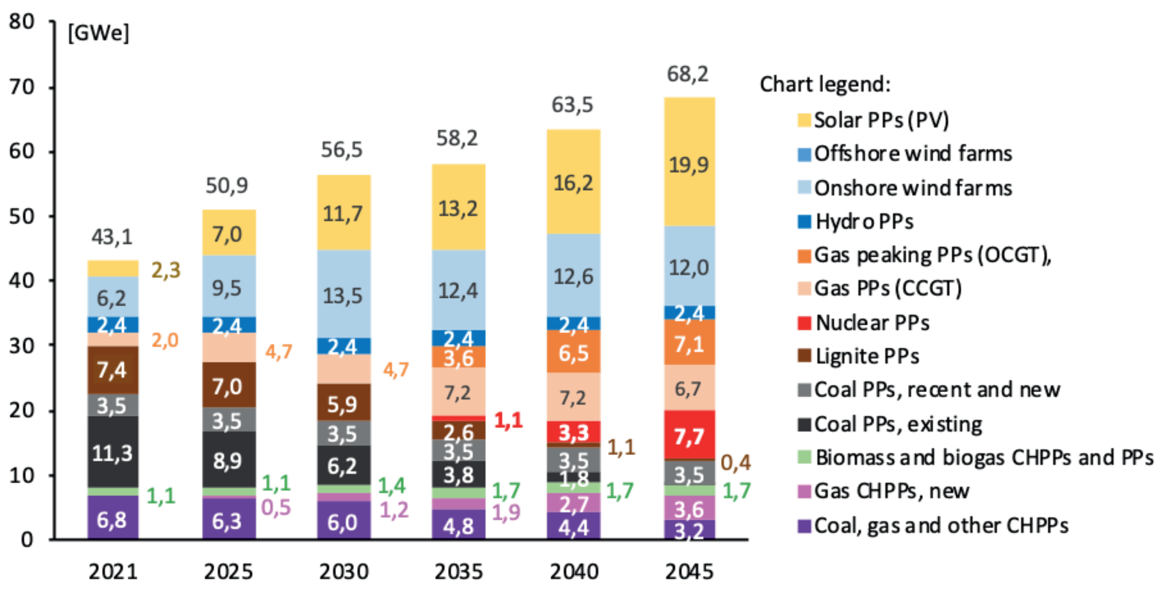


Figure 2. Model structure of installed capacity in the PPS for the years 2021– 2045 [GW]; – Free optimisation

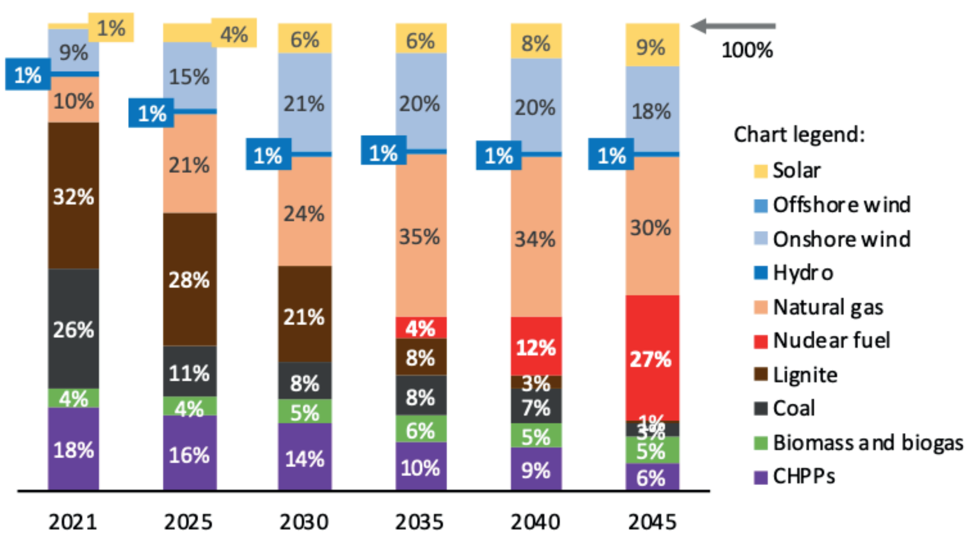


Figure 3. Share of sources in electricity generation structure [%]; – Free optimisation

3.2. Scenario II – Strategic variant, total cost model

In line with the strategic direction of the PEP2040 project envisaging the development of nuclear power, the model provides for the construction of 6 nuclear units with a total capacity of 6.6 GWe in 2045. The first nuclear unit appears in 2033, with the following ones commissioned every 2 years. The NPPs share in electricity production in 2035 is 9% and it increases to 16% in 2040 and 23% in 2045. Early development of offshore wind farms (OWF) in line with the *draft Act on the promotion of electricity generation in offshore wind farms,* was modeled with an assumption of steady connection of OWF at a rate of 1 GWe/year starting in 2026, ending at 9.6 GWe in 2034. The adopted assumption is aimed at a rational distribution of projects over time. If the formal and technical conditions are met and the investor is ready, it is possible to connect those sources to the grid earlier (in the case of connection agreements with dates earlier than those assumed in the forecast). The implemented strategic decisions result in limiting the development of photovoltaic sources (S.II - 13.5 GWe vs S.I - 19.9 GWe in 2045) and onshore wind farms (S.II - 9.2 GWe vs S.I - 12 GWe in 2045). The values of the installed capacity in PV and onshore wind farms (WF) over the years 2025-2035 are the result of strategic decisions in the development of the offshore wind farm sector and the minimization of the total cost of electricity generation in the Polish power system. The earlier development of the OWF (ensured by the act) resulted in a significant increase in the production of electricity from variable sources over the years 2025-2035. Due to the need to ensure the balance of power and energy production in the , as well as to minimize the total costs of

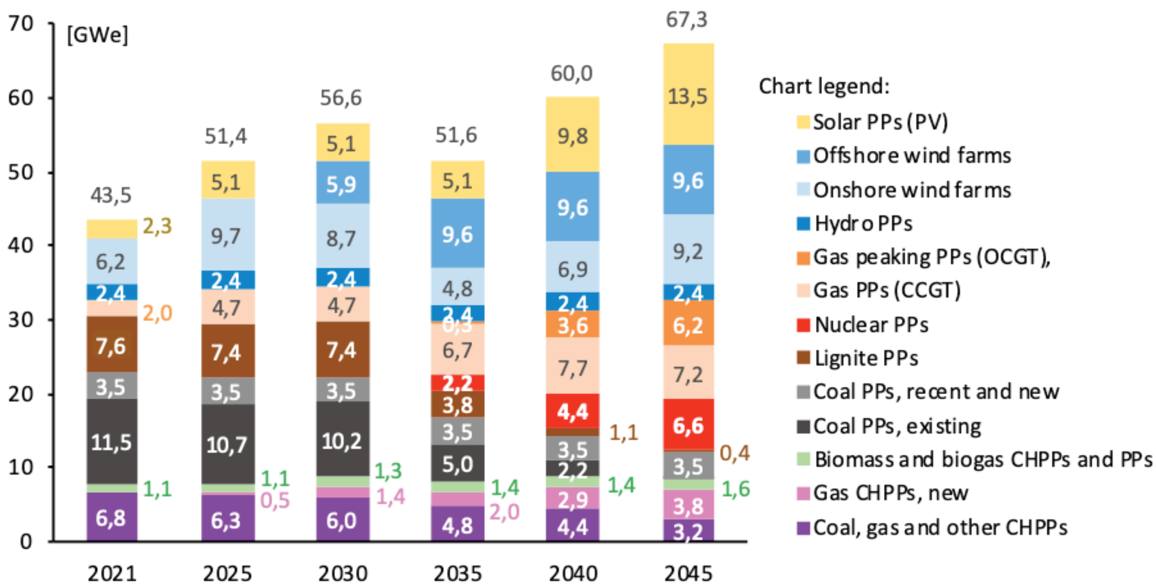


Figure 4. Model structure of installed capacity in the PPS for the years 2021– 2045 [GW]; Scenario II – Strategic variant

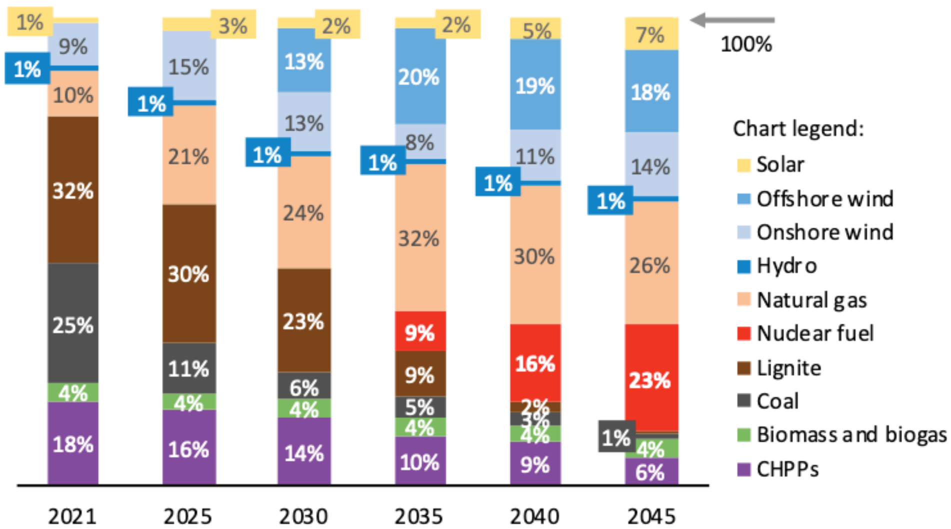


Figure 5. Share of sources in electricity generation structure [%]; Scenario II – Strategic variant

transformation, apart from variable sources, dispatchable sources securing the system's operation are developed. Additional increase in the production of unstable energy in the years 2025-2035, in which there is an accumulation of decommissioning of old coal sources, would simultaneously increase the already large investment needs in dispatchable sources, necessary to maintain a power reserve. The model avoids excessive accumulation of investment outlays in the years 2025-2035, as a result of which there is no expansion of the installed PV and WF capacity. Greater development of these technologies in the discussed period is possible, however, taking into account the forecast balance situation in the Polish power system, it will bring about an increase in the costs of ensuring security of energy supply.

3.3. Scenario III – No nuclear power, total cost model

In scenario III, based on the total cost model, gas power plants (CCGT) take over the role of the primary source (expansion to 12.7 GWe of capacity in 2045).This leads to a significant increase in gas use for electricity production (from 45% to 49% in 2035, from 34% to 52% in 2040, and from 30% to 46% in 2045 relative to Scenario I). In the absence of nuclear power, the optimiser opts for earlier construction of offshore wind farms (OWF) than under the free optimisation scenario – the first farm appears in 2042 instead of 2046. The total OWF installed capacity is 3.6 GWe in 2045. Photovoltaic installed capacity also increases (from 19.9 GWe to

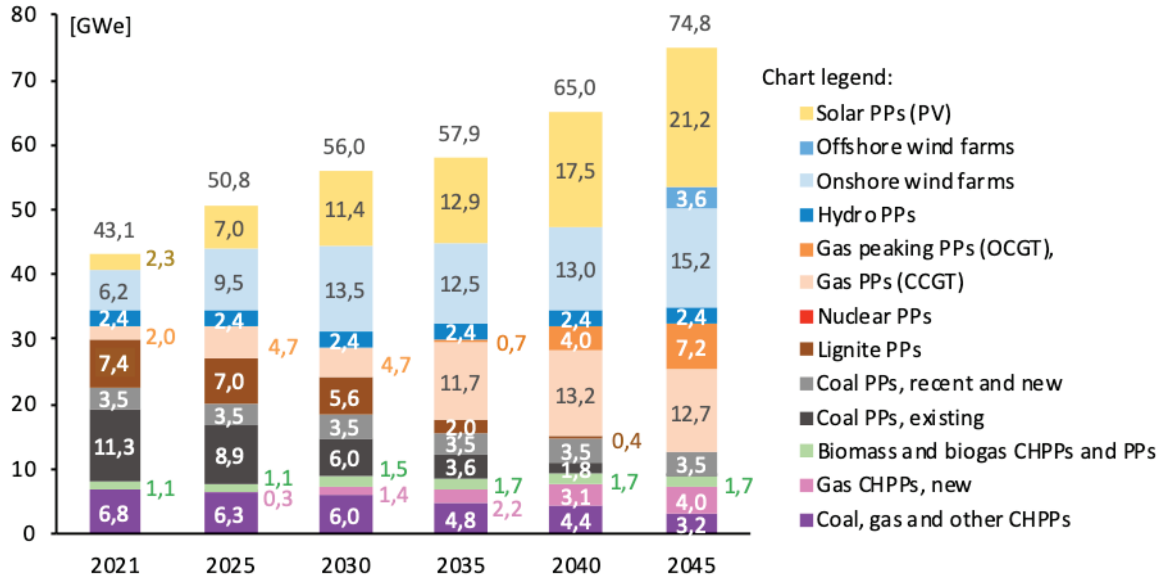


Figure 6. Model structure of installed capacity in the PPS for the years 2021– 2045 [GW]; Scenario III – No nuclear power (TCM)

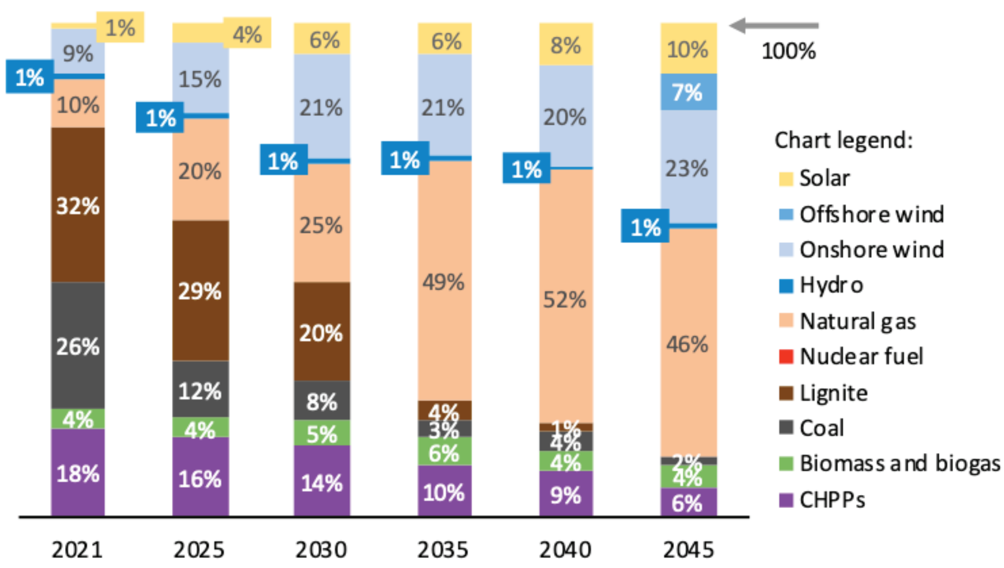


Figure 7. Share of sources in electricity generation structure [%]; Scenario III – No nuclear power (TCM)

21.2 GWe in 2045 relative to Scenario I). The capacity of onshore wind farms also changes (from 12.0 GWe to 15.2 GWe in 2045 relative to Scenario I). The absence of more extensive development of this technology is caused by a high system cost arising from high penetration of onshore wind power in the power system.

3.4. Scenario IV – No nuclear power, investor model (IM)

In Scenario IV, based on the investor model, the forced lack of nuclear power causes a significant increase of installed capacity in wind farms (both offshore and onshore) due to lack of system costs consideration Installed capacity in onshore wind farms increases from 15.2 GWe to 21.0 GWe compared to scenario III, and in the case of offshore wind farms from 3.6 GWe to 6.0 GWe in 2045. A similar increase is also taking place for photovoltaics, which increases from 21.2 GWe to 25.7 GWe. By 2045, 9.2 GWe of combined cycle gas turbine units (CCGT) and 9.7 GWe of peaking power plants (OCGT) is to be commissioned. Despite a significant expansion of gas assets in Scenario IV, the share of this fuel in electricity production increases slightly over the 2035-2043 period relative to Scenario I and decreases relative to Scenario III. A comparison with

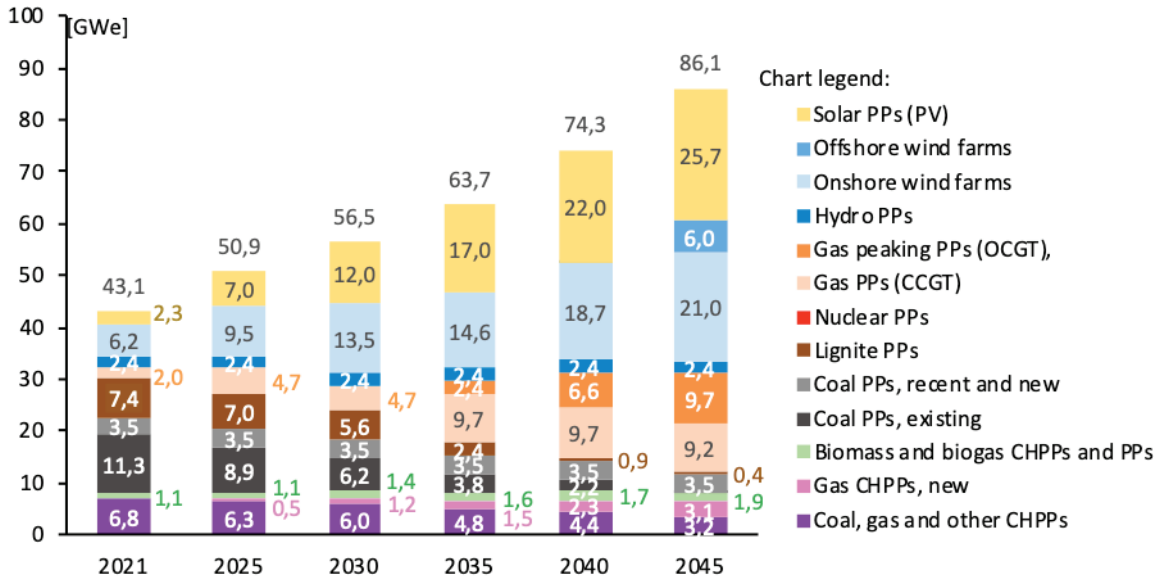


Figure 8. Model structure of installed capacity in the PPS for the years 2021– 2045; [GW]; Scenario IV – No nuclear power (MI)

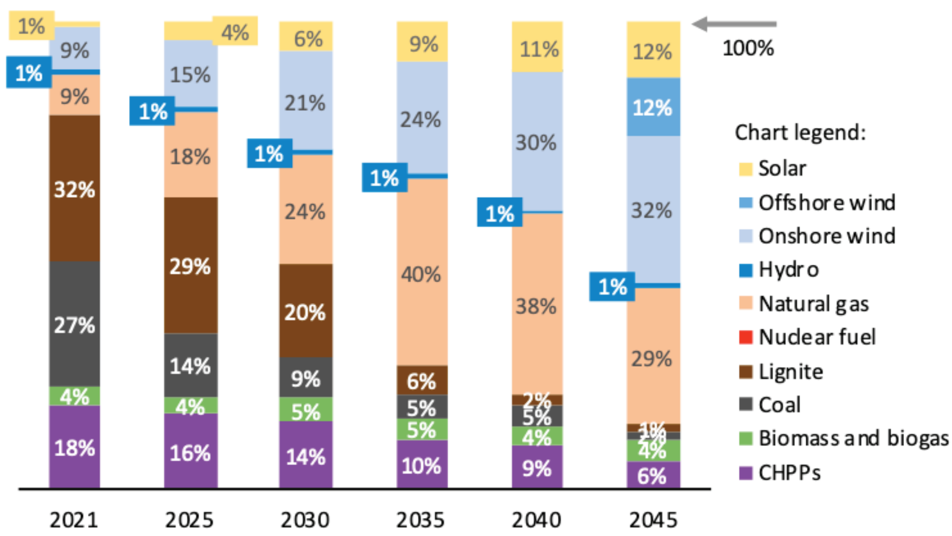


Figure 9. Share of sources in electricity generation structure [%]; Scenario IV – No nuclear power (MI)

Scenario I shows that a significant part of new assets operates as reserve. Low utilisation of gas capacity, resulting from a significant expansion of variable sources (56% share in electricity production) significantly increases the risk of early closures of new plants for economic reasons. This risk is augmented by in the case price-competitive energy storage solutions appear in the market. A dynamic development of RES, excluding system costs, may lead to over-investment in generating capacity which will not see a return on the capital invested.

3.5. Comparative analysis of the total cost of electricity generation in the Polish power system

A comparison of the economics of the different scenarios has been carried at three levels of the cost of electricity generation: private cost, external cost and total cost. The analyzed curves reflect the costs of the electricity generation sector (depreciation, fixed and variable operating costs, fuel, emission allowances, etc.), the power system costs (profile costs, balancing and grid development costs) and social costs (environmental costs) incurred in a given year, in relation to the annual volume of energy produced in the system. Thus, the presented indicators are not identical to the wholesale and retail prices of electricity - they represent the average total cost incurred by the economy in relation to electricity production and supply (excluding taxes and fees). The applied indicators eliminate the need to consider in the cost comparison of all support mechanisms (capacity market, RES auctions, OWF support system), because they take into account the reimbursement of all costs incurred by investors.

At the private cost level, Scenario II is the most expensive variant, Scenarios I and III are very similar, while Scenario IV is the variant with the lowest private cost (it is the only one that optimizes this cost).A significant disturbance causing a dynamic increase in the private costs of the Polish power system until 2030 in all scenarios is the expected increase in prices of CO_2 emission allowances caused by a possible increase in the target of reducing greenhouse gas emissions for 2030 to a level of 50% reduction compared to the base emission from 1990. The difference between Scenario II and the other scenarios (visible from 2025) is caused by the strategic decision to quickly expand offshore wind farms, taken among others in order to build appropriate competences and economic potential in this area, which at present require a support system to justify the earlier profitability of the investment. The average annual cost of electricity generation in Scenario II stabilizes around the start of operation of the first nuclear power unit in 2033, and then decreases as further nuclear power units appear in the system.

The free optimisation scenario (S.I), in which nuclear power plants of 7.7 GWe are built as decided by the optimiser, is comparable in terms of cost to Scenario III. based on investor optimisation and relying on a dynamic development of RES. It is worth noting that despite the implementation of the first nuclear reactor in 2035, the private cost of electricity generation has not increased. This confirms the lack of a negative impact of nuclear power plants on the average cost of electricity generation in Poland, and the competitiveness of this technology in the long-term development of the power sector.

.At the external cost level (Figure 11), Scenario II (strategic variant) is the most advantageous. The development of much more stable, more predictable offshore wind farms and highly dispatchable nuclear power plants allows the increase of system and environmental costs to be reduced to PLN 8.8 bn/year in 2045.

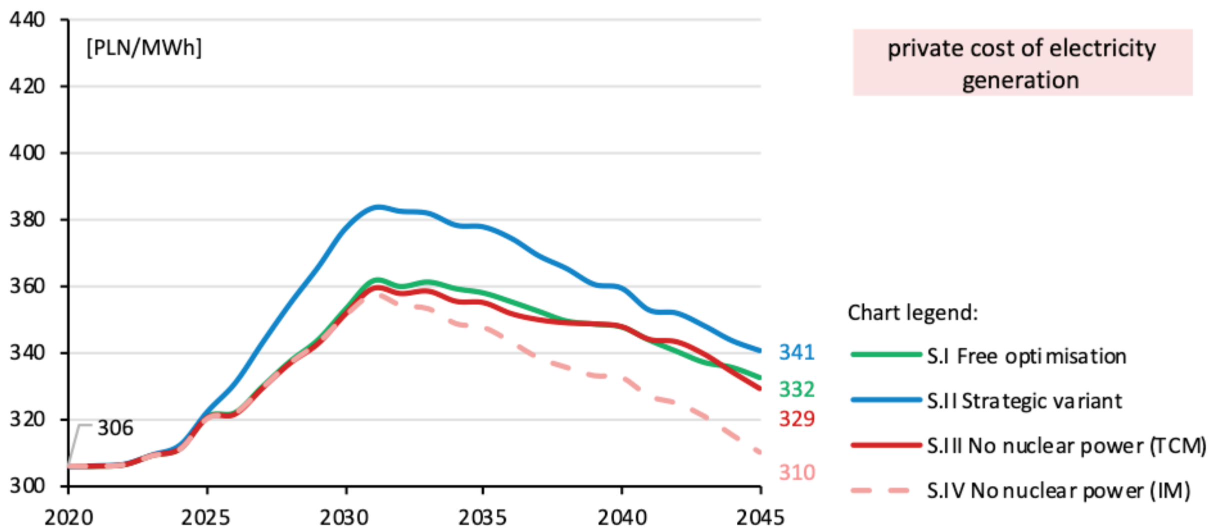


Figure 10. Annual unit cost of electricity generation in the Polish power system (investor cost only) [PLN/MWh]

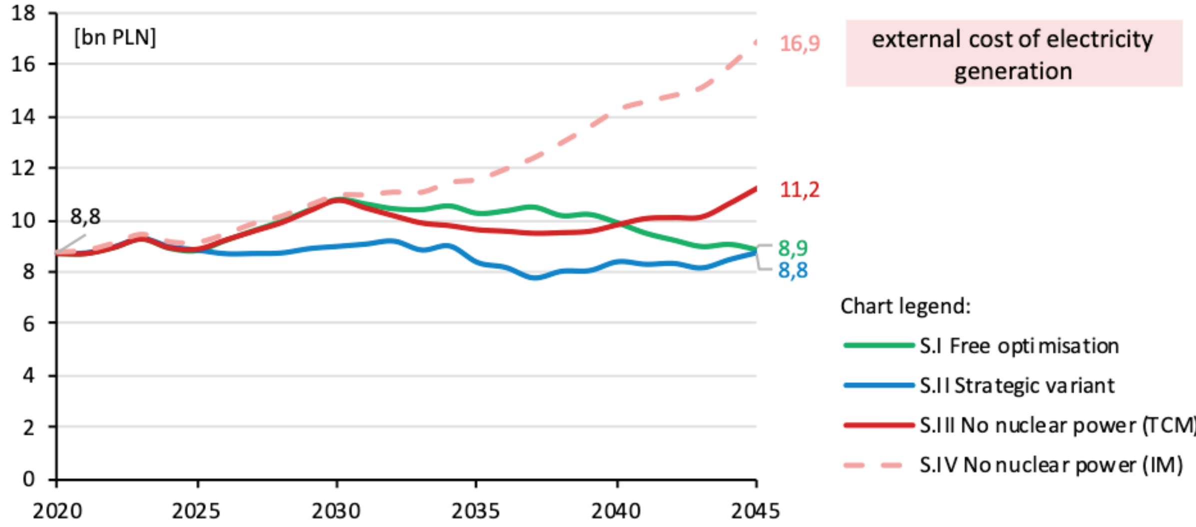


Figure 11. Average annual external cost of electricity generation in the Polish power system [PLN bn]

Scenario I (free optimisation) shows a continued stable yet higher external cost at a level of PLN 8.9 bn/year in 2045. Owing to the lowest total cost under this scenario (Figure 12), taking into account private, system and environmental costs, higher external costs are socially justified (while the total cost amount is still the lowest). The highest external costs, and a tendency of further growth, are demonstrated by Scenarios III and IV which provide for no nuclear power development. A scenario with an extremely high cost is Scenario IV, optimised in the investor model. The exclusion of system costs in technology selection causes an increase of external costs to PLN 16.9 bn/year in 2045.

The optimum scenario, in terms of the curve pattern and amount of total cost of electricity generation is the free optimisation scenario (S.I). The unit total cost under this scenario is 374 PLN/MWh at the end of the forecast. The scenarios without nuclear power (S.III and S.IV) are diverse relative to the optimum solution after 2040, but an extremely high coast is shown by the scenario based on optimisation using the investor model (S.IV - 388 PLN/MWh). The extended perspective of the model until 2050 shows a growing divergence between Scenarios I and IV. This phenomenon confirms that the failure to take system costs into account when optimizing the generation structure leads to excessive socialization of these costs through an increase in fees passed on to citizens. The strategic Scenario (S.II) proves that the implementation of nuclear power allows for the reduction of the total cost of energy generation. After the connection of the second nuclear unit in 2035, there is an accelerated reduction of the costs of Scenario II, and the connection of the third reactor brings the total cost curve to a trajectory similar to the curve of the free optimization Scenario (S.I). The shift of the curve

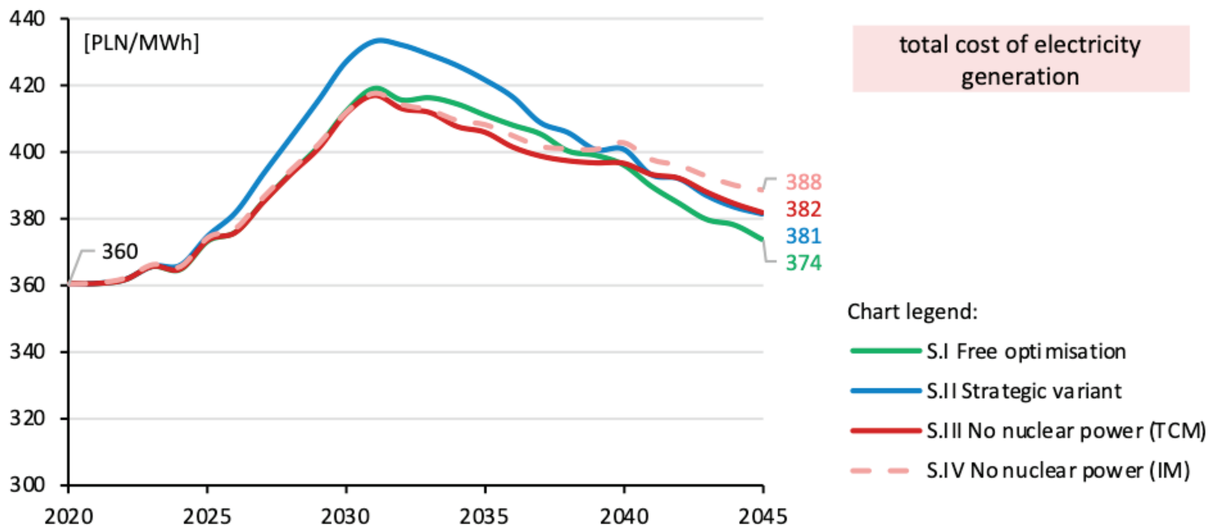


Figure 12. The average annual unit ***total cost*** of electricity generation in the Polish power system [PLN/MWh]

from the strategic variant (S.II) relative to the free optimisation Scenario (S.I) results from the higher costs of early development of offshore wind farms assumed as a strategic decision of the Government. The increase in the total cost under this scenario is correlated with the commencement of investment in OWF in 2026, and the differences begin to decrease after the limit of 9.6 GWe of the installed capacity covered by support in 2034 is used up.

3.6. Comparative analysis of the CO_2 emission reduction potential and forecasts for the use of natural gas at power plants and combined heat and power plants

The greatest potential for reducing CO_2 emissions is provided by the strategic scenario (S.II), in which the final value of annual emissions falls from 134 million tCO_2 in 2020 to 41 million in 2045 (almost 70%). Compared to the scenario of no development of nuclear power, optimized in the total cost model (S. III), the strategic scenario allows to avoid emissions of nearly 93 million tons of CO_2 over 25 years. Emission benchmarks for the power sector, as well as the emission volume, decrease steadily in the successive years of the forecast. Implementation of nuclear power under the strategic scenario (S.I) allows the emission benchmark to be achieved in 2045 lower by approx. 16.5% relative to scenarios without nuclear power (S.III). In the case of the strategic scenario (S.II), the difference in emissions relative to the scenarios without nuclear power is nearly 30%. This results from reducing natural gas consumption under both scenarios including nuclear power (S.I and S.II), which enables a faster reduction of CO_2 emissions.

What represents an important issue in terms of the strategy for the diversification of directions of gas fuel supply, as well as the reduction of capital outflow related to gas imports, is the reduction of long-term and peak demand for natural gas in power plants and combined heat and power plants.

Owing to the role of natural gas as transitional fuel in energy transition, adjusting the development of gas infrastructure to the instantaneous peak demand causes an inefficient allocation of domestic capital. Both nuclear scenarios (S.I and S.II) guarantee stable and limited use of natural gas for electricity production. The scenario without nuclear power, based on the total cost model (S.III), shows the highest peak demand of 20.8 bn m_3, as well as the highest average demand for natural gas in electricity generation sector. The lack of zero-emission baseload sources, stimulating more extensive RES development and inclusion of system costs reducing the decrease in utilisation of dispatchable capacity, shifts the burden of stable electricity production to gas power plants. Scenario IV, based on the investor model, limits gas consumption by expanding much greater numbers of RES. The falling demand for gas after 2040 in this scenario poses the risk of over-investment and lack of full depreciation of transmission infrastructure and generating capacity both in S.III and in S.IV.

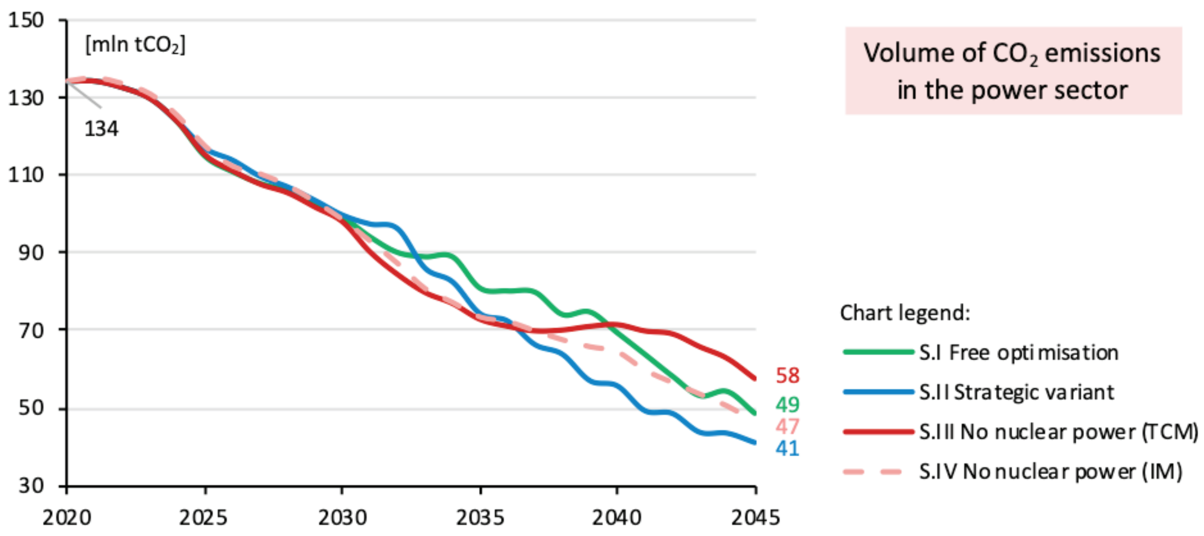


Figure 13. Volume of CO_2 emissions at power plants and combined heat and power plants [m tCO_2]

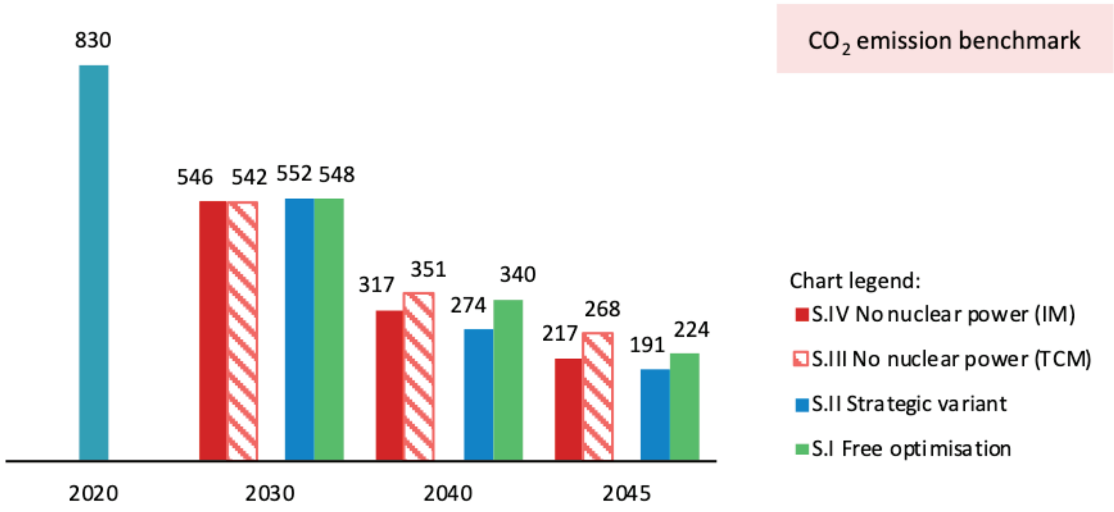


Figure 14. CO_2 emission benchmarks for power plants and combined heat and power plants [kgCO_2/MWh]

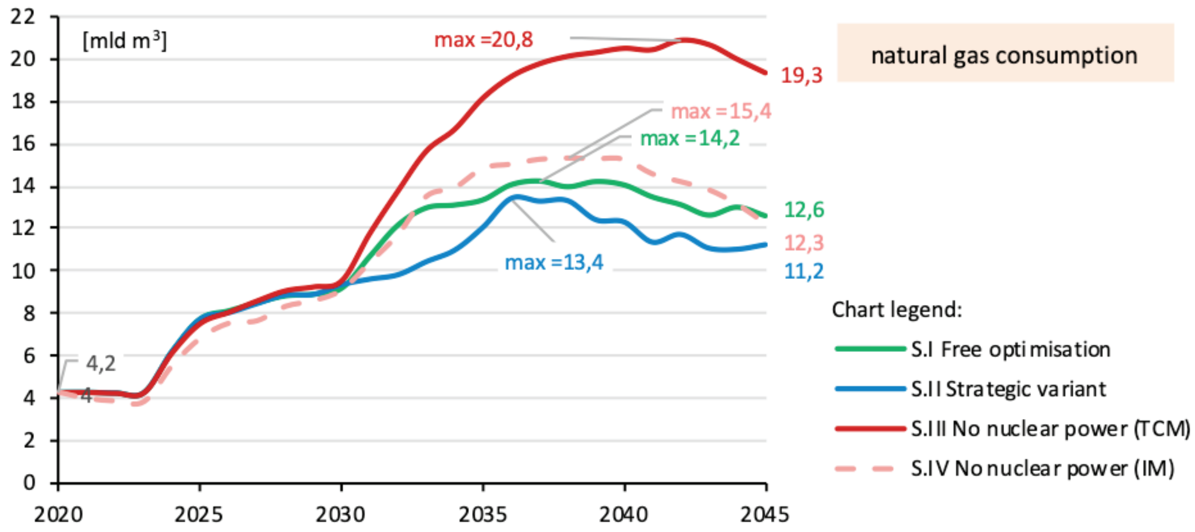


Figure 15. Natural gas consumption in power plants and combined heat and power plants [bn m³]

4. Results of sensitivity analysis of the total cost of electricity generation

The charts below present the results of the sensitivity analysis of the total cost of electricity generation by the respective sources. The cost level was calculated for 2035, on the assumption that each RES technology is considered individually in a hypothetical energy mix, in which it has a 30% share of electricity production. System and environmental costs presented in this section are based on the same assumptions as in subsection 3, but are not the same as the costs that were used for optimization. Optimization model selects the amount of system costs associated with variable energy sources in a dynamic way dynamic, depending on changing share of these sources in electricity over the period 2020-2050. The sensitivity analysis presents the total cost of electricity generation from individual technologies put into operation in a fixed year and under given system operating conditions (share of variable sources), close to the date of connection of the first nuclear reactor to the power system. The results of the sensitivity analysis show a strong dependence of the total electricity generation cost from nuclear units on a number of factors related in particular to the investment stage. At the same time, the impact of fuel prices on the total cost of electricity generation from nuclear sources is much lower, at a marginal level. The CO_2 emission allowance prices have no direct impact on the costs of nuclear power, but they indirectly influence its competitiveness in relation to technologies based on fossil fuels.

The results show that nuclear power is characterised by the lowest total levelised cost among all the analysed sources for the weighted average cost of capital (WACC) lower than 6%. At the same time, with an increase in the cost of financing, the discounted levelised total cost of electricity for nuclear technologies grows the fastest. For example, the total cost electricity production would increase for nuclear power by more than 350% if the cost of capital increased from 0% to 15%, where, by comparison, the same increase in the cost of capital for gas power causes an increase in total cost by only 25%. This shows how important an element of investment in nuclear power the development of an efficient financing model is, which, combined with substantial support from the state, will allow the cost of capital for a nuclear power plant to be reduced, making it an inexpensive source of energy for society and the economy.

A similar dependence, although to a lesser extent, can be seen when analysing the sensitivity of the total cost to the extension of the project construction time. For example, the total cost of electricity production from nuclear technology increases by more than 20%, with extension of the nuclear power plant construction time by 5 years. By comparison, the same period of construction time extension for the CCGT gas technology causes the total cost of electricity production to increase by just 5%.

It should be emphasised that the discounted total levelised cost of electricity generated in nuclear sources clearly depends on the capacity factor. The analyses show that the cost may from more than 750 PLN/MWh, in a situation where the capacity factor is 30%, even down to approx. 300 PLN/MWh when the factor is 90% (at WACC=6%). This is a relatively the biggest decrease in the total leveraged cost among all conventional sources. In case of RES, the initial steep decrease in total cost with an increase of the capacity factor slows down after its value reaches approx. 25-30%, due to increasing share of system costs.

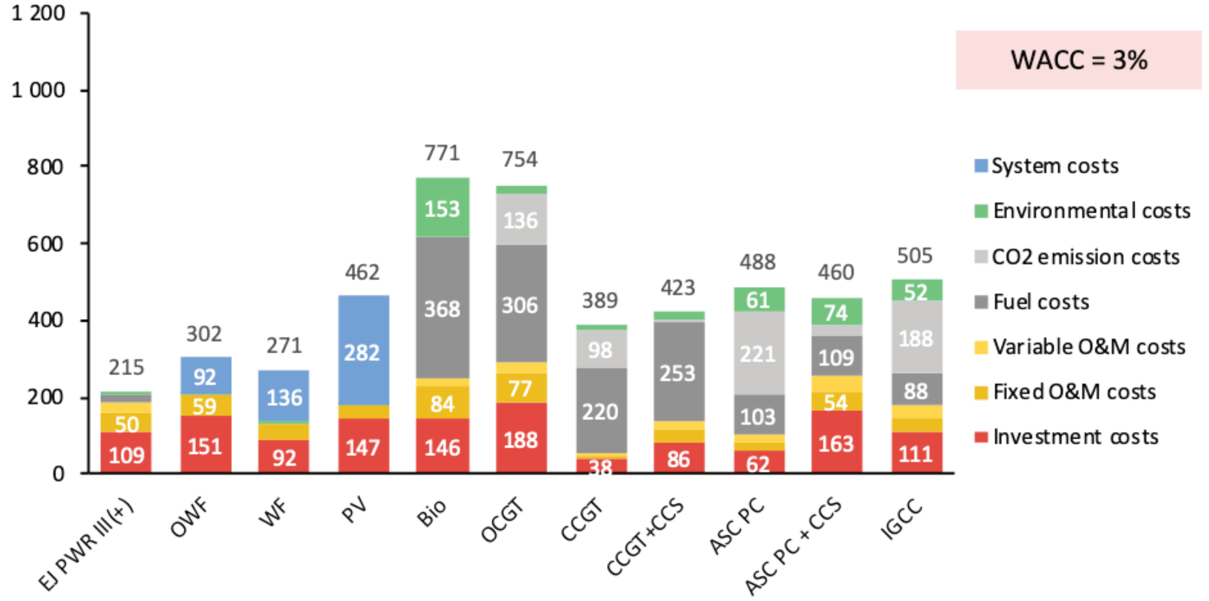
Nuclear power is a technology in which the cost of electricity depends the most on capital expenditure incurred. A sensitivity analysis shows that an increase (decrease) of the expenditure by 50% causes an increase (decrease) of the total levelised cost by 25% to 41% depending on the cost of capital assumed. High sensitivity to a change in expenditure level is characteristic of this technology. Similar dependencies (albeit smaller) can be seen in the case of offshore wind farms and coal sources with CCS. As with the cost of capital and extension of construction time, the lowest sensitivity to a change in capital expenditure occurs in the case of gas sources.

A reverse situation occurs in testing the sensitivity of the total cost to the primary fuel price. The share of fuel costs in the price of electricity produced in nuclear sources represents a small fraction of the costs. For this reason, the price sensitivity to a change in the cost of this fuel is also very low. The above analyses show that an increase (or decrease) in fuel price causes an increase of the total cost of electricity production from nuclear sources by just 2% to 6% depending on the cost of capital assumed. By comparison, the same change of the gas price causes a change on the total cost for CCGT sources by 24 to %. A high sensitivity to the price of primary fuel is also shown by biomass-fired sources and, to a lesser extent, coal sources. The sensitivity of the total cost of renewable energy sources, owing to the lack of primary fuel, is zero; however, the need to provide for the necessary capacity reserve in the event of inadequate weather conditions must be kept in mind.

Nuclear power, as a zero-emission source, does not have to incur costs of CO_2 emission allowances. As is the case with renewable energy sources, the increase in CO_2 emission allowance prices has no impact whatsoever on an increase of the total cost of electricity generated by those sources. The highest sensitivity to a change in CO_2 emission allowance prices are shown by coal sources and, to a lesser extent, gas sources.

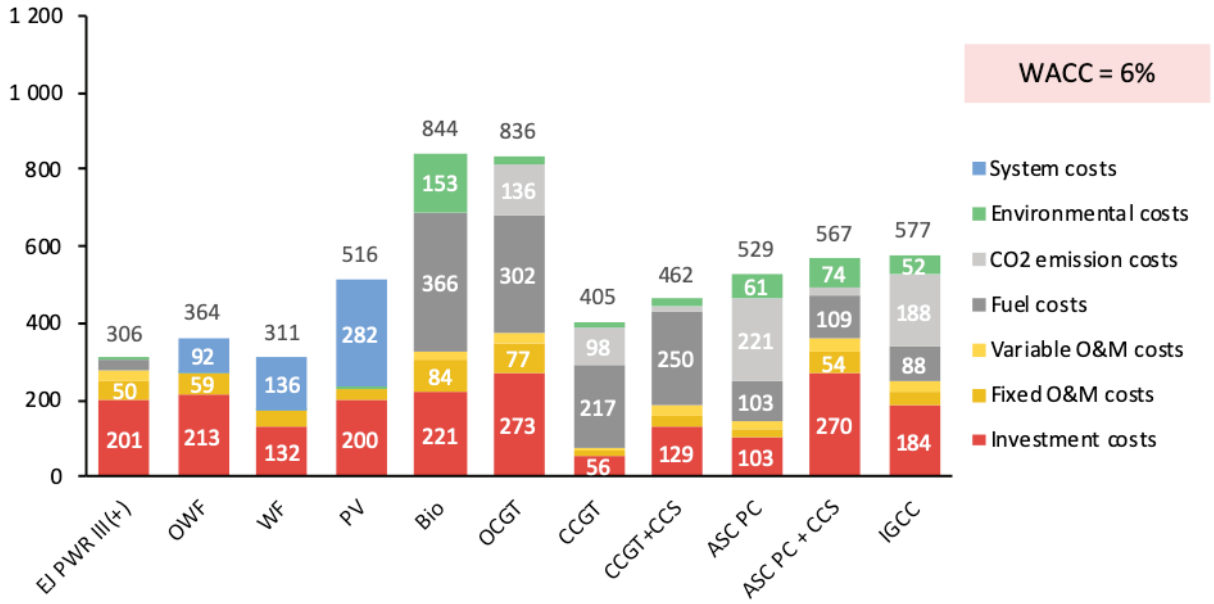
According to analyses, an increase of those prices by 50% causes an increase of the total cost of electricity generated from coal sources by 17 to 23% and an increase in the total cost of gas sources by 11 to 13%. This is particularly important in the context of the EU climate policy and its impact on the Polish generating assets. Again, the need to ensure capacity reserve for uncontrollable RES indirectly increases the sensitivity of the whole energy mix to the prices of the primary source used in the reserve.

Chart 1. 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.



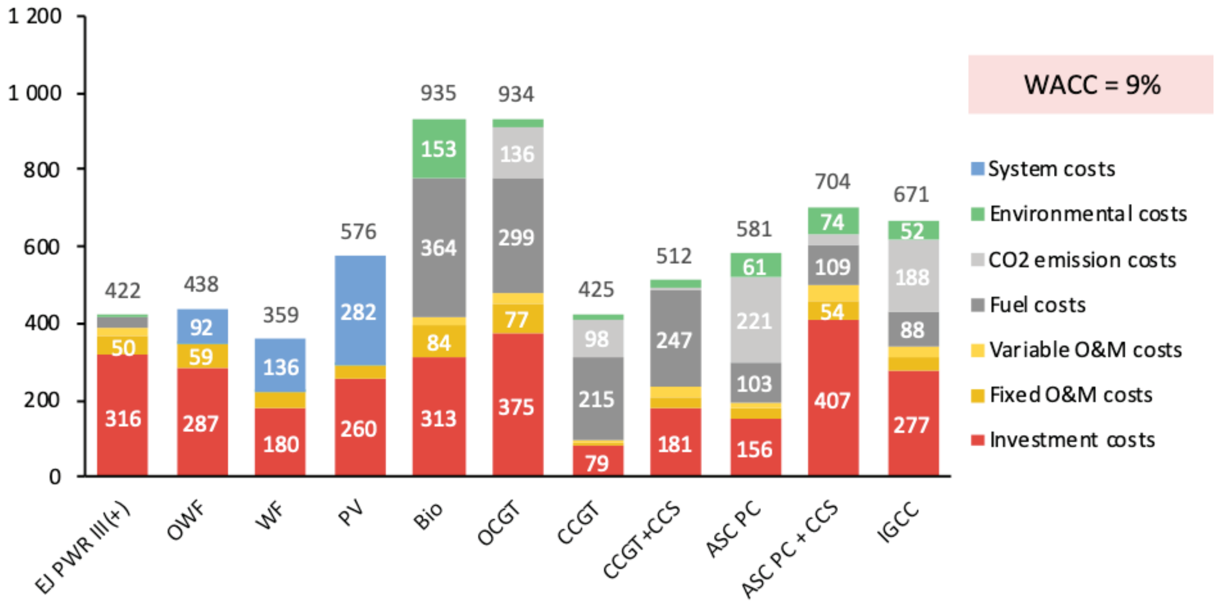
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 2. Decomposition of the total levelised cost of electricity (T-LCOE):
WACC = 6%; power generation technologies commissioned in 2035; 30% penetration of the given variable RES technology in the system.



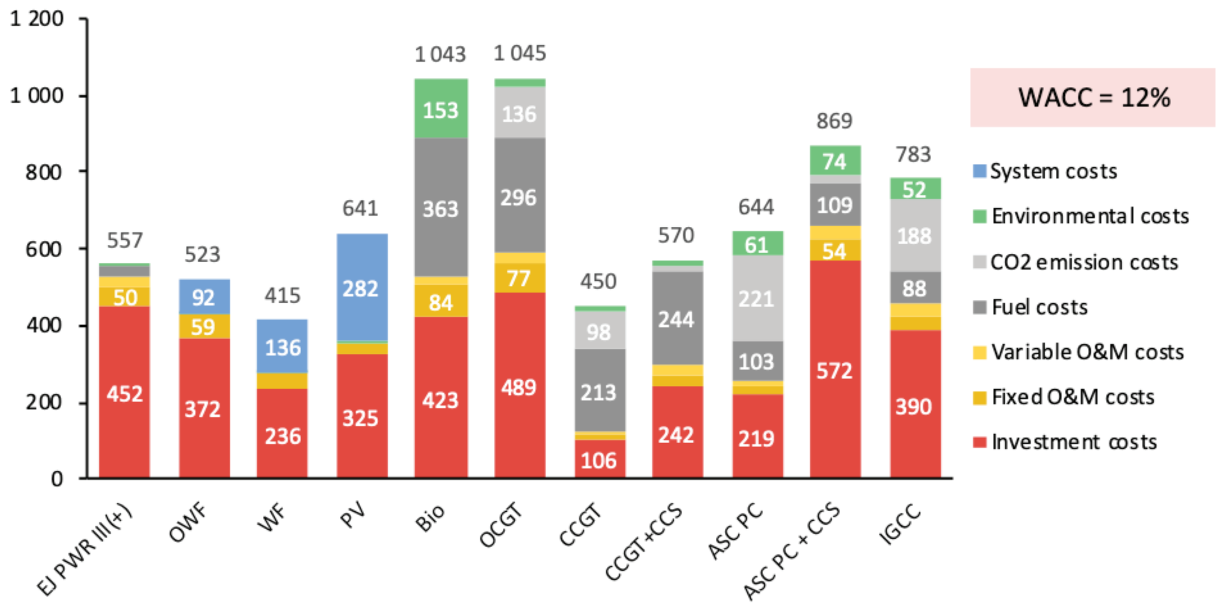
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 3. Decomposition of the total levelised cost of electricity (T-LCOE):
WACC = 9%; power generation technologies commissioned in 2035; 30% penetration of the given variable RES technology in the system.



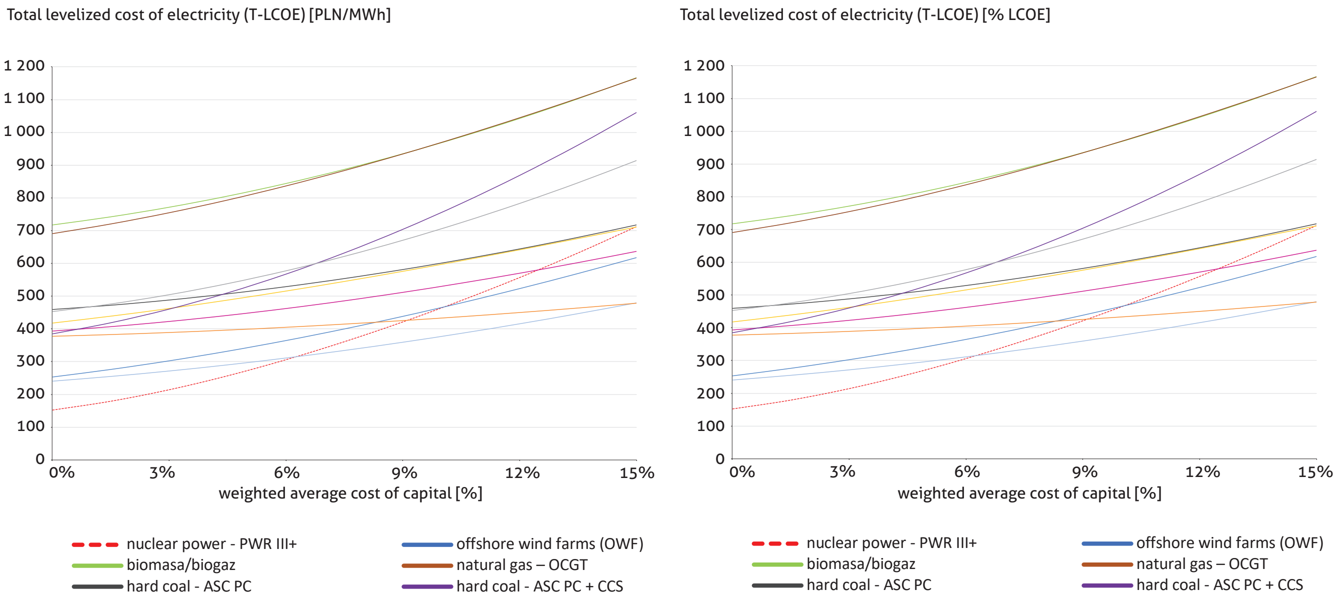
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 4. Decomposition of the total levelised cost of electricity (T-LCOE):
WACC = 12%; power generation technologies commissioned in 2035; 30% penetration of the given variable RES technology in the system.



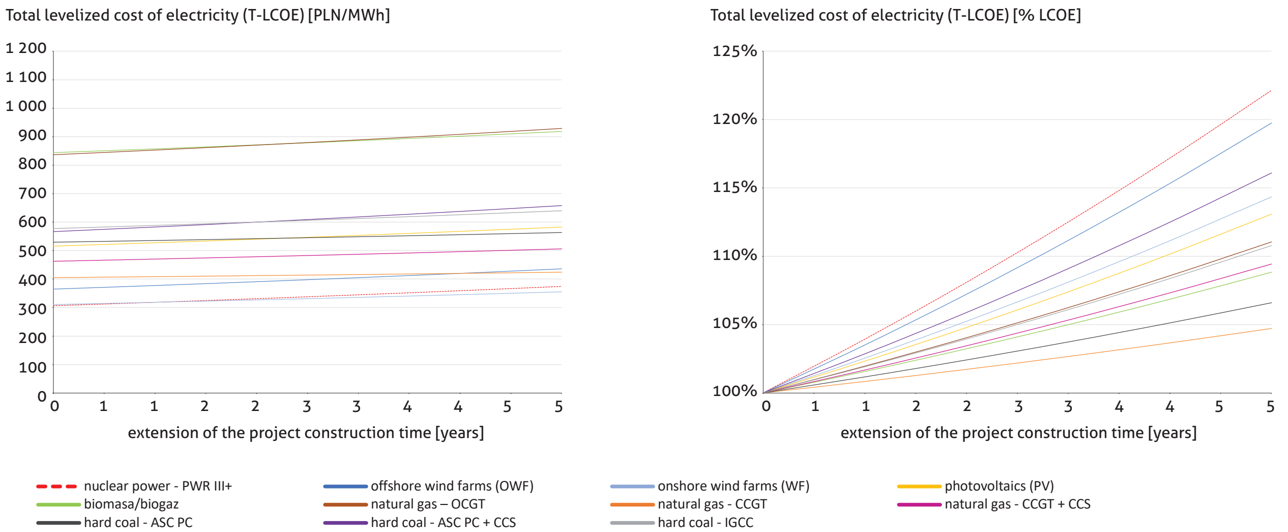
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Charts 5 and 6 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.



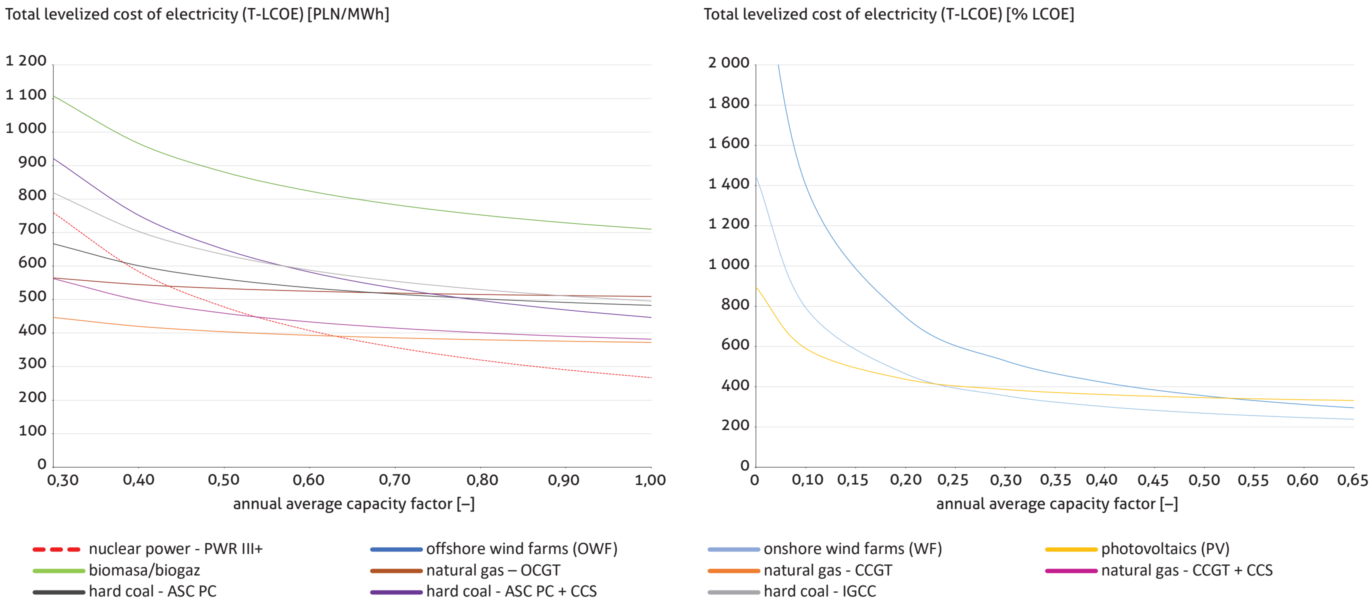
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Charts 7 and 8 Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035
Variable: extension of the project construction time
Constant: WACC – 6%, 30% penetration of the given RES technology n the system.



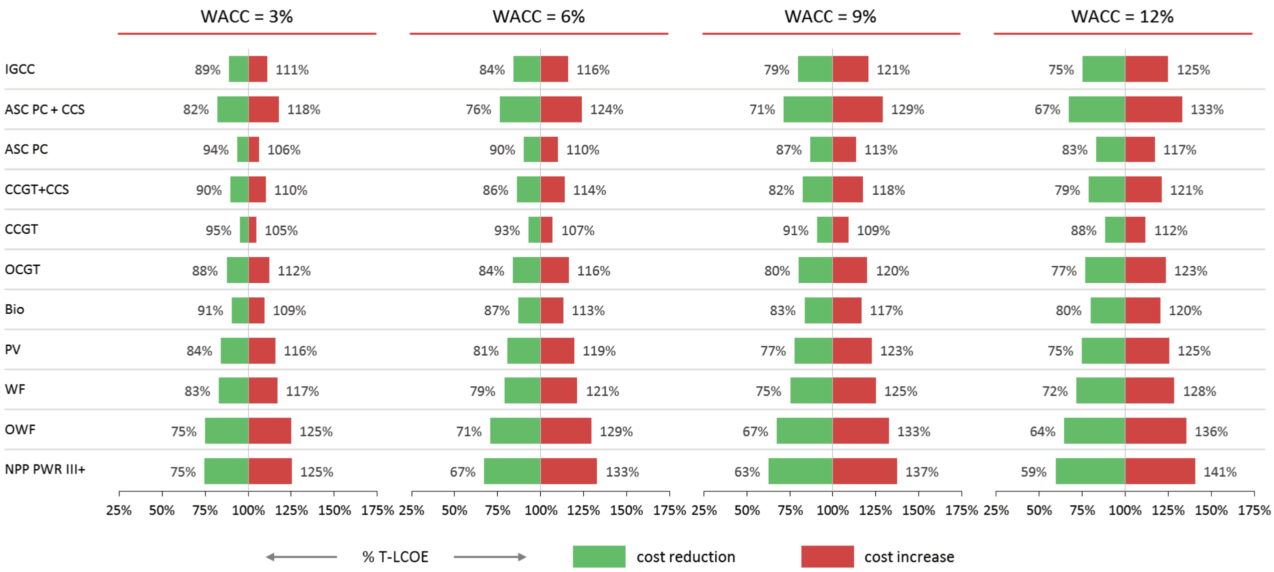
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Charts 9 and 10 Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035
Variable: capacity factor (CF);
Constant: WACC – 6%, 30% penetration of a given variable RES technology in the system.



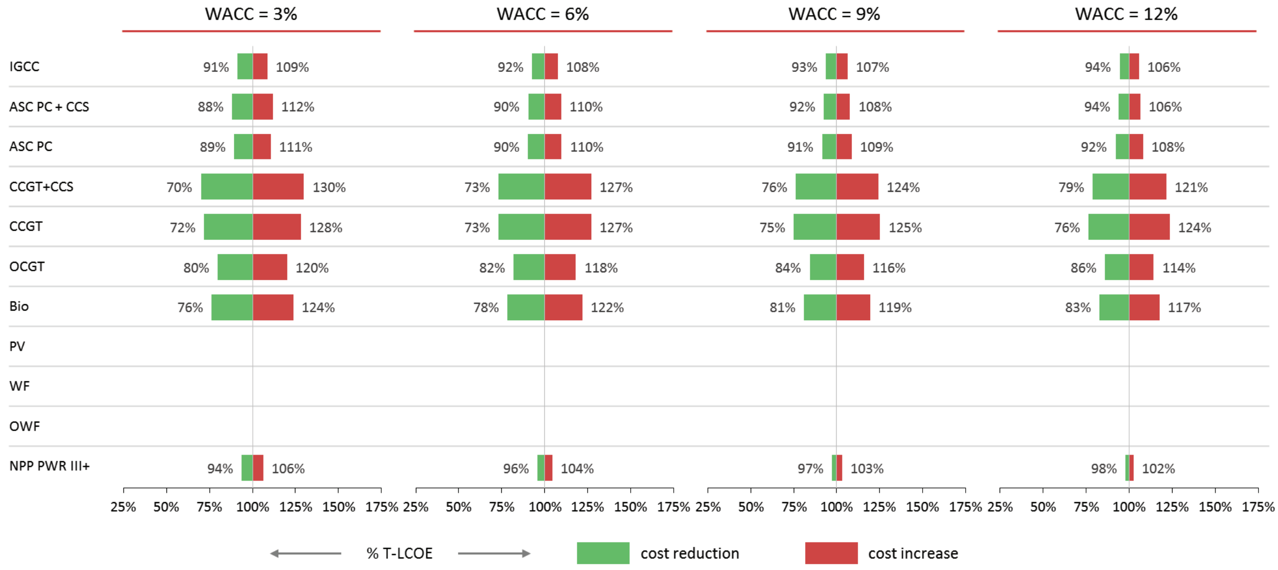
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 11. Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035
Variable: amount of capital expenditure, contractual (+/–50%, 30% penetration of the given RES technology in the system.



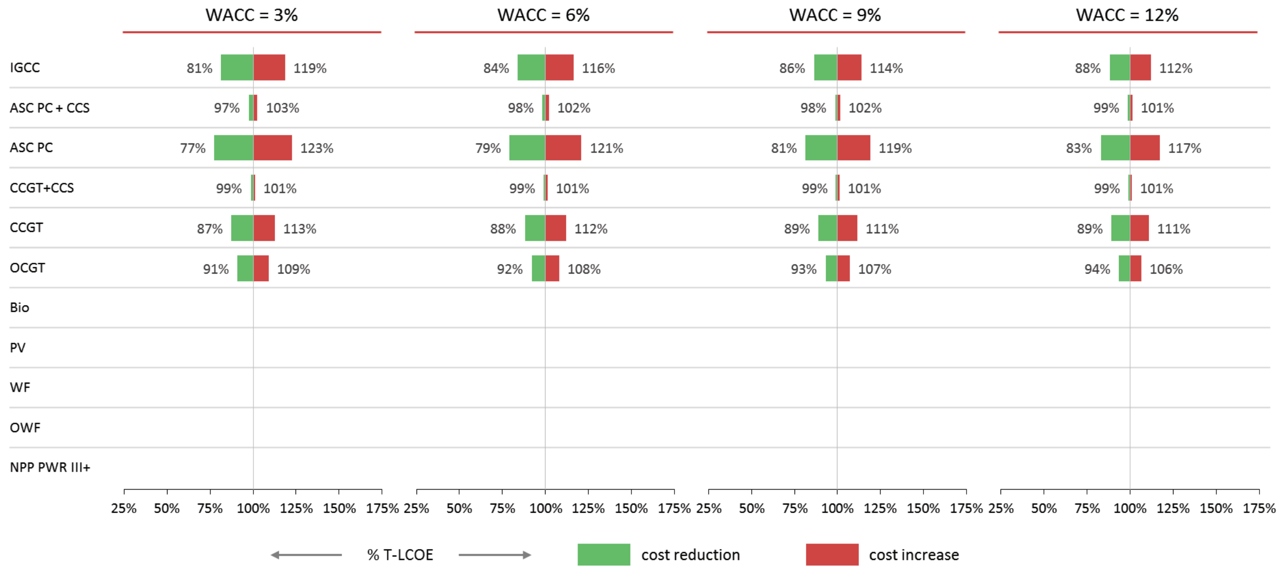
Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 12. Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035
Variable: price of primary fuel (+/-50%).



Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Chart 13. Sensitivity analysis of the total levelised cost of electricity (T-LCOE) in 2035
Variable: CO_2 emission allowance price (+/-50%).



Source: Analysis by the Office of the Government Plenipotentiary for Strategic Energy Infrastructure

5. Main technical and economic assumptions

The technical and economic assumptions adopted have been consulted and their direction is aligned with the assumptions adopted by the transmission system operator for long-term forecasting of changes in the generation structure of the power sector. All economic indicators used in the study have been adopted on the basis of forecast paths described as realistic or medium. Optimistic and pessimistic forecasts were disregarded owing to the inability to determine the actual cost technologies, especially in the case of new branches of the sector that may emerge in Poland such as offshore wind farms, nuclear power or CCS technologies. The adoption of medium values was considered as the most rational assumption carrying the lowest risk of overestimating or underestimating of technology costs.

All cost values presented in the document were expressed in constant PLN2018 prices. Cost indicators expressed in constant prices of a different base year and in a different currency were indexed using the inflation presented by the World Bank (CPI) and the European Central Bank (HICP) according to the area and currency, and converted to the Polish currency (PLN).

For the purposes of the analysis, the average annual values of the power utilization factors and the efficiency of electricity generation were used. This approach is to reflect the real working conditions of particular technologies in the power system, in which the units do not operate in accordance with the nominal conditions declared by technology producers.

Table 1. Contract unit capital expenditure – Overnight Cost (OVN) [PLNm/GW net]

	2020	2025	2030	2035	2040	2045
Nuclear power – PWR GEN III(+)	22 346	21 657	21 147	20 576	19 996	19 444
Offshore wind farms (OWF)	15 010	13 396	11 953	10 692	9 590	8 627
Onshore wind farms (WF)	6 462	5 880	5 298	5 032	4 761	4 486
Photovoltaics (PV)	3 903	3 518	3 129	2 956	2 782	2 632
Biomass	13 802	13 733	13 502	13 233	12 957	12 700
Natural gas – OCGT	2 326	2 203	2 148	2 108	2 078	2 057
Natural gas – CCGT	3 266	3 133	3 069	3 017	2 975	2 942
Natural gas – CCGT + CCS	8 002	7 478	7 155	6 894	6 669	6 471
Hard coal – ASC PC	7 363	7 363	7 363	7 363	7 363	7 363
Hard coal – ASC PC + CCS	20 684	20 113	19 708	19 247	18 776	18 332
Hard coal – IGCC	14 536	13 816	13 434	13 125	12 863	12 643

Source: Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on forecasts of the National Renewable Energy Laboratory (NREL) – ATB'19[52], International Energy Agency (IEA) – WEO'19[53] and Polskie Sieci Elektroenergetyczne (PSE) – PRSP'20[54]

[52] NREL (2019), 2019 Annual Technology Baseline, Mid Scenarios.

[53] IEA (2019), World Energy Outlook 2019, EU Stated Policies scenarios.

[54] PSE (2020), Development Plan for meeting the current and future electricity demand for 2021-2030 – Main document, Analysis of generation adequacy for the years 2020-2030.

Table 2. Unit fixed O&M costs (FOM) [PLNm/GW net]

	2020	2025	2030	2035	2040	2045
Nuclear power – PWR GEN III(+)	371	371	371	371	371	371
Offshore wind farms (OWF)	405	344	292	247	210	178
Onshore wind farms (WF)	156	150	143	138	133	127
Photovoltaics (PV)	47	42	38	35	33	32
Biomass	411	411	411	411	411	411
Natural gas – OCGT	45	45	45	45	45	45
Natural gas – CCGT	39	39	39	39	39	39
Natural gas – CCGT + CCS	124	124	124	124	124	124
Hard coal – ASC PC	121	121	121	121	121	121
Hard coal – ASC PC + CCS	295	295	295	295	295	295
Hard coal – IGCC	199	199	199	199	199	199

Source: Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on forecasts of the National Renewable Energy Laboratory (NREL) – ATB'19

Table 3. Unit variable O&M costs (VOM) [PLN/MWh]

	2020	2025	2030	2035	2040	2045
Nuclear power – PWR GEN III(+)	26	26	26	26	26	26
Offshore wind farms (OWF)	–	–	–	–	–	–
Onshore wind farms (WF)	–	–	–	–	–	–
Photovoltaics (PV)	–	–	–	–	–	–
Biomass	20	20	20	20	20	20
Natural gas – OCGT	26	26	26	26	26	26
Natural gas – CCGT	10	10	10	10	10	10
Natural gas – CCGT + CCS	26	26	26	26	26	26
Hard coal – ASC PC	18	18	18	18	18	18
Hard coal – ASC PC + CCS	37	37	37	37	37	37
Hard coal – IGCC	29	29	29	29	29	29

Source: Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on forecasts of the National Renewable Energy Laboratory (NREL) – ATB'19; VOM for nuclear power plants includes the decommissioning fund charge in accordance with the Regulation of the Council of Ministers of 10 October 2012.[55]

[55] Regulation of the Council of Ministers of 10 October 2012 on the amount of payment towards the costs of the final handling of spent nuclear fuel and radioactive waste as well as the costs of decommissioning of a nuclear power plant by the organisational unit which has obtained the nuclear power plant operation permit (Journal of Laws, item 1213).

Table 4. Price paths of CO_2 emission allowances [EUR2018/tCO_2]

	2020	2025	2030	2035	2040
EU-ETS prices forecast	25	35	54	60	60

Source: Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on forecast of Center for Climate and Energy Analysis, The National Centre for Emissions Management (KOBiZE).

Table 5. Costs of fuel [PLN/GJ] and CO_2 emission allowances [PLN/tCO_2]

	2020	2025	2030	2035	2040	2045
Coal	12,5	10,7	10,9	11,2	11,2	11,2
Biomass (including waste)	23,0	23,6	24,2	24,7	25,3	25,9
Natural gas	26,3	27,3	27,3	28,7	30,4	32,1
Uranium	2,3	2,3	2,3	2,3	2,4	2,4
CO_2 emission allowances	106.6	109.5	118.8	133.9	154.8	181.5

Source: International Energy Agency (IEA) - WEO'19 and Polskie Sieci Elektroenergetyczne (PSE) - PRSP'20; elaboration - Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Table 6. Average annual capacity factor (CF) [%]

	2020	2025	2030	2035	2040	2045
Nuclear power - PWR GEN III(+)	84,2%	84,2%	84,2%	84,2%	84,2%	84,2%
Offshore wind farms (OWF)	44,5%	45,7%	46,9%	48,2%	49,5%	50,8%
Onshore wind farms (WF)	35,4%	36,2%	36,9%	37,6%	38,4%	39,1%
Photovoltaics (PV)	10,6%	11,5%	12,4%	13,2%	14,1%	15,0%
Biomass	56,0%	56,0%	56,0%	56,0%	56,0%	56,0%
Natural gas – OCGT	6,7%	6,7%	6,7%	6,7%	6,7%	6,7%
Natural gas - CCGT	49,0%	49,0%	49,0%	49,0%	49,0%	49,0%
Natural gas - CCGT + CCS	49,0%	49,0%	49,0%	49,0%	49,0%	49,0%
Hard coal - ASC PC	62,8%	62,8%	62,8%	62,8%	62,8%	62,8%
Hard coal - ASC PC + CCS	62,8%	62,8%	62,8%	62,8%	62,8%	62,8%
Hard coal - IGCC	62,8%	62,8%	62,8%	62,8%	62,8%	62,8%

Source: National Renewable Energy Laboratory (NREL) - ATB'19, Polskie Sieci Elektroenergetyczne (PSE) PRSP'20; elaboration - Office of the Government Plenipotentiary for Strategic Energy Infrastructure.)

Table 7. Average annual electricity generation efficiency [%]

	2020	2025	2030	2035	2040	2045
Nuclear power - PWR GEN III(+)	32,6%	32,6%	32,6%	32,6%	32,6%	32,6%
Biomass	25,3%	25,3%	25,3%	25,3%	25,3%	25,3%
Natural gas – OCGT	35,4%	36,6%	37,9%	37,6%	37,6%	37,6%
Natural gas - CCGT	51,2%	51,8%	52,4%	52,3%	52,3%	52,3%
Natural gas - CCGT + CCS	45,4%	45,5%	45,6%	45,5%	45,5%	45,5%
Hard coal - ASC PC	38,8%	39,0%	39,1%	39,0%	39,0%	39,0%
Hard coal - ASC PC + CCS	30,9%	33,9%	37,7%	36,9%	36,9%	36,9%
Hard coal - IGCC	40,7%	43,4%	46,5%	45,8%	45,8%	45,8%

Źródło: National Renewable Energy Laboratory (NREL) – ATB’19 oraz dane zagregowane Polskich Sieci Elektroenergetycznych (PSE); opracowanie – Biuro
Source: National Renewable Energy Laboratory (NREL) - ATB’19 and aggregated data of Polskie Sieci Elektroenergetyczne (PSE); elaboration - Office of the Government Plenipotentiary for Strategic Energy Infrastructure

Table 8: Project life cycle – lifetime, construction time [years]; capital expenditure timeline [% CAPEX]

	Lifetime	Construction time	%CAPEX Year 1	%CAPEX Year 2	%CAPEX Year 3	%CAPEX Year 4	%CAPEX Year 5	%CAPEX Year 6
Nuclear power – PWR GEN III(+)	60	6	10%	20%	20%	20%	20%	10%
Offshore wind farms (OWF)	25	3	40%	40%	20%	0%	0%	0%
Onshore wind farms (WF)	25	3	80%	10%	10%	0%	0%	0%
Photovoltaics (PV)	25	1	100%	0%	0%	0%	0%	0%
Biomass	30	4	40%	30%	20%	10%	0%	0%
Natural gas – OCGT	30	2	80%	20%	0%	0%	0%	0%
Natural gas – CCGT	30	3	80%	10%	10%	0%	0%	0%
Natural gas – CCGT + CCS	30	3	80%	10%	10%	0%	0%	0%
Hard coal – ASC PC	40	6	10%	20%	20%	20%	20%	10%
Hard coal – ASC PC + CCS	40	6	10%	20%	20%	20%	20%	10%
Hard coal – IGCC	40	6	10%	20%	20%	20%	20%	10%

Source: Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on data from the Fraunhofer Institute[56] (plant lifetime) forecasts of the National Renewable Energy Laboratory (NREL) – ATB’19;

[56] Fraunhofer Institute (2018), Levelized Cost of Electricity – Renewable Energy Technologies, 2018

System costs – own study of the Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on the following sources:

– OECD-NEA (2018), The Full Costs of Electricity Provision,

– OECD-NEA (2012), Nuclear Energy and Renewables: System Effects in Low-Carbon Electricity Systems,

– IEA (2014), The Power of Transformation. Wind, Sun and the Economics of Flexible Power Systems,

– Hirth et. al. (2015), Integration costs revisited – An economic framework for wind and solar variability,

– Ueckerdt et al. (2013), What are the costs of variable renewables?, *Energy*, Elsevier, vol. 63(C),

– AGORA Energiewende (2015), The Integration Costs of Wind and Solar Power,

– Imperial College of London (2013), Grid Integration Cost of PhotoVoltaic Power Generation,

Environmental costs – own study of the Office of the Government Plenipotentiary for Strategic Energy Infrastructure based on the following sources:

– NEEDS (2004-2008) - New Energy Externalities Developments for Sustainability,

– European Commission (1990-2005), External Costs of Energy.

The analytical environment used - PLEXOS software from Energy Exemplar.

The software used for the calculations is a tool with the features of a typical object model. Its main task is to solve a set of equations with a specific objective function, consisting of the performance of the optimization task in the form of minimizing the total cost of electricity generation in the long-term planning horizon. The analyzes are conducted based on the provided input data and the set constraints. The parameterized calculation model makes it possible to find the optimal combination of new investments in the generation sector, with minimum costs of covering the electricity demand in the power system, in a long-term planning horizon.

The formulation of the computational task is realized in the form of the following optimization task (objective function):

$$\min \left\{ \begin{array}{l} \sum_{y}\sum_{g} \mathrm{DF}_{y} \times (\mathrm{BuildCost}_{g} \times GenBuild_{g,y}) + \\ + \sum_{y} \mathrm{DF}_{y} \times \left[\mathrm{FOMCharge}_{g} \times 1000 \times \mathrm{PMAX}_{g} \left(\mathrm{Units}_{g} + \sum_{i \le y} GenBuild\ \mathrm{Units}_{g,i} \right) + \right] \\ + \sum_{t} \mathrm{DF}_{t \in y} \times \mathrm{L}_{t} \times \left[\mathrm{VoLL} \times USE_{t} + \sum_{g} \left(\mathrm{SRMC}_{g} \times GenLoad_{g,t} \right) \right] \end{array} \right\} \quad (1)$$

Where:

$GenBuild_{(g,y)}$ - number of generating units built in the year y for the generator (technology) g,

$GenLoad_{(g,t)}$ - load level of the generating unit g in period t,

USE_t – energy not served in the t band allocated to generation units,

D – discount rate, where $DF_y = 1/(1 + D)^y$ is the discount rate applied for the year y, and DFt is the discount factor in period t,

L_t - duration of load distribution in period t [hours],

$BuildCost_g$ - overnight build cost of for each new build generation unit g [PLN],

$PMAX_g$ - maximum generation capacity from each generation unit g [MW],

$Units_g$ - number of installed generating units of the generator g,

VoLL - costs resulting from the loss of load (Value of Lost Load) [PLN/MWh],

$SRMC_g$ - short-term production cost for generator g determined in accordance with the formula: unit fuel consumption for electricity production x fuel price + unit fuel consumption for electricity production x fuel CO_2 emission factor x price of CO_2 emission allowances + other variable costs (including system costs and environmental) [PLN/MWh],

$FOMCharge_g$ - fixed costs resulting from the maintenance and maintenance of the generator g [PLN].

The basic constraints of the objective function include:

– equation of the power balance in a given system operation state in a given period,

– individual limitations resulting from technical power limitations (e.g. minimum / maximum / flexibility) of existing and under construction units,

– limitation / enforcement of the total capacity installed of units from a given technology,

– taking into account emergency shutdowns and maintenance shutdowns,

– fuel and production restrictions - e.g. daily and annual limits,

– emission limits,

– enforcement of the requirement to meet the RES target (in the power industry),

– restrictions on adapting generating units to environmental requirements.

The tool is highly flexible in the configuration of activities. It allows to specify very detailed input data or estimate reliable results from the limited amount of available data. The basic input data used for the calculations are::

– hourly forecast of energy demand,

– prices of fuels and CO_2 emission allowances,

– technical and economic parameters of the existing generation sources,

– technical and economic parameters of potential new generation sources,

– profiles of energy production in non-dispatchable sources: wind, photovoltaic, water, as well as in cogeneration units,

– determination of the required system reserve in the power system.

The conducted analyzes allow for the preparation of summaries of output data concerning, among others:

– directions of development of generation sources,

– electricity generation from every energy sources and individual generating units,

– fuel consumption and CO_2 emissions,

– available generation capacities and their withdrawals,

– costs and expenditures related to the power system.

List of abbreviations and acronyms:

LCOE – Levelized Cost of Electricity,

OZE – pol. odnawialne źródła energii – renewable energy sources,

N-OZE – variable renewable energy sources,

NPP PWR III(+) - Nuclear Power Plant with Pressurized Water Reactor of generation III or III+,

OCGT –Open Cycle Gas Turbine,

CCGT –Combined Cycle Gas Turbine,

CCS –Carbon Capture and Storage,

ASC PC –Advanced Supercritical Pulverized Coal,

ASC + CCS - Advanced Supercritical Coal Power + Carbon Capture and Storage,

IGCC – Integrated Gasification Combined Cycle (coal fired in the analysis).

Appendix 6. Conclusions of the strategic environmental impact assessment

An assessment of the effects of implementation of the *PNP Programme* is provided in the Environmental Impact Forecast. Conclusions of the strategic assessment, containing the rationale for the Programme adopted were provided in the document titled "Written summary containing the results of the strategic environmental impact assessment and rationale for the choice of the Polish Nuclear power Programme". The following provisions have been introduced to the *PNP Programme*, by this Appendix, resulting from the strategic environmental impact assessment performed:

- the primary objective and positive environmental effect of the implementation of the *PNP Programme* is to be the minimisation of negative impacts currently related to the operation of the energy sector, in particular by reducing social costs associated with energy production as well as the reduction of greenhouse gas emissions.

- from the point of view of environmental impact, the selection of sites of future nuclear power plants is an extremely important aspect. In selecting the location, technological capabilities and economic efficiency of heat and electricity cogeneration in a NPP should be taken into consideration and analysed. As demonstrated in the Environmental Impact Forecast, it is a variant that allows negative environmental effects of the NPP to be significantly minimised. The possibility of using a cogeneration system should be one of the factors to be considered in selecting a site for the first nuclear power plant in Poland.

- **Activities limiting the possible scale of social conflicts**
  The development of new directions of electricity generation in Poland, in particular the development of nuclear power, requires social consent and acceptance. The development of nuclear power should be conducted in such a manner as to prevent the escalation of potential social conflicts, ensuring full transparency of activities and dialogue with all stakeholders. Apart from following best practices and using best technologies that ensure nuclear power plant safety and security, it is important to achieve the intended objectives by supplying of inexpensive and "green" energy, taking care of the condition of the environment and improving the quality of life of the population.

  Finally, nuclear power plants must become an element that diversifies energy sources, while leading to meeting of the needs and ensuring the country's energy security. Each citizen must have the inalienable right to be informed about the functioning of the power plant and its impact on the surrounding environment (insofar as such information poses no threat to the security of the plant).

  To this end, the implementation of an information and education programme is absolutely necessary. Yet, such a programme must not be a propaganda for nuclear power. Instead, it should provide the public with reliable information, pointing out the strengths and weaknesses of nuclear energy and defining its place among the other methods of energy generation.

- **Activities during the environmental impact assessment phase**
  Taking into account, in a comprehensive manner, the necessary infrastructure which must be built for NPP site and issuing one decision on environmental conditions for the entire project.

  An application for the issue of the decision on environmental conditions should be submitted upon completion of expert studies aimed to assess the environmental impact for at least two equivalent site locations. The selection of the final site should be made after the preliminary assessment of the NPP's environmental impact is completed. The results should be published and made available to the public. It is only on the basis of the information obtained that the site should be chosen. An application for the decision on environmental conditions will be submitted for the selected site location. Such approach will guarantee that environmental protection issues will be considered at the same level of significance as social and economic issues.

Appendix 7. References to other strategic documents

Plans for the introduction of nuclear power have remained an area of focus for the Polish state for a long time. In 1990, despite the closure of the NPP Żarnowiec project, both the Council of Ministers in its *Assumptions of State Energy Policy to 2010*, and the Sejm in its resolution on that documents[57] expected the possibility of nuclear power implementation after the year 2000. In 2005, the Council of Ministers decided to include nuclear power in the *Energy Policy of Poland to 2025*[58] in order to diversify energy sources and reduce carbon dioxide and sulphur emissions. Another document of very high significance for further work on the implementation of nuclear power in Poland was Resolution of the Council of Ministers No. 4/2009 of 13 January 2009[59] finding it necessary to prepare *the PNP Programme.* As a complementary document the above resolution, on 11 August 2009 the Council of Ministers adopted the framework timeline for nuclear power. In 2011, on proposal from the Council of Ministers, the Sejm adopted a package of acts enabling the construction of nuclear power plants in Poland (with only 1 vote against). The legislative package was widely consulted with the public in several stages (draft assumptions, draft act, regulations). In 2014, the Council of Ministers adopted the *PNP Programme* after several rounds of in-depth and long public consultations, including cross -border consultations[60].

In the current configuration of strategic documents, the *PNP Programme* is consistent with the *Strategy for Responsible Development* (hereinafter: SRD)[61] – a mid-term national development strategy. The SRD chapter "Energy" contains the objective "Ensure common access to energy from different sources", which is being implemented through "Intervention Direction IV.1. Supporting the acquisition and use of energy from new sources", and, within its framework, the Strategic Project *Polish Nuclear power Programme.* With regard to the *PNP Programme* , the SRD provides for the continuation of work on the programme in order to diversify energy sources, reduce the environmental impact of energy, the development of R&D centres, and Polish industry (including export activities).

In the European dimension, the *PNP Programme* is consistent with the European Commission's 2018 strategy "A Clean Planet for all"[62]. The *Programme* also falls in line with the objectives of the document *European Green Deal*[63] which will replace the Europe 2020 Strategy as the main strategic document for the EU.

The objective of the *PNP Programme* is consistent with the *Energy Policy of Poland to 2030*[64] currently in force, implementing objective No. 4 of the *Policy: Diversification of the energy generation structure through the introduction of nuclear power.* It is also consistent with the draft *Energy Policy of Poland to 2040*[65] implementing direction currently in force, implementing direction No. 5 of the *Policy:* Implementation of nuclear power (objective: reduction of the energy sector's emissions and ensuring operational security of the system). At the same time, implementation of nuclear power is one of the key measures in the "energy security" dimension identified in the *National Energy and Climate Plan*[66]. This measure is characterised by positive interaction with other NECP dimensions: "reduction of emissions" and "scientific research, innovation and competitiveness".

The *PNP Programme* also takes into account the objectives of the sectoral strategy National Environmental Policy 2030 - Development Strategy for the Environment and Water Management[67], in particular its specific objective No. 1 *Improvement of the quality of the environment and environmental safety.*

[57] Resolution of the Sejm of the Republic of Poland of 9 November 1990 on the assumptions for the energy policy of Poland to 2010. (Monitor Polski [M.P.] No.43, item 332).
[58] Energy Policy of Poland to 2025, a document adopted by the Council of Ministers on 4 January 2005 (*Monitor Polski* [M.P.] No. 42, item 562).
[59] Resolution No. 4/2009 of the Council of Ministers of 13 January 2009 on nuclear power development activities (unpubl.).
[60] Resolution No. 15/2014 of the Council of Ministers of 28 January 2014 on the multi-annual programme referred to as the Polish Nuclear Energy Programme (Polish Monitor [M.P.], item 502).
[61] Resolution No. 8 of the Council of Ministers of 14 February 2017 on the adoption of the Strategy for Responsible Development to 2020 (looking forward to 2030) (*Monitor Polski* [M.P.], item 260).
[62] Communication from the Commission to the European Parliament, the European Council, the Council, the European Social and Economic Committee, the Committee of the Regions and the European Investment Bank of 28 November 2018 "A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy", COM(2018) 773 final.
[63] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "The European Green Deal", COM(2019) 640 final
[64] Resolution No. 202/2009 of the Council of Ministers of 10 November 2009 on the "Energy Policy of Poland to 2030" (unpubl.) as amended by Resolution No. 157/2010 of the Council of Ministers of 29 September 2010 (unpubl.). Published in *Monitor Polski* as an appendix to the announcement of the Minister of Economy of 21 December 2009 on the national energy policy to 2030 (*Monitor Polski* [M.P.] of 2010, No. 2, item 11).
[65] Published by the Ministry of Energy on 8 November 2019 [https://www.gov.pl/web/aktywa-panstwowe/zaktualizowany-projekt-polityki-energetycznej-polski-do-2040-r].
[66] The National Energy and Climate Plan for 2021-2030 submitted to the European Commission on 30 January 2019.
[67] Resolution No. 67 of the Council of Ministers of 16 July 2019 on the adoption of the "National Environmental Policy 2030 – Development Strategy for the Environment and Water Management" (Polish Monitor [M.P.], item 794).

The objective of the *PNP Programme* corresponds with the electromobility development programme – one of the flagship SRD projects, and with a key strategic document in this area, i.e. the Electromobility Development Plan "Energy for the Future", adopted by the Council of Ministers on 16 March 2017. The implementation of nuclear power, a zero-emission source of electricity, will enable the basic objective of electromobility development to be achieved, i.e. a dramatic reduction of CO_2 emissions in the transport sector.

„The objective of the PNP Programme is also reflected in a number of other governmental strategic documents:"

- *Strategy for Innovation and Economic Efficiency "Dynamic Poland 2020"*[68];
- *Assumptions of the National Programme for the Development of Low-Carbon Economy*[69];
- *Strategic Adaptation Plan for Climate Change-Sensitive Sectors and Areas to 2020 Looking forward to 2030*[70];
- *Strategy for the Development of the National Security System of the Republic of Poland 2022*[71];
- *National Strategy for Regional Development 2030*[72];
- *Territorial Contract for the Pomorskie Voivodeship*[73].

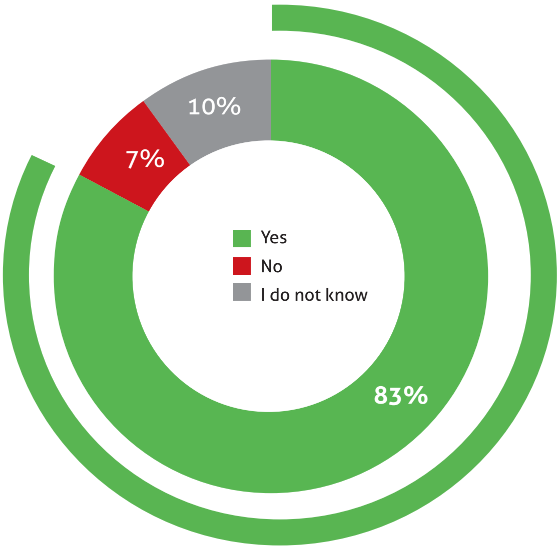
Nuclear power was present also in other strategies, including the *National Development Strategy 2020*[74] and in the Strategy for Energy Security and the Environment – 2020 Perspective[75].

[68] Resolution No. 7 of the Council of Ministers of 15 January 2013 on the Strategy for Innovation and Economic Efficiency "Dynamic Poland 2020" (Polish Monitor [M.P.], item 73).
[69] Minutes No. 33/2011 of the meeting of the Council of Ministers of 16 August 2011.
[70] Minutes No. 46/2013 of the meeting of the Council of Ministers of 29 October 2013.
[71] Resolution No. 67 of the Council of Ministers of 9 September 2013 on the adoption of the "Strategy for the Development of the National Security System of the Republic of Poland 2022" (Polish Monitor [M.P.], item 377).
[72] Resolution No. 102 of the Council of Ministers of 17 September 2019 on the adoption of the "National Development Strategy 2030" (Polish Monitor [M.P.], item 1060).
[73] Resolution No. 234 of the Council of Ministers of 14 November 2014 on the approval of the Territorial Contract for the Pomorskie Voivodeship (Monitor Polski [M.P.], item 1144) as amended by Resolution No. 77 of the Council of Ministers of 19 May 2017 on the approval of the amendment to the Territorial Contract for the Pomorskie Voivodeship (Monitor Polski [M.P.], item 540).
[74] Resolution No. 157 of the Council of Ministers of 25 September 2012 on the adoption of the National Development Strategy 2020 (Polish Monitor [M.P.], item 882).
[75] Resolution No. 58 of the Council of Ministers of 15 April 2014 on the adoption of the "Strategy for Energy Security and the Environment – 2020 Perspective" (Monitor Polski [M.P.], item 469).

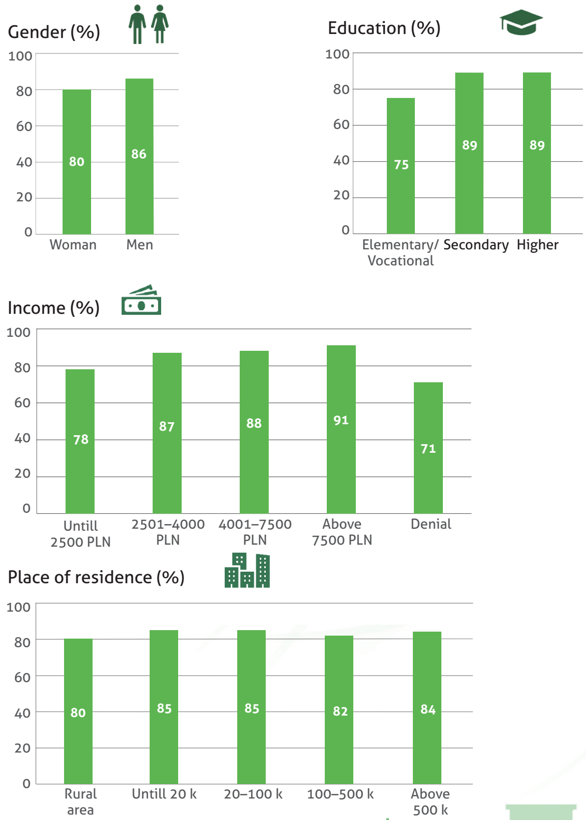
Appendix 8. Opinion poll results

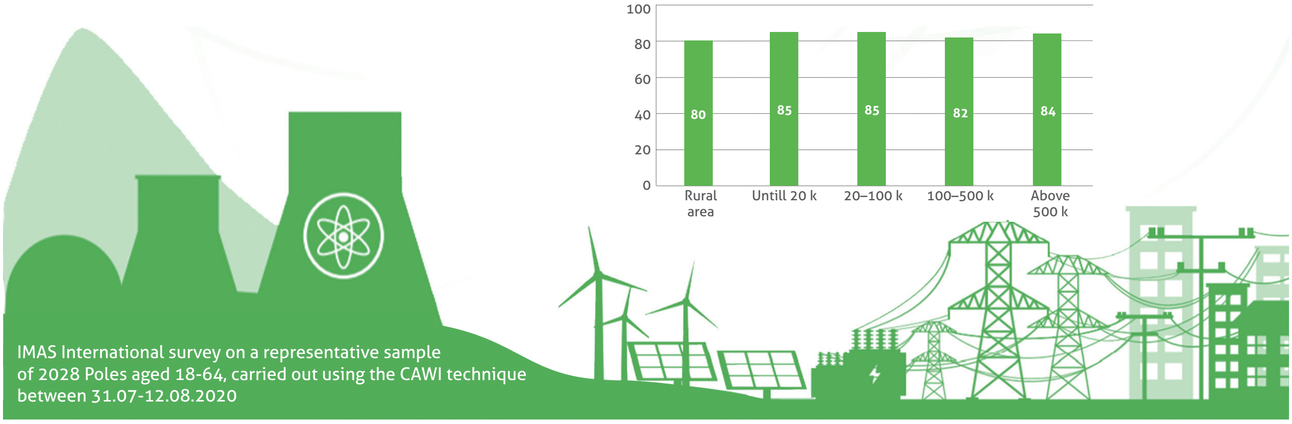
Is a nuclear power plant in Poland needed?

Do you need nationwide broad information and education activities that provide the society with up-to-date, objective and reliable knowledge in the field of energy and nuclear power?



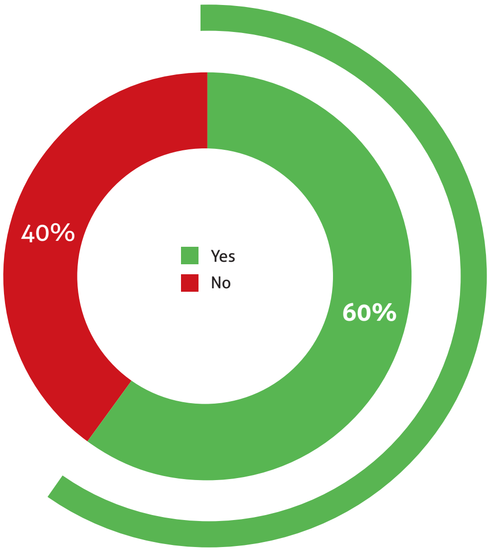
The following groups of respondents spoke out in favor of information and education activities



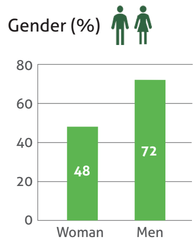


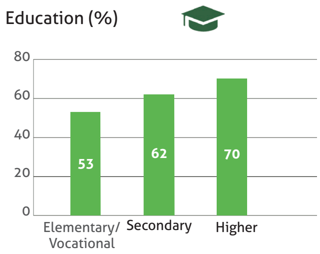
IMAS International survey on a representative sample of 2028 Poles aged 18-64, carried out using the CAWI technique between 31.07-12.08.2020

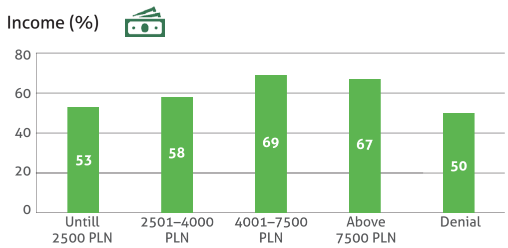
Do you have knowledge about plans to build nuclear power plants in Poland?

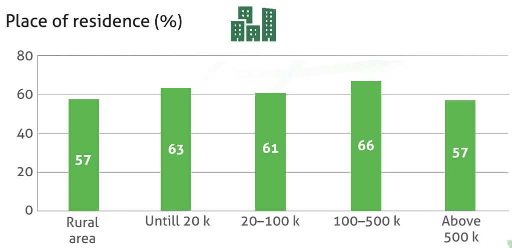


How the YES responses of the respondents from particular groups were shaped









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