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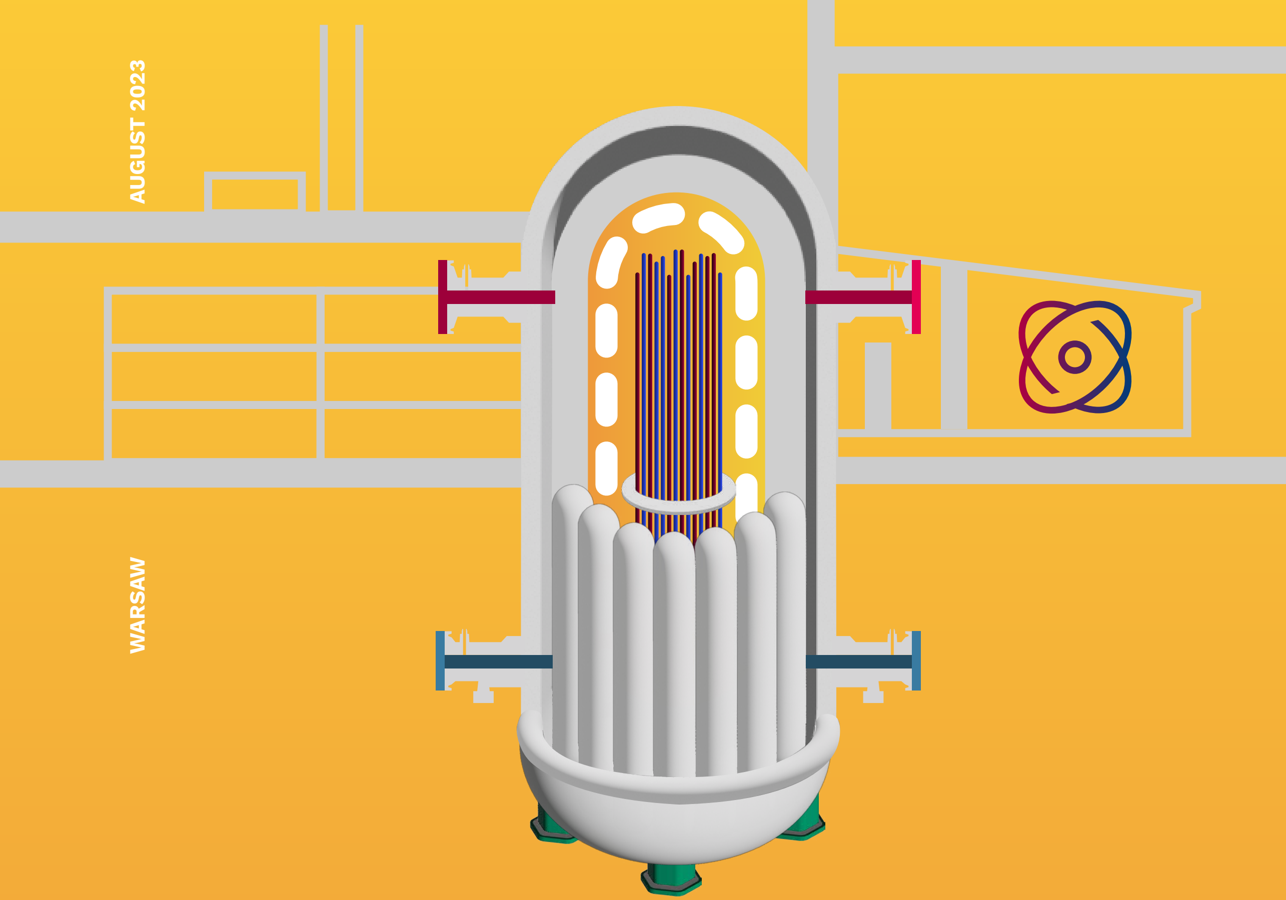

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Prospects for the use of SMRs in Poland’s energy transition

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Key numbers

3 SMRs

operating based on the cogeneration model (the simultaneous production of heat and electricity) could provide 60% of the system heat needed by Warsaw

half

the experts surveyed believe that producing at least 20% of system heat for Poland's largest agglomerations using SMRs would be of great importance for the country's energy transition

67% of the experts

believe that, in the future, SMRs could meet at least 20% of the demand for system heat in Poland's ten largest agglomerations

42%

of the experts believe that the installed capacity of SMRs in Poland will exceed 5 GWe between 2041 and 2045

88%

of the experts believe that social acceptance for SMRs will be similar or greater than that for large-scale nuclear energy

4.4 points

on a scale of 0 to 5 — significance of high prices of CO_2 emission allowances for the development of SMR technology in Poland (this factor received the highest score)

over 70 designs

of various SMRs are currently being developed around the world; most of them are still at the (conceptual or advanced) design stage

over 100

number of SMRs set to be built in Poland, according to official announcements

10:1

ratio between supporters and opponents of using the latest nuclear technologies to produce electricity in Poland

Key findings

- **The purpose of this report is to present experts' opinion on the speed at which SMR projects are developing in Poland.** The Russian invasion of Ukraine has urged Poland to make changes to its energy policy. With investment in large-scale power plants in Poland underway and considerable interest in SMR projects, it is worth analysing the potential problems when it comes to bringing them to life. They are of key importance in Poland's Energy Policy until 2040 and will be one of the factors increasing the country's energy sovereignty.

- **Many of the experts indicate that — while they could play a significant role in the decarbonisation process — building SMRs does not remove the need to invest in renewable energy sources (RES) and large-scale nuclear energy.** They point out that, while there is potential to use SMRs to produce electricity (mainly for industry's own needs) and heat (both systemic and industrial), not a single reactor of this kind has started operating in Western countries so far. For this reason, they were somewhat sceptical about the announcement that the first SMRs in Poland will be built before 2030; 58% of them believe that they will start operating in 2036-2040. The progress of projects in the US, Canada, Britain and the EU countries taking steps to implement SMR technology (France and Romania) will show whether these timeframes are realistic.

- Assessments of the speed at which SMRs are developing and their significance in the global energy transition vary greatly. **According to the most optimistic forecasts by the Nuclear Energy Agency, SMR units' installed capacity could exceed 375 GWe in 2050.**

- **According to the experts surveyed by the PEI, SMRs' most important role in Poland's energy transition could be their use in heat production.** In contrast, their contribution to producing low-emission hydrogen will be the least significant.

- **The experts consider high CO_2 emission allowance and fossil fuels prices the most important factors supporting the rapid development of SMRs.** In their opinion, support from EU funds is the least important.

- **According to the experts, the main barriers that could hamper SMRs' development in Poland are the lengthy procedures (the process of obtaining approval and permits for building reactors), the lack of human resources, and the high cost of the investments.** Polish companies' lack of experience when it comes to nuclear energy investments and potential delays caused by the newness of the technology and the high demand on the European market, which may exceed manufacturers' ability to fulfil orders on time, are significant, too.

- **The experts consider potential social opposition to the construction of SMRs the least significant barrier;** as many as 88% of them believe that the level of social acceptance for SMRs will be similar to or greater than that for large-scale nuclear energy. In Poland, 84% of respondents support using the latest nuclear technologies to produce electricity, 15 pp more than in France and Sweden, and 23 pp more than in the US.
- **Representatives of Poland's largest cities are less enthusiastic about SMR technology than the general public.** They do not rule out using it in the future, especially to produce heat by cogeneration. However, they point out that this is not being considered at the moment, even in long-term strategies, due to the lack of technology on the market and the installations' potentially high costs. **Even in Poland's richest cities such as Warsaw or Gdańsk there is an expectation that the investment would be mostly financed by the central authorities or the largest energy companies.**

Introduction

The need for a rapid energy transition has forced countries to return to the idea of using smaller energy generation units. The rapid growth of renewable energy sources (RES) – especially solar and wind farms – has shown that, apart from huge energy investments, mainly by the state, there is a need for energy generation units that, due to their much smaller scale, can be financed by private investors.

Nuclear energy has not received much interest among private investors in recent decades due to the high cost and time it takes to build large-scale power plants. SMRs could reverse this trend. The units currently being designed range from micro-reactors with a capacity of a few MW to reactors with a capacity of several hundred MW. A major advantage will also be the modularisation of certain elements, which could be transported to the construction site in the form of ready-to-install modules (Mignacca, Giorgio, Sainati, 2020; Lipka, 2020).[1] According to manufacturers' announcements, this will reduce the time it takes to build the investments significantly.

Many countries — including Canada, the US, France and Britain — have announced public support for the development of this technology. Interest in SMRs is also very high in Poland; when this report was published, the total number of SMRs in Polish entities' declarations exceeded 100.[2] According to announcements, SMRs will also be included in the update to Poland's Energy Policy until 2040 (www1). Some experts are less enthusiastic, pointing out that most of the designs are at an early stage of development. Specialists also note that nuclear projects, especially First of a Kind (FOAK) ones, usually involve delays.

To answer the many questions about SMR technology and its growing importance in the public debate, we decided to examine SMRs' potential in the future of Poland's energy transition. In particular, we wanted to collect and aggregate energy experts' opinions, which we believe are not receiving enough attention in this debate. In the first chapter, we discuss the current state of SMR technology and the steps taken in selected EU countries. In the second chapter, we discuss the advantages and disadvantages of SMRs and review their potential applications, including producing energy for industry, heat generation, and hydrogen production. In the third chapter, we discuss the results of our survey of almost 50 experts on the future of SMRs in Poland. The report ends with a summary.

[1] It should be noted that this applies only to certain components (e.g. steam generating systems). According to the announcement, building most of the SMRs is still expected to last 2-4 years. It is worth noting that modularisation has been used in the nuclear industry since the 1960s and was relatively important in the construction of the AP1000 reactors in Sanmen, for example.

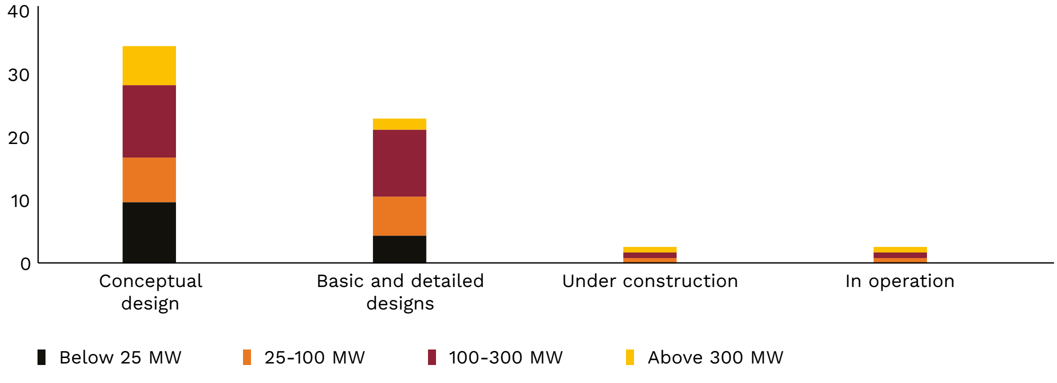
[2] The total number of reactors announced by Orlen Synthos Green Energy, KGHM, Respect Energy and Last Energy, among others.

1. The current state of SMR technology

The World Nuclear Association (WNA) defines Small Modular Reactors (SMRs) as reactors with a power capacity of 300 MW or less, designed with modular technology to enable series production and a short construction time (www2). The International Atomic Energy Agency (IAEA, www3) and the US Nuclear Energy Institute (NEI, www4) define SMRs in a similar way. However, the boundaries remain fluid and this category often includes, for example, the Rolls-Royce SMR, which has a power capacity of 470 MW.

At the end of 2022, the International Nuclear Energy Agency's Advanced Reactors Information System (ARIS) database contained over 40 projects for units referred to as SMRs.[3] These designs have a power capacity of 3.5-630 MW (in practice, this category also includes medium-sized reactors that meet the modularity criterion). The largest number of designs are being developed in the US (13) and Russia (7). If we take into account not only designs at an advanced stage of development, but also those in the initial stages, this number rises to around 70 (www5).

Chart 1. Number of SMR designs, based on stage of development and size (MWe)



Source: prepared by PEI based on IEA data.

[3] According to the IAEA, there are currently over 80 different SMRs designs at various stages of development (including early stages).

SMR designs can be qualified in many ways. The reactor designs currently being developed vary in terms of the coolants and forms of fuel used, as well as the level of technological readiness or progress in the licensing process. However, most SMR projects fall into one of five categories (OECD, 2021):

- **Single-unit** Light Water Reactors (LWRs), which could replace small fossil fuel units or be deployed as distributed generation sources. This type of reactor includes the CAREM, the SMART, the ACP100, the UK SMR (also known as the Rolls Royce SMR) and the BWRX-300.
- **Multi-module** LWRs, which can be used as a substitute for medium-sized baseloads or in a distributed network. This category includes the NuScale, RITM-200 and Nuward reactors.
- **Mobile units** (which currently use LWR technology too) designed to be moved as required. This category includes the ACPR50S and KLT-40S floating reactors used at the Russian floating nuclear power station Akademik Lomonosov, which is already operating.
- **Generation IV SMRs.** They are based on technologies that differ from those used in LWRs and use many of the concepts explored as part of the work on large-scale Generation IV reactors at the Generation IV International Forum. Most of these designs are still in the early stages of conceptual work. Examples include the Xe100, ARC-100, KPR, Natrium and Westinghouse Lead Fast Reactor.
- **Micro Modular Reactors** (MMRs). Designs with a unit capacity of less than 10 MWe, often equipped with a semi-automatic operation function. Due to their size, they are more mobile than larger SMRs. Microreactors are not typically based on LWR technology and are characterised by a wide range of technological approaches, including Generation IV technologies. MMRs mainly meant for work outside the network, in less accessible locations. These reactors are also mostly in the early design stages (with the exception of the US Aurora 2 MWe micro-reactor, which is undergoing the licensing process).

Among the SMRs designs being developed, the following reactors are worth mentioning:

- **NuScale** – one of the best-known SMRs. The company has had its designed approved by the US Nuclear Regulatory Commission and has applied for certification in the US and Canada.[4] NuScale reactors have 77 MW in electrical power and are intended to be offered in 4-, 6- or 12-reactor VOYGR power plant packages (308-924 MWe in total). One module is set to weigh about 700 tonnes and be transported in three parts from the factory to its destination. The fuel cycle is 24 months (www7). The first power

[4] In 2023, NuScale received partial approval from the Nuclear Regulatory Commission in the US, but it concerns a 50 MW reactor design, which the company does not plan to build. The 77 MW reactor must go through a separate licensing process (www6).

plant based on NuScale technology is set to be built in the US in 2029. Cykl paliwowy to 24 miesiące (www7). Pierwsza elektrownia oparta na technologii NuScale ma stanąć w USA w 2029 r.

- **Rolls Royce SMR** – also known as UK SMR, work on this 470 MWe reactor began in 2015. According to the manufacturer's announcement, it is set to be built in 4 years and operate for 60 years (IAEA, 2019); the first reactor will be built in the early 2030s. The high public support from the British government, which backed it with EUR 240 million in 2021 (www8), makes this project stand out. In April 2022, the design was sent to the UK's Office for Nuclear Regulation (ONR) for assessment (www9).
- **BWRX-300** – a small modular Boiling Water Reactor (BWR) with an electrical power of 300 MW with a natural cooling circuit (www10). The first reactor is set to be built at the Darlington power plant, where a large-scale nuclear power plant is already operating, which made it easier to obtain an environmental and location decision. According to GE Hitachi Nuclear Energy, this will make it possible to complete the construction of the reactor in 2028 and launch it commercially in 2029 (www11).
- **CAREM-25** (Central ARgentina de Elementos Modulares) – a small Pressured Water Reactor (PWR) with a block capacity of 32 MWe (CNEA, 2017). In addition to the use of passive safety systems, the entire CAREM core cooling system is housed in a single pressurised tank and uses free convection to circulate the coolant. This removes the need for pumps in the primary circuit and reduces the scope and complexity of the piping system required, as well as the risk of loss-of-coolant accidents. Work on the design began in 2011 and the construction of a prototype on the site adjacent to the Atucha Nuclear Power Plant started in and in 2014 (www12). The contractor, Techint Engineering & Construction, halted construction in 2019 due to delays in government payments and changes to the design (www13). Construction resumed in 2020 and is expected to be completed in 2024.
- **KLT–40S** – the reactor operating on the Akademik Lomonosov floating unit (completed in 2019; construction began in 2007). The plant's total power is 70 MWe (two reactors, 35 MWe each). Its successor is the RITM-200N reactor design being developed in Russia (OECD, 2016).
- **ACP100** – a Chinese PWR with a power of 126 MWe (385 MWt), which, according to the manufacturers, has many potential applications (heat production, electricity production, desalination of sea water). Research on it began in 2010, and the design received a positive opinion from the International Nuclear Energy Agency in terms of safety in 2016. The first reactor of this type is currently being installed on Changjiang Island. Construction began in 2019 and the entire process should last no more than 58 months, according to the manufacturer (www14).

- **Nuward** – presented as the first reactor designed in the EU, it is set to be built by French EDF (Électricité de France) in cooperation with French Alternative Energies, the Atomic Energy Commission (CEA), Naval Grup and TechnicAtome. These are PWR reactors with a power of 170 MWe, which are meant to form two-unit power plants, bringing the total up to 340 MWe (www15). According to EDF, the design phase is set to be completed by 2030 at the latest, including obtaining full certification. The construction of the first Nuward demonstration reactor is supposed to begin in 2030 and take 3 years (www16).

The value of the SMR market was estimated at approximately USD 3.5 billion in 2020. According to market forecasts by Allied Market Research, this will reach almost USD 19 billion by 2030. The speed at which SMRs will develop, the market interest, and therefore the installed capacity, remain to be seen. According to NEA forecasts, in 2035, SMR projects' installed capacity will exceed 20 GW[5] and, in the scenario involving the technology's rapid development, could reach as much as 375 GW by 2050, which would reduce CO_2 emissions by 15 Gt in total (NEA,2021). The British National Nuclear Laboratory forecasts that SMRs' global installed capacity could be in the 65-85 GW range in 2035 (including 7 GW in Britain) and that the market will worth EUR 285-456 billion (www17). In the US, the Nuclear Energy Institute estimates that the SMR installed capacity needed to achieve affiliated institutions and companies climate targets will be 90 GW in 2050 (Derr, 2022).

Many EU countries are expressing an interest in SMR technology. They include:

- Belgium – in May 2022, the country's nuclear research institute received a EUR 100 million grant for the study of SMR technology (Nucleareurope, 2022),
- Bulgaria – in November 2021, state-owned energy company Bulgarian Energy Holding signed a memorandum with Fluor Corporation (associated with NuScale) on the development of SMRs (Nucleareurope, 2022),
- Czech Republic – signed memorandum on cooperation with NuScale, GE-Hitachi, Rolls-Royce SMR, EDF, Korea Hydro and Nuclear Power, and Holtec; the first SMRs are set to be built on the site of the Temelin nuclear power plant (Nucleareurope, 2022),
- Denmark – in April 2022, Samsung Heavy Industries and Danish company Seaborg signed a memorandum on the development of floating nuclear reactors (Nucleareurope, 2022),
- Estonia – projects linked to SMR technology have been developed there since 2019; in February 2023, Fermi Energia announced that the SMR power plant in Estonia will be built on the basis of BWRX-300 reactors (www18),

[5] Results of the positive scenario — in the negative scenario, in 2035 there will be further delays in reactors' development. In that case, SMRs will remain at the research and pilot project stage.

- France – work has begun on the Nuward reactor, with a pilot version expected to be ready in the first half of the 2030s. The French government announced that it will spend EUR 1 billion on the development of SMR technology by 2030; of this, EUR 500 million will go towards the development of the Nuward reactor (Nucleareurope, 2022),
- Romania – at the end of December 2022, RoPower signed an agreement with NuScale for the initial design and engineering assumptions (Front End Engineering Design, FEED). The contract concerns the construction of a six-module VOYGR unit to replace the coal power plant in Doicești (www19),
- Sweden – in February 2022, the Swedish Energy Agency provided Swedish Modular Reactors AB with around EUR 9.4 million to support the construction of a demonstration model of the lead-cooled Swedish Advanced Lead Reactor (SEALER) (www20); In addition, the Swedish company Kärnfull Next signed an agreement with GE Hitachi in March 2022 to distribute BWRX300 reactors, and the construction of SMRs at the existing Ringhals nuclear power plant is also being considered.

In Poland, there is also considerable interest in SMRs. In 2022, PKN Orlen and Synthos S.A. established Orlen Synthos Green Energy S.A. (OSGE), a joint special purpose vehicle that will be responsible for preparing and commercialising SMRs in Poland. The company signed a technological agreement with GE Hitachi Nuclear Energy (BWRX-300 reactors) and agreements with suppliers of power plant components. According to OSGE's announcements, over 300 Polish companies may contract about 50% of the expenses related to the construction of power plants based on BWRX-300 reactors (www21). According to announcements, OSGE wants to build as many as 76 reactors in 26 locations; the first is meant to be built in 2028-2029 (www22; www23). In July 2022, a technology assessment request was sent to the National Atomic Energy Agency (www24).

The company KGHM has also announced that it will invest in SMRs. In contrast to OSGE, the investment would only seek to meet KGHM's demand for electricity; around 3 TWh per year (Pieńkowski, 2022). KGHM plans to build 6- or 12-module VOYGR power plants based on NuScale reactors with a capacity of 77 MWe each. According to announcements, the first of the units is set to be operational as early as 2029. KGHM sent the National Atomic Energy Agency a technology assessment request in July 2022 and signed a cooperation agreement on the development of NuScale reactors with Romanian nuclear power plant operator SN Nuclearelectrica in September that year. The aim of the cooperation, which will last 36 months, is to exchange technical, economic, legal, financial and organisational knowledge and experience (www25).

Other companies in Poland have also expressed an interest in SMRs. They include Ciech (www26), UNIMOT (www27) and Respect Energy, which has signed a cooperation agreement with EDF on the development of Nuward reactors (www28). Last year, several Polish entities (Enea and the Katowice and Legnica Special Economic Zones) also signed agreements with US company Last Energy on the construction of PWR-20 reactors (www29).

2. Advantages and disadvantages of SMRs. Potential future applications

The objections raised against the development of large-scale nuclear power plants include the high cost and long construction time. The two-reactor nuclear power plant based on the currently-available technologies has a capacity of 2.2-3.3 GW and produces 17-26 TWh per year, at a cost of approximately PLN 20 billion per GW. In practice, such big investments are extremely difficult for any investor, apart from the state, to implement.

SMRs are supposed to respond to these challenges with their advantages, which, according to the manufacturers' announcements, include:

- **A very flexible investment.** Many designs — from very small reactors to medium-sized ones — offer considerable opportunities to adapt them to the investor's needs. At the same time, SMRs can be built in more potential locations than large-scale nuclear power plants (OECD, 2021).
- **High safety.** The reactors' lower capacities enable safety arrangements to be simplified and may result in slightly smaller contingency planning zones and restricted use areas around these nuclear facilities. Refuelling is also expected to become less frequent. Current large-scale reactors need to be refuelled once every 1-2 years. For some SMR designs, this could even be once every 3-7 years (Lliou, 2021).
- **Modularity.** The smaller size and weight is meant to enable the mass production of more components, which can be transported and assembled onsite (rather than building from scratch in a given location, as in the case of large nuclear reactors). The modularity of the power plants, which consist of a few or a dozen low-capacity units, reduces the risk of blackout if one of the modules is turned off temporarily, and makes modernisation and refuelling easier to plan.

- **The lower cost and shorter construction time** reduce the risks faced by investors. This makes it possible to attract private capital, whether that means investing in SMRs for one's own needs (industry) or to resell the energy produced (for example, investment funds) (OECD, 2021).

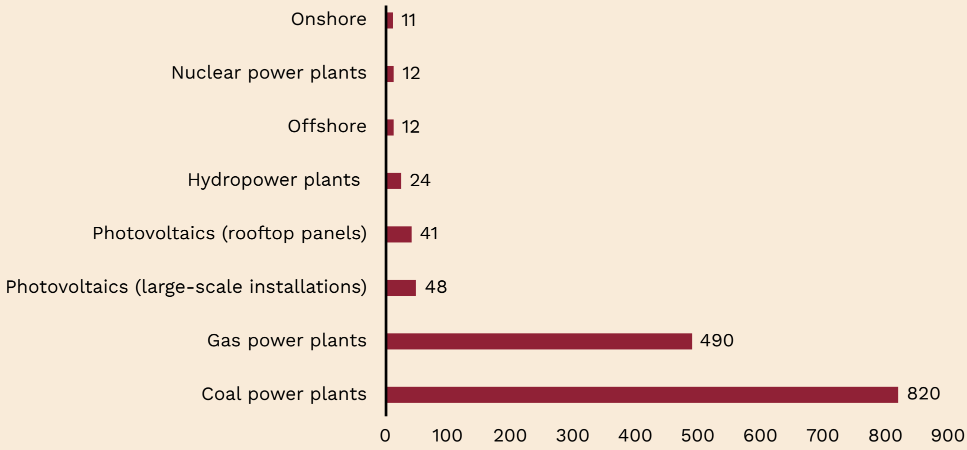
The wide range of possibilities offered by the cogeneration model mean that modular nuclear reactors can be used as power plants stabilising renewable energy sources, serving to produce hydrogen and desalinate water, among other things, when there is an excess supply of energy from RES compared to demand (Locatelli et al., 2018). In addition, some of the reactors will be similar in size and power to the decommissioned units at coal-fired power plants, over 90% of which have a capacity of less than 500 MWe (Juszczak, 2022).

However, experts also point to the disadvantages of SMR technology. The first and most important is the early stage of development: currently, advanced pilot projects only exist in China and Russia. The first SMRs' launch dates have been postponed many times in the past. For example, according to the original schedule, production of modules for the NuScale reactor was set to begin in 2021 and the first power plant based on this reactor was meant to start operating in 2026 (according to current announcements, the first NuScale reactor will start operating in 2029). This translates into a rising cost of installed capacity, which may result in these investments becoming less attractive, compared to other solutions (Lipka, 2020). Another important challenge is to create a supply chain that is shorter — compared to building classic reactors — and will enable reactors to be produced using ready-made components (Lipka, 2020). However, this could reduce domestic companies' ability to be involved in the implementation of the investments (local content). It should also be noted that while, according to announcements, SMRs are meant to lower the cost of building a nuclear power plant, compared to large reactors, this does not translate into a lower cost per MW.

Box 1. The environmental benefits of using nuclear energy

Nuclear power – both large-scale and, according to announcements, smaller reactors — have one of the smallest carbon footprints of any energy source. Over the course of its entire life cycle, which includes fuel extraction, power plant construction, operation and demolition, the average nuclear power plant's emission intensity is 12 gCO_2 eq/kWh. This is similar to that of wind farms, 3.5-4 times lower than in the case of photovoltaics and 68 times lower than for coal-fired power plants (IPCC, 2014). Nuclear power also has the lowest space requirement per unit of energy produced (Brook, Bradshaw, 2015) and one of the lowest eutrophic footprints (emissions in grams of phosphorus equivalent per MWh produced) (UNECE, 2022).

Chart 2. Median emission intensity over the course of the power plant's life cycle (gCO$_2$eq/kWh)



Source: prepared by PEI based on IPCC data.

2.1. Use of SMRs in industry

According to the manufacturers' announcements, SMRs are meant to meet industry's own needs. The rising prices of energy from fossil fuels, which have been named one of the biggest barriers to industry (Jackowiak, 2022; www30), make a low-emission alternative necessary.

In Poland, total energy consumption in the industrial processing sector amounted to 54 TWh in 2020, around 31% of the country's electricity demand. The production of metals (8 TWh), chemicals and chemical products (7.8 TWh) consume the most energy. Electricity consumption in the mining and quarrying sector remains at a similar level (7.9 TWh). Taken together, the most energy-intensive enterprises in Poland consume around 20 TWh per year in total (www31). However, this demand will grow: decarbonisation and the related electrification of Poland's steel industry will increase the demand for electricity from the current 6-7 TWh to as much as 30 TWh or more (www32).

The use of SMR technology in industry is highly dependent on its cost-effectiveness. According to announcements by both NuScale and GE Hitachi, the planned Levelised Cost of Electricity (LCOE) will be USD 50-119 MWh (www33; Weimar, 2021); that is, PLN 207-490/MWh.[6] For comparison, according to the Lower Silesian Institute for Energy Studies, in 2030, the LCOE for 1 MWh from gas sources in Poland may range from PLN 639 to as much

[6] USD/PLN exchange rate on 10.05.2023.

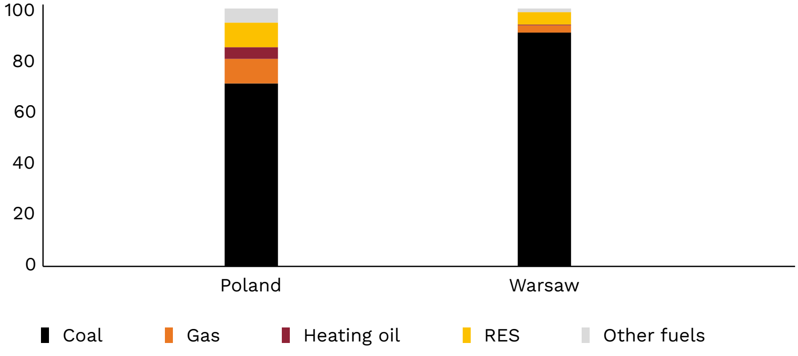
as over PLN 3000 (depending on the price of gas and CO_2 emission allowances; DISE, 2022). The LCOE of individual renewable sources (offshore, onshore, photovoltaics) is estimated at approximately PLN 295-355/MWh (DISE, 2022). This means that if the LCOE remains at the level announced by SMR manufacturers, they could not only compete successfully with fossil fuels, but also be an alternative to certain renewable sources.

SMR reactors might seem like a solution that is only available to the biggest enterprises. This is true when the investor is a single entity. However, there are ways to spread the risk and share the costs of the power plant. One potential model is the Mankala model present in Finland since 1970, which has been used to build most of the large Finnish power plants. It involves bringing together shareholder companies, which jointly finance the project, sharing the costs of building and maintaining the power plant. In return, according to the size of their shares in the power plant, the companies can buy electricity from it at production cost. The company can use the energy or resell it on market terms. The Mankala model accounts for about two-thirds of Finland's total electricity production (Juszczak, 2022). A similar model could be used by Polish enterprises that are interested in energy from SMRs but unable to finance the entire project on their own.

2.2. Use of SMRs for district heating

Poland remains one of the EU countries with the most developed system heating. Over 40% of 13.5 million households are connected to the heating network. It also accounts for about a quarter of the total heat generated (including in industry). In heating networks' installed capacity of 53.5 GW, coal remains the fundamental fuel (71% of the total fuel consumption, around 14.5 million tonnes per year) (Tomaszewski, 2020).

Chart 3. How heat for district heating was generated in Poland and Warsaw in 2020 (%)



Source: prepared by PEI based on City of Warsaw and Polityka Insight data.

One of the cities that could significantly benefit from using SMRs to decarbonise heating is Warsaw. In 2020, the demand for district heating in the Polish capital amounted to 8.9 TWh; of this, as much as 90.7% was generated at heating plants using hard coal (www34). In 2040, the demand for district heating in Warsaw could be higher, reaching as much as 14 TWh. According to the scenarios prepared by the Think Atom think tank, three SMRs with a heating capacity of 400 MWt, intended solely for heating purposes, would cover around 58% of Warsaw's annual heat demand (Think Atom, 2019).

However, the demand for district heating in Poland is subject to big seasonal fluctuations of as much as several hundred percent. This means that using SMRs to produce heat and electricity in cogeneration could be a better model than using them to produce heat only. Three reactors with a heating capacity of around 900 MWt (the equivalent of around 300 MWe) could meet up to 81% of Warsaw's annual demand for heat in 2040, while increasing the production of electricity to the grid between May and September (at a level of around 400-500 MWe), when the demand for heat decreases and the consumption of electricity for air conditioning increases (Think Atom, 2019).

The situation is similar in smaller cities: with demand at 2.5 TWh per year, SMR units focused solely on heat production with a total capacity of 200-300 MWt could meet 50-70% of the demand. If we opt for the cogeneration model (four reactors with a capacity of 200 MWt, which corresponds to around 70 MWe), this share increases to 97% (with the capacity to produce 130-200 MWe of electricity in the summer months) (Think Atom, 2019).

2.3. Use of SMRs for hydrogen production

Like large reactors, SMRs can be used to produce hydrogen — in a cogeneration model or exclusively. In 2020, global hydrogen production amounted 87 Mt (mostly from fossil fuels). According to International Energy Agency (IEA) forecasts, in the scenario of striving to achieve climate neutrality, the global demand for hydrogen will amount to 212 Mt in 2030 (including 150 Mt of low-emission hydrogen), and to 528 Mt in 2050 (including 520 Mt of low-emission hydrogen). 50% of the hydrogen will be used for heavy industry and transport. Another 30% will be processed into other fuels, mainly ammonia for shipping and electricity generation, synthetic kerosene for aviation, and synthetic methane that will be fed into gas networks (IEA, 2021).

According to the IEA's scenario, in 2050, 60% of low-emission hydrogen (312 Mt) could be obtained by electrolysis, with 95% of the electricity used to produce hydrogen coming from RES in 95% and just 3% of it from nuclear power plants. In this scenario, annual purple hydrogen production would amount to around 9 Mt per year, using 351-435 TWh (44.5-55 GW of installed capacity at nuclear power plants). Meeting these needs with SMRs would require the construction of 148 to 184 units with a capacity of 300 MW.[7]

[7] Calculated by PEI.

According to IEA forecasts, in 2050, 40% of low-emission hydrogen will be produced directly from natural gas using carbon capture, utilisation and storage (CCUS) technology. In addition, 2% of the hydrogen generated by electrolysis will be produced using electricity generated from fossil fuels using CCUS. Combined with the 8 Mt of high-carbon hydrogen that would still to be used, this translates into 222 Mt of hydrogen produced using fossil fuels (including 925 bcm of natural gas, which is expected to account for 50% of the total global demand for this fuel).

Increasing the production of purple hydrogen from 9.3 to 23.6 Mt would completely eliminate carbon-intensive hydrogen and the use of electricity from fossil fuels in electrolysis (the "electrolysis without CCUS" scenario). This would require the construction of an additional 68-84 GW of installed nuclear energy capacity compared to the IEA's baseline scenario (227-280 SMR units with a capacity of 300 MW).[8]

However, eliminating hydrogen obtained directly from natural gas using the CCUS process could turn out to be much more difficult — reducing the projected share in global hydrogen production from 40% to 35% in 2050 would require that installed nuclear power capacity increase more than twice as much as in the "electrolysis without CCUS" scenario and over fivefold compared to the IEA's baseline scenario.[9]

Table 1. Scenarios for global hydrogen production in 2050, with the share of purple hydrogen

Scenario	Hydrogen production method				Electricity required to produce purple hydrogen (TWh)	Nuclear power plants' additional installed capacity (GW)	Number of SMR units with a capacity of 300 MW
	Fossil fuels without CCUS (Mt)	RES (Mt)	CCUS natural gas (Mt)	Nuclear energy (Mt)			
IEA	8	296.4	214.24	9.36	351-435	45-55	148-184
"Pure Hydrogen"	0	296.4	214.24	17.36	651-807	83-102	275-341
"Clean Electricity"	0	296.4	208	23.6	885-1097	112-139	374-463
"35% CCUS"	0	296.4	182	49.6	1860-2306	236-293	786-975

Note: according to the IEA, in 2050, producing 312 Mt of hydrogen will require 14,500 TWh, which translates into an efficiency of 46.5 kWh/kg. However, these values vary depending on the electrolysis process. The use of solid oxide cells is expected to require less energy than PEM and alkaline cells — 37.5-39 kWh/kg (Milewski et al., 2021). In our analysis, we adopted 37.5 kWh/kg and 46.5 kWh/kg as the limit values. We assumed a capacity factor of 90% for nuclear power plants. The IEA scenario is based on the International Energy Agency's assumptions; the other scenarios were prepared by PEI.

Source: prepared by PEI.

[8] Calculated by PEI.
[9] Calculated by PEI. Scenarios prepared by PEI based on IEA data.

According to DISE forecasts, the demand for hydrogen in Poland could exceed 130 TWh (3.94 Mt) in 2050 (DISE, 2021).[10] To produce this amount of low-emission hydrogen by electrolysis, it will be necessary to consume 148-183 TWh (annual electricity consumption in Poland currently amounts to around 174 TWh). Generating this amount of energy in nuclear reactors would require from almost 19 GW to as much as 23 GW of power.[11]

Box 2. Other ways in which SMRs could be used in the future

One of the most interesting potential applications of SMRs remains the construction of floating nuclear power plants (FNPP). The first of them, Russian FNPP Akademik Lomonosov, has been operating since 2019 using two KLT-40S reactors, each with a capacity of 150 MWt (35 MWe) (www35). FNPPs have numerous advantages; notably, it facilitates the cooling process and increases mobility, which is especially important for countries with an extensive national power grid. Placing the units on the water may also address some of the public's concerns. According to a report by Think Atom, these kinds of units could be produced in the future in Finland, among other countries (Think Atom, 2022).

SMR reactors could also be a backup source of energy for windmills and photovoltaic panels. During periods when these sources produce less energy, SMRs would fill the gaps. During periods when renewable units cover the entire demand for electricity in the network, SMR units would use the oversupply of energy for water desalination. According to announcements, NuScale reactors will be adapted to this models (Think Atom, 2022).

[10] Assuming that 1 kg of hydrogen makes it possible to produce 33 kWh of electricity.
[11] Calculated by PEI, assuming a power utilisation indicator of 90%.

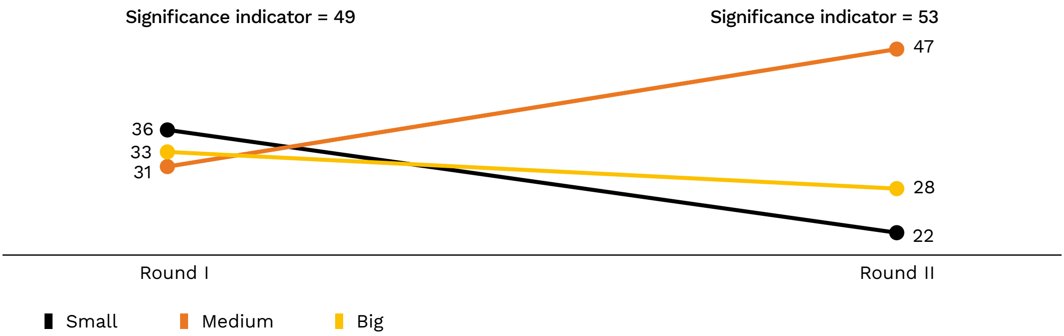
3. SMRs as seen by experts – survey results

3.1. Delphic theses (Part I of the study)

Thesis 1. A first SMR will start operating in Poland

Nearly half of the experts surveyed (47%) believe that the construction of a first SMR would be of medium importance for the energy transition in Poland (a thesis significance indicator of 53 out of 100 points). This is a big difference compared to the result in the first round (31%), in which opinions were almost evenly distributed between the three options (Chart 4).

Chart 4. Significance of the thesis: A first SMR will start operating in Poland – comparison of two rounds of the Delphi study (%)



Source: prepared by PEI.

Justified their opinion, the experts cited the high uncertainty regarding the mass development of SMR technology. In their opinion, depending on the development of other technologies and the final costs and problems faced by pilot projects, the first reactor could be the beginning of the construction of SMRs on a larger scale, or a minor, one-off curiosity. They also pointed to location-related limitations and the lack of financing mechanisms.

Examples of the experts' answers:

It depends on the development of energy storage and hydrogen technologies until SMRs are available on a larger scale.

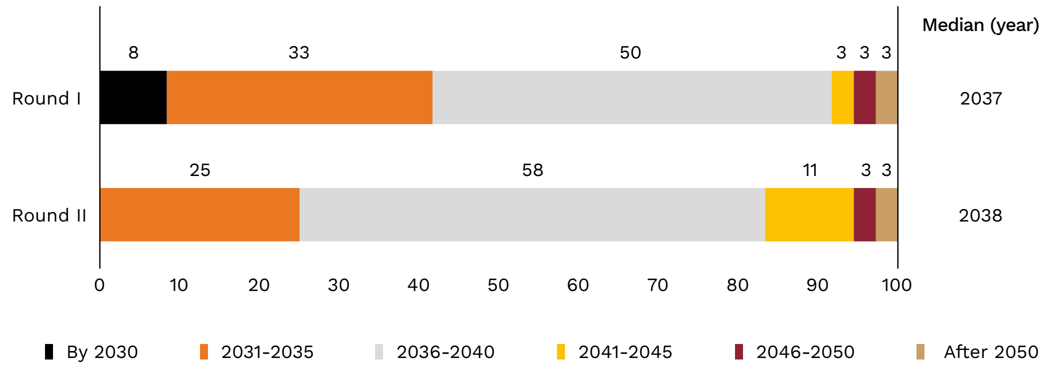
SMR reactors require similar location arrangements to large III+ reactors, in most cases their use is limited by their application possibilities.

28% of the experts believe that the construction of the first SMR will be of great importance for the energy transition; in particular, they cited the decarbonisation of industrial customers and the heating sector. In contrast, almost a quarter (22%) of the experts believe that the construction of the first SMR would not be of great importance for the energy transition, pointing to the shortage of appropriate staff and unproven technology:

Even if SMRs have obtained (will obtain) the appropriate certificates, their practical application and the reliability of the installation as a whole remain untested when it comes to real, practical operation. Implementing this technology in Poland, amid limited competencies in the field of nuclear engineering, will be difficult and potentially risky.

As many as 58% of the experts surveyed believe that the first SMR in Poland will not be built until 2036-2040. The median answer is 2038, eight years later than manufacturers' announcements. Experts cite the current state of the technology's development and the challenge of building the first SMRs — the lack of appropriate legislation, the need to establish a stable supply chain and manage the production of components, and the insufficient number of qualified staff.

Chart 5. Timeframe for the thesis: A first SMR will start operating in Poland – comparison of two rounds of the Delphi study (%) and median timeframe (years)



Source: prepared by PEI.

Examples of the experts' answers:

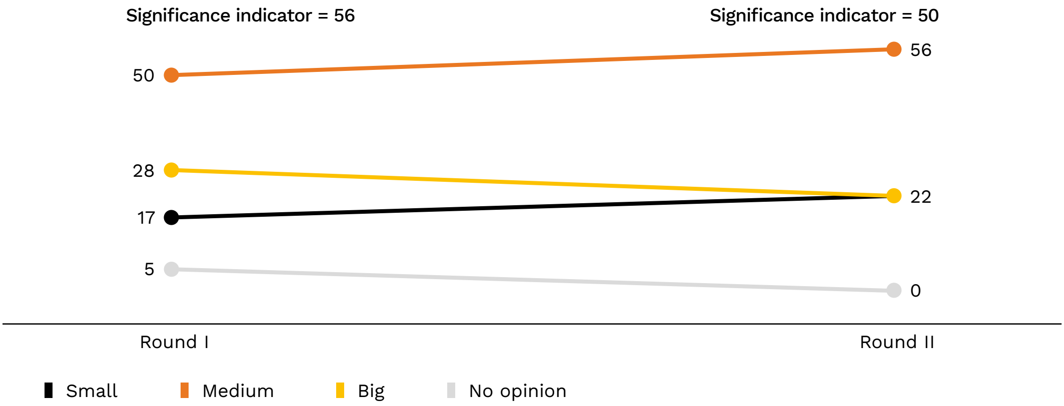
(...) due to the current state of development of this technology and the challenges associated with implementing it on a large scale, the most likely scenario is that this technology will become widespread in the late 2030s.

Given that most aspects of SMRs and their civilian use are still being developed (legislation, production, management of multi-modular production units, etc.), it can be expected that at least 10-15 years are needed to cope with the potential adversities and complete construction. Problems such as the shortage of staff (engineers and scientists) and the lack of uniform and stable development in the Polish nuclear power industry further increase the whole project's interior.

Thesis 2. The installed capacity of SMR units in Poland will exceed 5 GWe

Over half the experts surveyed (56%) believe that the development of SMR units' installed capacity beyond 5 GWe will be of medium significance for Poland's energy transition (a significance indicator of 50 points, Chart 6).

Chart 6. Significance of the thesis: The installed capacity of SMR units in Poland will exceed 5 GWe – comparison of two rounds of the Delphi study (%)



Source: prepared by PEI.

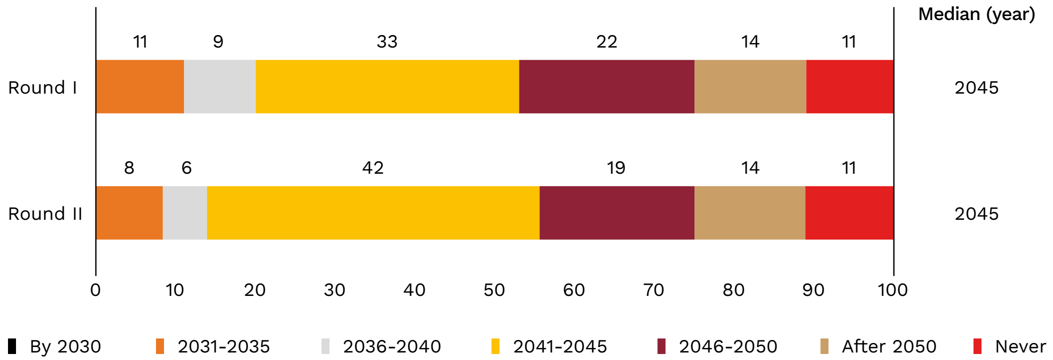
The experts indicated that, while 5 GWe will give SMRs a share in Poland's energy generation structure that cannot be overlooked, this is too little to consider it a very significant contribution to the energy transition. Moreover, they see considerable obstacles to achieving this target, citing both the uncertain speed at which the industry will develop and (if the first projects are successful) the high demand in many EU countries, which may affect the ability to complete projects on time:

If the power, transport and heating sectors are decarbonised already, a capacity of 5 GWe in any technology will have a medium (but recognisable) significance in the overall national energy balance.

Ultimately, SMRs' capacity may exceed 5 GW, but this target will be difficult to achieve in the short term; among other things, due to the current status of the technology's development, as well as the expected high demand for these technological solutions throughout the EU, which will affect the supply.

The experts deemed 2041-2045 (with a median of result of 2045) the most likely timeframe for the thesis, arguing that, as in the case of the construction of large-scale nuclear power plants in other countries, delays should also be expected in the case of SMRs. They also cited staff shortages and the lack of a strong research structure in the field of nuclear energy in Poland.

Chart 7. Timeframe for the thesis: The installed capacity of SMR units in Poland will exceed 5 GWe – comparison of two rounds of the Delphi study (%) and median timeframe (years)



Source: prepared by PEI.

Examples of the experts' comments:

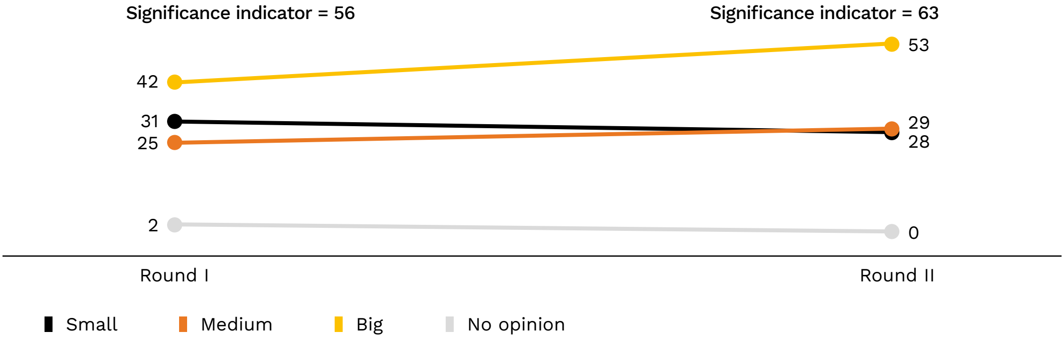
Poland could reach an installed capacity of 5 GW at SMRs around 2040, but this is subject to the assumptions regarding investment costs, the costs of the energy generated, and the availability of the capacity to build SMRs (primarily construction work) due to the parallel construction of large-scale nuclear power plants within the framework of the Polish Nuclear Power Programme, being met.

While reaching an installed capacity of 5 GW at SMRs would be of great importance for Poland's achievement of climate targets in line with EU policy, I consider this goal difficult to achieve; for example, because many EU member states plan to build SMRs during the same timeframe, which will obviously translate into difficulties and challenges when it comes to delivering the required number of SMRs within this timeframe (supply chains, production capacity, and so on).

Thesis 3. SMR units will start being used to produce system heat in Poland

More than half the experts (53%) believe that using SMRs to produce system heat in Poland will be of great significance for the energy transition. The thesis significance index was higher than in the case of the previous theses and amounted to 63 points.

Chart 8. Significance of the thesis: SMR units will start being used to produce system heat in Poland – comparison of two rounds of the Delphi study (%)



Source: prepared by PEI.

Experts who deemed the thesis highly significant cited the high need to decarbonise the heating sector, which is largely based on burning coal at the moment. At the same time, according to the respondents, there is less competition from alternative technologies than in the case of electricity production, which makes using of SMRs for heat production (for both municipal and industrial purposes) one of the most important potential applications. Examples of the experts' comments:

Heat from nuclear power plants should be used to the largest possible extent. Heating houses and water is one of the more obvious ways to use it and, in Poland, the infrastructure in many places could be adapted to this relatively easily. It is therefore feasible, but it requires considerable work and expertise; at the planning stage, not only in terms of the technical aspects, but the social ones, too.

This is one of the most logical applications of SMRs. The challenge may be building them near urban agglomerations (SMRs remain nuclear power plants, with most of the related restrictions).

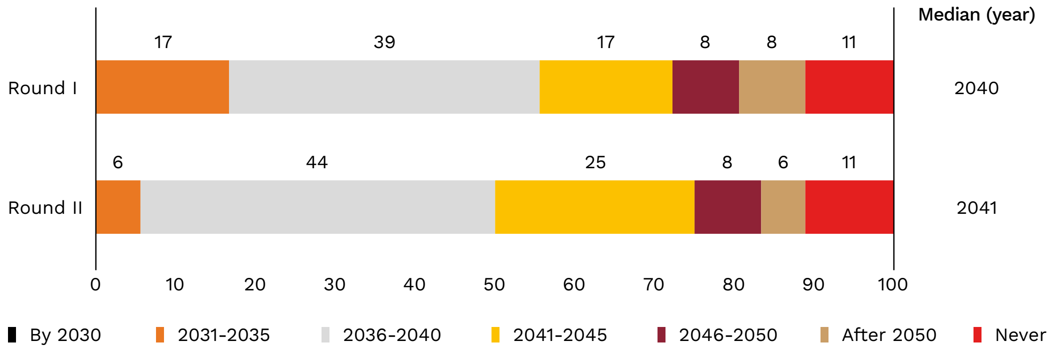
Currently operating nuclear reactors are already used to produce heat in a few cases. In the context of SMRs, this function is being analysed in Finland (for the city of Helsinki), among other places. Obviously, given SMRs' advantages, including where they can be located, using them to produce heat (especially in the context of the need to replace current heat production methods) seems like a natural and advisable solution.

28% of the experts surveyed were of the opposite opinion. In their opinion, the production of system heat using SMRs has little chance of playing a significant role in Poland's energy transition. They pointed out that the existing large-scale power industry is not used to produce system heat on a mass scale (although cases exist) and that locating them near cities may be impossible:

I don't think that SMRs will ever be located in cities; by then, there will be other solutions that may make SMRs unnecessary. Perhaps they will be a solution for industry.

According to half the experts surveyed, SMR reactors will not be used for system heatingbefore 2041 (Chart 9). According to 44%, SMRs will start being used to produce system heat in the second half of the next decade, while 25% of respondents chose 2041-2045.

Chart 9. Timeframe for the thesis: SMR units will start being used to produce system heat in Poland – comparison of two rounds of the Delphi study (%) and median timeframe (years)



Source: prepared by PEI.

Examples of the experts' answers:

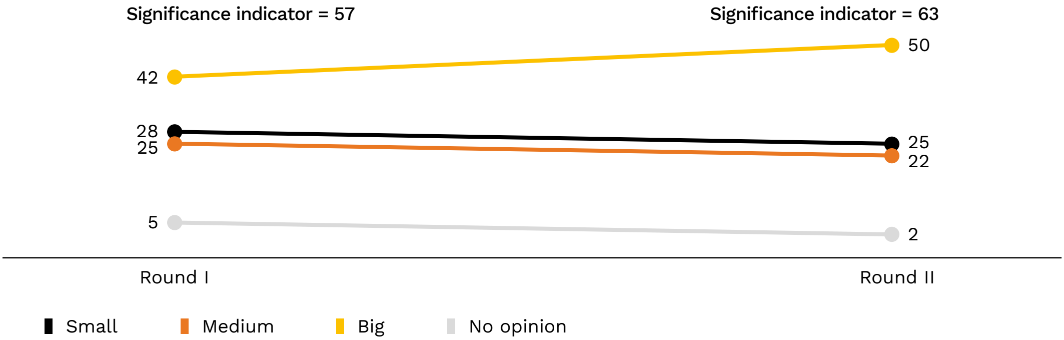
If the state considers investing in the development of the heating network and adapting it to nuclear energy standards early enough, this thesis could have a significant impact on decarbonisation and will be feasible in 15-20 years.

If system heat is municipal heat, then 2031-2035; if it is industrial heat, then 2036-2040.

Thesis 4. At least 20% of system heat in the 10 largest Polish agglomerations[12] will come from SMRs

Half the experts surveyed (50%) believe that if at least 20% of system heat in the 10 largest agglomerations in Poland were to be produced by SMRs, it would be of great importance for the energy transition (thesis significance index 63 points, Chart 10).

Chart 10. Significance of the thesis: At least 20% of system heat in the 10 largest Polish agglomerations will come from SMRs – comparison of two rounds of the Delphi study (%)



Source: prepared by PEI.

Experts pointed out that while the thesis could be implemented and would significantly contribute to decarbonisation, it is conditional on many factors that are currently unknown, including the possibility of locating SMRs near cities, the cost of energy from SMRs, or the demand for SMRs in industry. Examples of the experts' comments:

Covering such a wide area would require the significant dispersion of the units, increasing the investment's complexity and definitely extending it. Nuclear energy should be used to the maximum extent, but also rationally. Factors such as the availability of coolant, mining activity must be taken into account to optimise potential investments, rather than acting "forcefully" in a given place, so as not to over-invest. 20% seems doable.

While the implementation of this thesis would greatly contribute to Poland's decarbonisation, in my opinion it will be difficult to achieve the proposed goal to this degree. Producing system heat is of course an attribute of SMRs, but I see the need to use SMRs in the context of decarbonising industry (for example, replacing gas in production in hard-to-abate sectors).

[12] The Upper Silesian, Warsaw, Kraków, Łódź, Tri-City, Poznań, Wrocław, Bydgoszcz-Toruń, Rybnik and Szczecin agglomerations.

It is possible to implement the thesis, conditional on being able to build SMRs near agglomerations and cost factors (the cost of energy / heat generated by SMRs is not currently known).

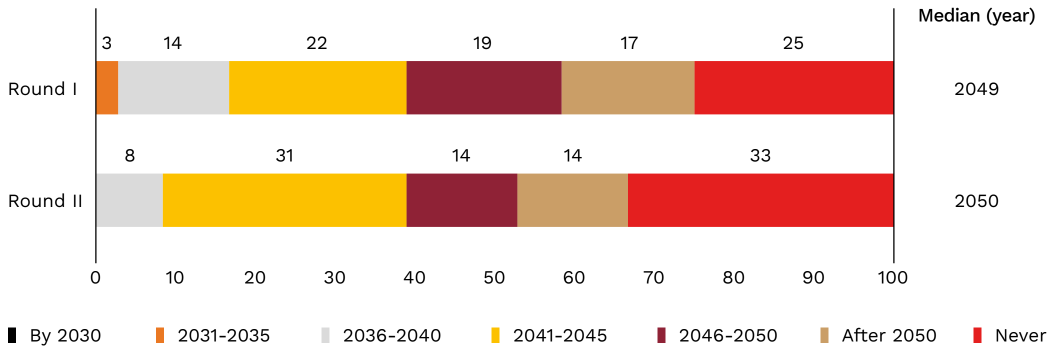
However, one in four experts was much more sceptical about the thesis, pointing to the likely social resistance to a larger number of SMRs being built near cities and the dominance of alternative forms of zero-emission heat production:

Nuclear reactors are not currently (and will not be) used to produce system heat. In the future (in the EU), system heat will come from electrification (heat pumps, electric heating).

A very unlikely solution, if only due to social resistance.

Half the experts believe that the thesis cannot be implemented before 2050. Individual respondents' opinions varied significantly here. As many as 39% believe that Poland's largest agglomerations will be able to produce 20% of system heat using SMRs by 2045. Meanwhile, 33% say that it will never happen (Chart 11).

Chart 11. Timeframe for the thesis: At least 20% of system heat in the 10 largest Polish agglomerations will come from SMRs – comparison of two rounds of the Delphi study (%) and median timeframe (years)

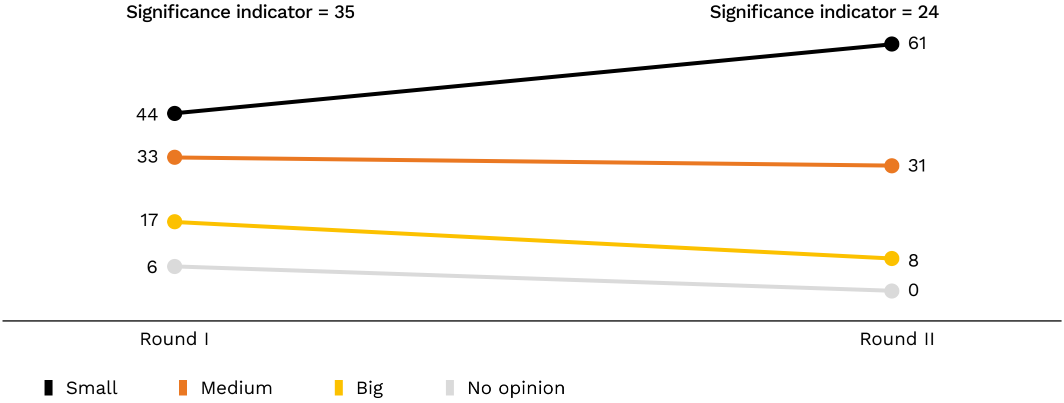


Source: prepared by PEI.

Thesis 5. 10% of hydrogen produced in Poland from low-emission sources (green and pink hydrogen) will come from SMRs

Most of the experts (61%) believe the thesis about producing 10% of low-emission hydrogen from SMRs is of little importance for the Polish energy transition. Only 8% of the experts deemed it to be of great importance. This translates into the lowest significance index (24 points) of all the theses considered by the respondents (Chart 12).

Chart 12. 10% of hydrogen produced in Poland from low-emission sources (green and pink hydrogen) will come from SMRs – comparison of two rounds of the Delphi study (%)



Source: prepared by PEI.

Justifying their answer, the experts pointed out that nuclear reactors, including SMRs, will mainly operate in the baseload of the power system and that hydrogen will mainly be produced from surpluses from RES installations:

By definition, nuclear power should work stably, in the base. Modern reactors, including SMRs, are adapted to rapid power changes, but they work optimally with a high and constant load. Hydrogen, produced from energy surpluses from RES and from dedicated nuclear installations, could be produced. Whether 10% is achieved only depends on prior investment planning based on current knowledge and technical limitations.

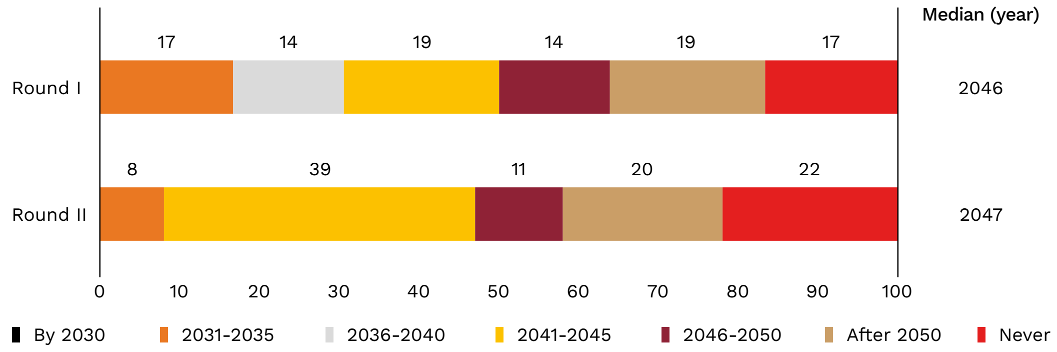
The potential use of SMRs is more likely to be system heat and powering industrial plants and small agglomerations. It will be better to use periodic surplus energy from RES to produce clean hydrogen.

Experts who considered the thesis of medium or high importance noted that, in the future, the cost of producing hydrogen from SMRs may be similar or lower to that of producing it from RES. However, they pointed out that a much depends not only on the final costs of energy from SMRs, but also on the version of the EU regulations on low-emission hydrogen in place:

The likelihood of this scenario largely depends on the ongoing work at the EU level on the definition of "green" hydrogen and setting decarbonisation targets to be achieved by individual member states, while, in my opinion, nuclear energy will have a significant role to play in the context of using SMRs to produce zero-emission hydrogen.

Half the experts surveyed believed that the thesis will not be implemented before 2047. As in the case of thesis 4, there were large discrepancies between the most frequently-chosen answers: 39% of the experts believed that producing 10% of low-emission hydrogen using SMRs will be possible between 2041 and 2045, while 22% of the experts believe that the thesis will never be implemented (Chart 13).

Chart 13. Timeframe for the thesis: 10% of hydrogen produced in Poland from low-emission sources (green and pink hydrogen) will come from SMRs – comparison of two rounds of the Delphi study (%) and median timeframe (years)



Source: prepared by PEI.

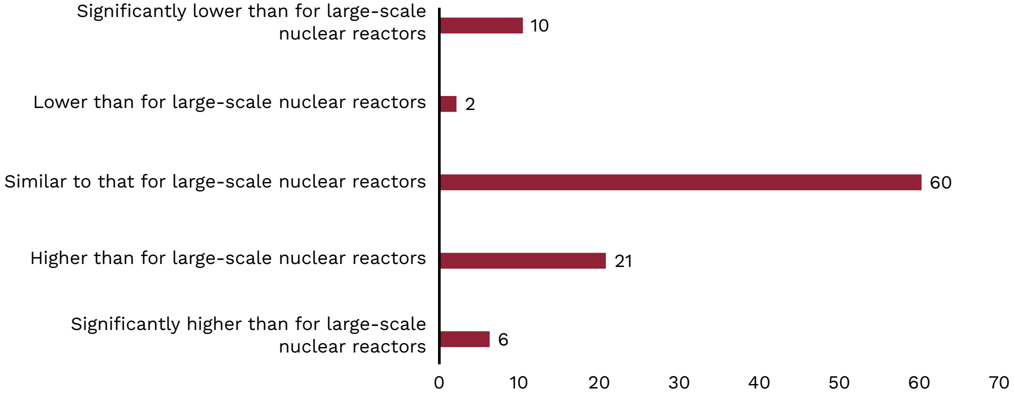
3.2. Other survey questions (Part II part of the study)

Most of the experts surveyed (60%) believe that social acceptance of SMRs will be at a similar level to that of large-scale nuclear energy, arguing that both technologies operate based on a similar principle (Chart 14):

There's no reason for it to differ. In particular, larger SMRs do not differ significantly from smaller "large-scale" ones.

SMR technology has not yet been tested on an industrial scale for a long period, so public concerns about this "novelty" will be greater. However, as commercial installations in highly energy-intensive industry, they will not be close to human settlements, so there will be no social resistance.

Chart 14. Social acceptance for SMRs according to the experts (%)



Source: prepared by PEI.

Some of the experts (27%) believe that acceptance of SMRs will be greater or significantly greater. The dominant argument made by these experts was the widespread opinion among members of the public that these reactors are safer due to their lower power:

Acceptance for both large-scale and modular reactors should remain high, but I also see certain attributes of SMRs that could achieve even higher support (for example, due to the lower volume of waste produced, the possibility of so-called recycling, passive safety systems, and so on).

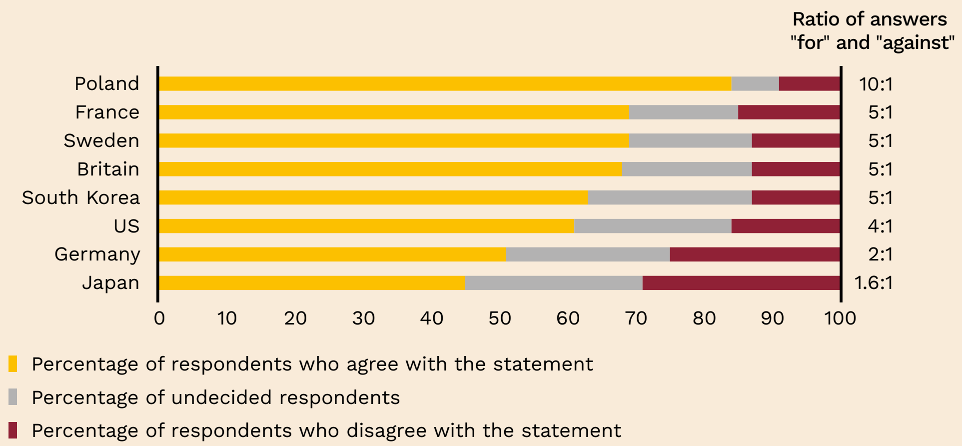
The following are regularly mentioned when criticising nuclear energy: the large scale of the project, the amount of capital needed and the time needed to implement the project. Moreover, opponents of nuclear power often promote a decentralised conception of the energy system. SMRs respond to all these allegations, to some extent.

In contrast, 12% of the experts believed that acceptance of SMR technology may be lower than that of large-scale nuclear power, pointing to concerns about unproven technology and the "Not in my backyard" effect.

Box 3. Social acceptance for nuclear energy in Poland

According to a new RePlanet survey, public support for using the latest nuclear technologies to produce electricity in Poland is at 84%, the highest result in the countries surveyed. This result is 15 pp higher than in France and Sweden (69%) and 23 pp higher than in the US (RePlanet, 2023).

Chart 15. Respondents' answers to the statement: I support the use of the latest nuclear technologies to produce electricity (alongside other energy sources) (%)



Source: prepared by PEI based on RePlanet (2023).

The supporters of nuclear energy in Poland include more men (88%) than women (79%), but high support not dependent on age (from 82% among people in the 18-34 age group to 86% in the 55+ age group) or the political party supported (from 83 to 92%).

The respondents also expressed their support for the following statements:

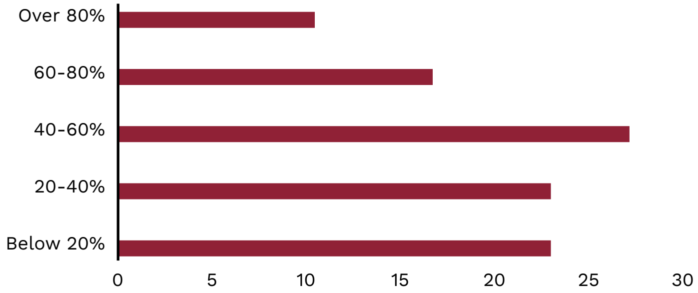
Table 2. Support for the statements below among respondents (%)

Statement	Percentage of respondents who support the statement
We need a way to produce more and more energy for our economy to keep growing	85
We need nuclear energy in the mix, along with renewables, if we are to meet our climate goals	78
Advanced nuclear energy could protect us from the sort of crisis of energy shortages and soaring costs we are experiencing right now	78
We should use advanced nuclear technologies to reduce energy dependence on other countries	78
Nuclear energy provides good-quality jobs for the local community	75

Source: analysis by PEI based on RePlanet.

The results of the RePlanet survey are consistent with the latest survey by the Ministry of Climate and Environment, conducted in 2022 (www36), in which 86% of respondents expressed their support for the construction of a nuclear power plant in Poland (an increase from 62.5% in 2020, www37).

Chart 16. Share of energy generated by SMRs used for the investors' own needs, according to the experts (%)



Source: prepared by PEI.

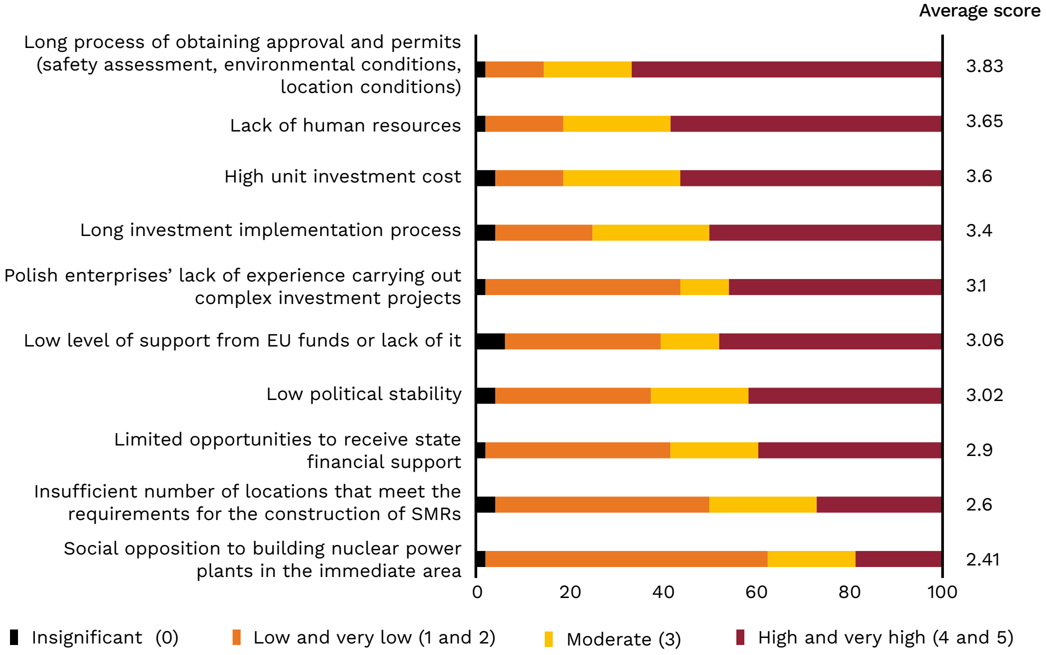
In the optional comments to the question, the most common response was that SMRs' greatest potential lies in industrial use. However, it was emphasised that the situation will depend on the technologies' development and the financing mechanisms worked out:

As far as I know, at the moment there are no other planned uses of SMRs than producing heat and electricity for one's own needs. This might change as the use of this technology develops. But SMRs' greatest potential of lies in their industrial use.

In my opinion, SMRs are an ideal solution for investors who want to use them, for example, to decarbonise their own economic production, which is why I see this as the largest application of SMRs in Poland.

In the experts' opinion, the biggest barriers to the development and use of SMRs in Poland include the long process of obtaining approval and permits for the construction of reactors (3.83/5), staff shortages (3.65/5) and the investment's high unit cost (3.6/5). For them, the least significant barriers are social opposition to the construction of SMRs in the immediate area (2.41/5) and the potentially insufficient number of locations that meet the construction requirements (2.6/5).

Chart 17. Barriers' significance for the future of the development of the SMR market in Poland, according to the experts (%) and average assessment (points)



Note: scale of 0 (the barrier is insignificant) to 5 (the barrier is very significant).

Source: prepared by PEI.

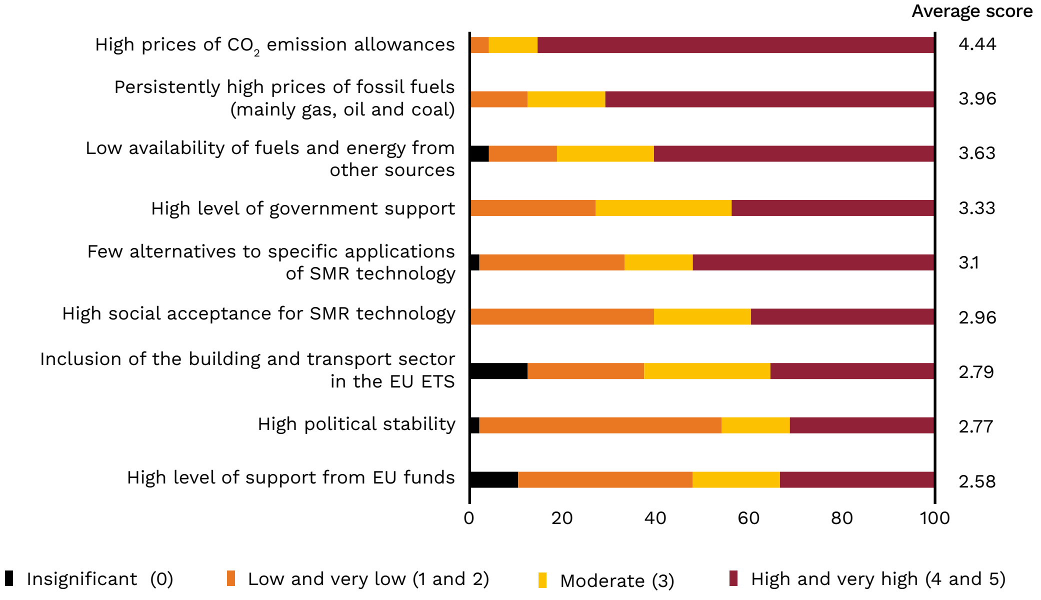
The comments also pointed to regulatory challenges, a cost of installed capacity higher than that announced by manufacturers, and manufacturers' potential problems fulfilling the large number of orders:

In addition to the challenges mentioned above, I would also add regulatory challenges that will be particularly visible when using several different types of SMR in Poland (and the lack of sufficient cooperation by regulatory authorities at the EU level) and challenges related to producing SMRs on the manufacturer's side (a large number of orders will have a key impact on the ability to carry out these investments within a predictable timeframe).

A serious limitation to the introduction of any new technology is the systematic approach. Staff shortages translate into reduced social trust, and this translates into susceptibility to disinformation, which raises additional questions (often due to a lack of knowledge). This can slow down investments significantly, especially ones that receive as much media attention as nuclear energy.

The high prices of CO_2 emission allowances, which will lead to rapid decarbonisation (4.44/5) were deemed the most important factor contributing to the development of SMRs in Poland. The experts also considered the high prices of fossil fuels (3.96/5) and the potential low availability of fuels and energy from other sources (3.63/5) significant.

Chart 18. Supporting factors' significance for the future of the development of the SMR market in Poland, according to the experts (%) and average assessment (points)



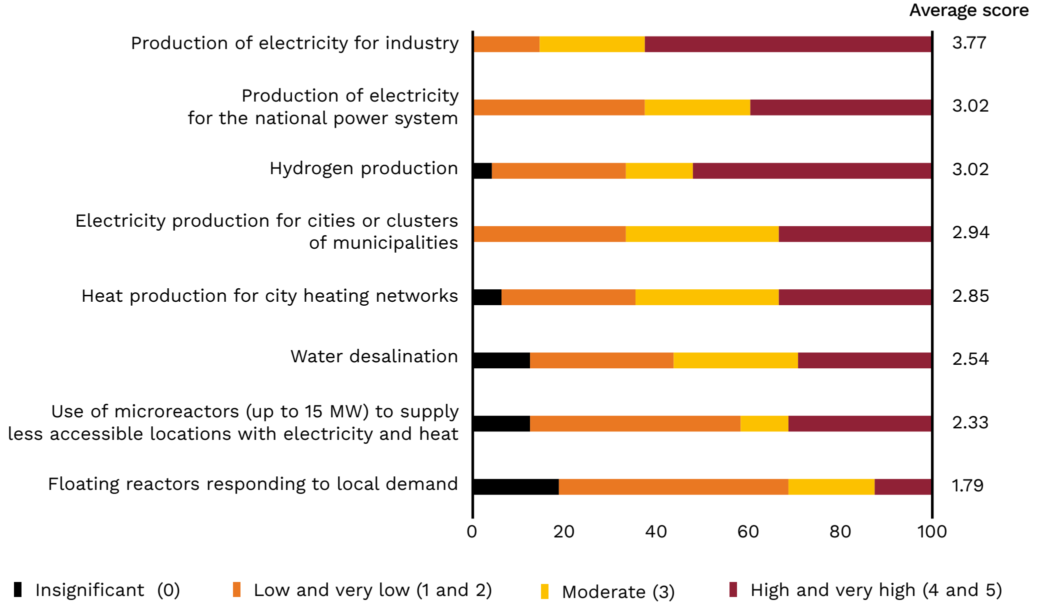
Note: scale of 0 (the factor is insignificant) to 5 (the factor is very significant).

Source: prepared by PEI.

For the experts, the greatest potential application of SMRs globally is producing electricity for industry's own needs (3.77/5), followed by producing hydrogen (3.02/5) and producing electricity for national power systems (also 3.02/5). They are the most sceptical about floating reactors (1.77/5).

In terms of applying SMR technology in Poland, they believe that producing electricity production for industry's own needs (3.7/5) has the most potential. However, most of the experts see zero potential when it comes to using SMRs in Poland to supply less accessible locations with electricity (0.79/5) or desalinate water (0.6/5), or the use of vessels (0.5/5).

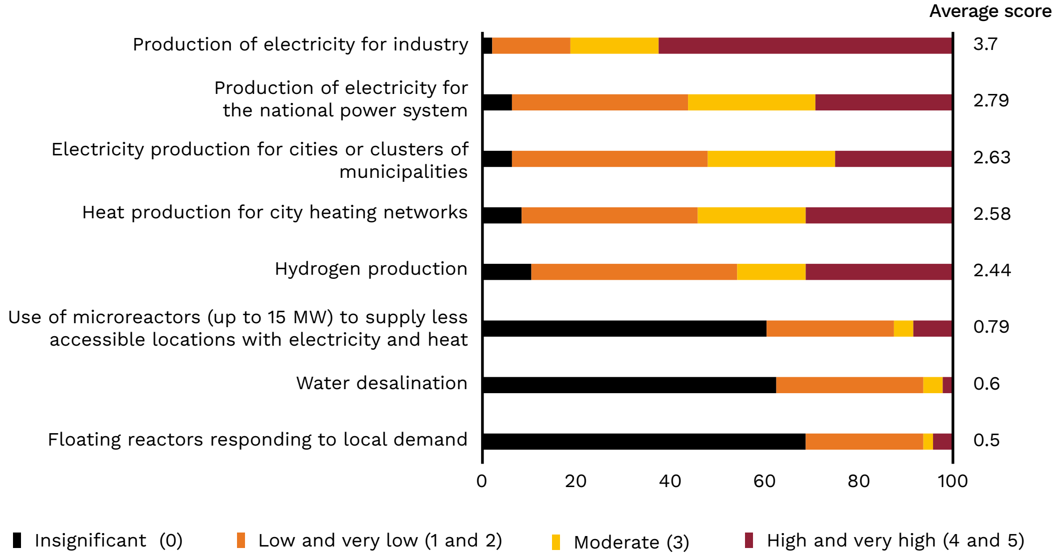
Chart 19. Potential of selected applications of SMR technologies globally in the future, according to the experts (%) and average assessment (points)



Note: scale of 0 (no potential) to 5 (very high potential).

Source: prepared by PEI.

Chart 20. Potential of selected applications of SMR technologies in Poland in the future, according to the experts (%) and average assessment (points)



Note: scale of 0 (no potential) to 5 (very high potential).

Source: prepared by PEI.

Box 4. Views on SMRs among representatives of Poland's largest cities

In response to the high significance assigned by the experts to the theses on producing system heat in Poland using SMRs, we decided to conduct in-depth interviews with representatives of Poland's largest cities. We sent out 25 inquiries; representatives of four cities (Warsaw, Gdańsk, Bytom and Rybnik) were willing to participate in our study.

In our in-depth interviews, representatives of the municipal offices responsible for energy did not rule out using this technology in the future, especially to produce heat in cogeneration. However, they pointed out that there are currently no plans, even in long-term strategies, to use SMRs, due to the lack of technology on the market and the high number of unknown factors, such as the cost or availability date of individual reactors.

Experts from municipal offices also pointed out that the possibility of using SMRs in certain locations is limited, especially in the case of Silesia, where some locations are exposed to mining tremors. Representatives of cities outside Silesia spoke of the possibility of using floating reactors (Gdańsk) or locating them in places currently occupied by coal and gas units (Warsaw). However, in the latter case, they noted the need to provide heating while the unit in a given location is being replaced and the fact that, in the case of some recently built or modernised coal and gas units, it will take over a decade to amortise the cost of the investment.

Summary

The high interest in SMRs over the past two years confirms the need for stable low-emission energy sources that entities other than the state and the largest energy companies could invest in. However, forecasts on the future of SMRs are subject to high uncertainty due to the technology' immaturity. According to forecasts by theNuclear Energy Agency, the most positive scenario for the development of SMR technology would translate into the construction of 375 GWe globally by 2050 and avoid emissions of 15 Gt CO_2. In the negative scenario, numerous delays at the stage of designing, licensing and building power plants as part of pilot projects would result in interest in this technology falling sharply. As a result, it would make a negligible contribution to the decarbonisation of the global economy.

The survey of experts conducted by the PEI confirms the large differences in opinion on the future of SMRs. 47% of respondents said that building the first SMR will be of medium significance for the Poland's energy transition. Many of the experts pointed out that, while it may play an important role in decarbonisation, this technology will not replace the need to invest in RES and large-scale nuclear energy. Experts were also sceptical about the announcement of the construction of the first SMRs in Poland before 2030; 58% believe that the first SMRs will start operating in 2036-2040 (the median was 2038). According to half the experts, a larger number of SMR units, with a total capacity of over 5 GWe, will be built no earlier than 2045. According to the experts, SMRs' main application will be producing electricity for industry's own needs; the most energy-intensive enterprises in Poland currently consume 20 TWh per year in total and industry as a whole consumes 54 TWh, 31% of the country's total demand for electricity. With the decarbonisation of industry, this demand will grow in the future — the electrification of the steel industry alone could quadruple energy consumption in the industry from the current 6-7 TWh to over 30 TWh.

Experts consider the potential to use SMRs for hydrogen production much lower. As many as 61% of the experts surveyed considered the thesis "10% of hydrogen produced in Poland from low-emission sources (green and pink hydrogen) will come from SMRs" of little importance for Poland's energy transition, just 8% deemed it of great importance. According to the respondents, nuclear energy, including SMRs, will operate in the baseloadof the system, and hydrogen will primarily be produced from surplus energy from RES (mainly offshore and onshore wind farms and photovoltaics).

Experts pointed to SMR's high potential in the production of system heat. 53% of them believe that it will have a significant impact on Poland's energy transition. Justifying their answer, they cited the need to decarbonise the heating sector, roughly 70% of which is currently based on coal. At the same time, according to the experts, there is less competition from alternative technologies than in the case of electricity production, which makes using SMRs for heat production (both municipal and industrial) one of the most important potential applications of them. According to half the respondents, this application of SMRs will start being implemented by 2041.

SMRs are being considered as a tool for decarbonising the heating sector in cities in other countries, too; for example, in Finland. If these solutions were transferred to Polish cities, it would require the construction of units with a total capacity of 900 MWe operating in the cogeneration model in the case of Warsaw (assuming a heat demand of 14 TWh per year), and units with a total capacity of 200-300 MWe in the case of smaller regional cities. According to the city representatives with whom PEI conducted in-depth interviews, even the richest local governments cannot afford such a large investment. The construction of SMRs meant to produce heat for Polish cities would therefore have to be mostly co-financed by the central authorities and/or the largest energy companies.

The experts deemed the long process of obtaining approval and permits (assesses safety, environmental conditions, location conditions), staff shortages and the high unit production costs the most significant barriers to the construction of SMRs in Poland. They also drew attention to the investment costs, which are expected to be significantly higher than initially announced. At the same time, in their view, the high prices of CO_2 emission allowances and fossil fuels, which will encourage consumers, especially energy-intensive industries, to urgently seek stable sources of low-emission energy, could provide a significant impetus for the rapid development of the SMR market in Poland.

Recommendations

- **To ensure the serial production of SMRs, common international requirements must be developed; for example, concerning the licensing and evaluation of the technology.** Talks with national nuclear regulators' participation are already being held as part of the Small Modular Reactor Regulators' Forum organised by the International Atomic Energy Agency.
- **It is necessary to start the process of selecting the first reactors' location as soon as possible, as well as the procedure for issuing a decision on the environmental conditions, along with extensive public consultations.** Due to SMRs' similar power, in the future they could be installed on the site of existing or decommissioned coal-fired power plants. Countries with nuclear power plants are considering building pilot SMR projects on the site of large-scale nuclear power plants, which would simplify the process of obtaining decisions on the location and the environmental impact assessment.
- **Despite high public support for nuclear power in Poland, further educational campaigns are needed, especially in the local community in the municipalities where SMRs are set to be built.** Local communities should have the greatest possible insight into the plans for the next stages of construction and the reactor's operation (including information on the disposal of radioactive waste) and have a real influence on the decision to build it in their neighbourhood.
- **Subsidies or state guarantees covering part of the SMRs' costs reduce the risk of complications during the project's implementation.** The cost of building a SMR remains significantly higher than in the case of a biogas plant, wind farm or photovoltaic panels. Coupled with the uncertainty associated with investing in pilot projects, this could reduce interest among potential investors. However, granting state aid should lead to real and measurable benefits for taxpayers and energy recipients.
- **In contracts signed with suppliers of SMR technology, emphasis on the timely delivery of the technology and suppliers' clearly-defined liability for delays are particularly important.** The experts surveyed by the PEI expressed scepticism regarding the construction date of the first SMRs in Poland, largely due to the technology's unavailability on the market. This is all the more important given how suppliers gave repeatedly changed the deadlines for obtaining certification for the technology and, as a result, for building pilot SMRs.

- **Intensive cooperation with universities of technology is needed increase the number of programmes and courses educating specialists on nuclear power, combined with efforts to encourage students to choosethis specialisation.** Like many other EU countries, Poland is struggling with a shortage of specialists on nuclear energy. Polish SMR projects will have to compete for specialists; for example, with three large-scale power plant projects.

Methodological appendix

Research methodology

The research presented in this report is based on the Delphi method, a type of study in which experts' intuitive opinions are treated as a valid contribution to formulating a vision for the future of the research subject. This method is used to predict the development of long-term phenomena in a situation of uncertainty, especially when: (I) the phenomena predicted do not lend themselves to analytical techniques characteristic of forecasting, (II) there is no reliable data on the anticipated processes, or (III) external factors determine the predicted phenomena (Nazarko, 2013, p. 46). The detailed research methodology consisted of seven stages (Figure 1).[13]

Figure 1. Procedure methodology

1. Construction of Delphi theses and auxiliary questions - Steering Committee and Climate and Energy Team
2. Development of the Delphi questionnaire - Climate and Energy Team
3. 1st round of evaluation of Delphi theses - experts
4. Preparation of the results of the first round - Climate and Energy Team
5. 2nd round of evaluation of Delphi theses - experts
6. Preparation of the results of the second round - Climate and Energy Team

Source: prepared by PEI.

The first stage involved PEI analysts, together with a four-member Steering Committee, developing five Delphi theses on the future of Poland's power industry. Additional survey questions were also developed; the experts were only asked these in the first round.

[13] The methodological section is based on the description of the foresight study in Dębkowska et al. (2021).

The theses were subjected to final verification. This work made it possible to develop the Delphi questionnaire (the second stage), the tool for conducting the first round of the evaluation of the Delphi theses by 48 experts, in the form of a Computer Assisted Web Interviewing (CAWI) survey. The chosen technique has many advantages. The key ones include:

- automatic verification of the logical correctness of the data entered,
- automatic saving of the test results on the server,
- possibility to conduct research in cases when the respondents are spread out over a large geographical area.

The experts for the Delphi study were chosen by means of purposive sampling. It was assumed that the group of the experts would be made up of eminent representatives of: academia, business, NGOs and the public administration.

Almost 150 representatives of these groups were selected and invited to participate in the study. 48 people agreed (see the list of the experts attached). It should be emphasised that participation in the study requires dedication. This was surely the reason why some of the experts declined to take part in the study.

The fourth stage focused on processing the results of the first round of the Delphi survey and presenting the results to a group of the same respondents in the second round (the fifth stage). In Delphi studies, the use of multiple survey rounds seeks to obtain results that are as unambiguous as possible. The second round allows the experts to verify their opinions by familiarising themselves with the distribution of answers in the first round. The final results obtained in the second round were then analysed in detail (the sixth stage).

For the purposes of the report and big data analysis, we have presented some variables from the questionnaire in the form of indicators that synthesise and organise the results of more detailed observations.

To determine the strategic importance of individual theses for the development of Poland’s power industry, significance indicators (SIs) were determined according to the following formula:

$$S_I = \frac{100 \bullet n_D + 50 \bullet n_S + \bullet 0 \bullet n_M}{n - n_{TO}} \quad (1)$$

where:

n_D is the number of "big" responses,

n_S is the number of "medium" responses,

n_M is the number of "small" responses,

n_{TO} is the number of "hard to say" replies,

n is the total number of responses.

The indicator ranges from 0 to 100; the closer the value to 1000, the greater the strategic importance of the given thesis

Research sample

48 experts took part in the first round of the study, in which one-off, additional questions were asked. The group of respondents was made up of 6 women and 42 men representing various areas of activity. 44% (21 people) were representatives of academia. Business and NGOs were each represented by 23% (11 people each). The media (2 people) and the public administration (2 people) had the fewest representatives.

Table 3. Characteristics of the group of experts who took part in the study

Area represented	
Academia	21
Business	11
NGOs	11
Public administration	2
Media	2
Other	1

Gender	
Men	42
Women	6

Source: prepared by PEI.

Of the 48 experts who took part in the first round of the Delphi study, along with the one-off, additional questionnaire, 36 took part in the second round of the study. For this reason, for the evaluation of the Delphi theses (part one of the questionnaire), we only took into account the experts who participated in both rounds.

The group of respondents was made up of 3 women and 33 men representing various areas of activity. Over 40% (15 people) were representatives of academia. Business and NGOs were each represented by 25% (9 people each). The media (2 people) and the public administration (1 person) had the fewest representatives.

Table 4. Characteristics of the group of experts who took part in both rounds of the Delphi study

Area represented	
Academia	15
Business	9
NGOs	9
Media	2
Public administration	1
Other	1

Gender	
Men	33
Women	3

Source: prepared by PEI.

Bibliography

Brook, B.W., Bradshaw, C.J.A. (2015), *Key role for nuclear energy in global biodiversity conservation*, "Conservation Biology", No. 29.

CNEA (2017), *Lima Carem 25 Nuclear Plant 33 MW*, https://www.globaldata.com/store/report/cnea-lima-carem-25-nuclear-plant-33-mw-buenos-aires/ [accessed: 02.02.2023].

Derr, E. (2022), *Energy Studies and Models Show Advanced Nuclear as the Backbone of Our Carbon-Free Future*, https://www.nei.org/news/2022/studies-and-models-show-demand-for-adv-nuclear [accessed: 03.02.2023].

Dębkowska, K., Juszczak, A., Maj, M., Szymańska, A. (2021), *Foresight energetyczny Polski*, Polish Economic Institute, Warsaw.

DISE (2021), *Zielony wodór z OZE w Polsce*, https://dise.org.pl/Raport-Zielony-Wodor-z-OZE.pdf [accessed: 05.03.2023].

DISE (2022), *Gaz Zakładnikiem Geopolityki, Wykorzystanie gazu ziemnego na cele energetyczne w Unii Europejskiej w aspekcie oddziaływania czynników geopolitycznych*, Warsaw.

IAEA (2019), *Status Report – UK SMR (Rolls-Royce and Partners)*, https://aris.iaea.org/PDF/UK-SMR_2020.pdf [accessed: 05.03.2023].

IEA (2021), *Net Zero by 2050 A Roadmap for the Global Energy Sector*, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf [accessed: 05.03.2023].

IPCC (2014), *Aneks III: Technology-specific Cost and Performance Parameters*, https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf [accessed: 09.05.2023].

Jackowiak, J. (2022), *Wysokie koszty energii i pracy doskwierają firmom*, https://grantthornton.pl/publikacja/wysokie-koszty-energii-i-pracy-doskwieraja-firmom/ [accessed: 05.03.2023].

Juszczak, A. (2022), *Ekonomiczne aspekty inwestycji jądrowych w Polsce – wpływ na biznes, rynek pracy i społeczności lokalne*, Polish Economic Institute, Warsaw.

Lliou, J. (2021), *What are Small Modular Reactors (SMRs)?*, https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs [accessed: 10.02.2023].

Lipka, M. (2020), *Program Polskiej Energetyki Jądrowej, a małe reaktory modułowe*, "PTJ" nr 63.

Locatelli, G. i in. (2018), *Load following of Small Modular Reactors (SMR) by cogeneration of hydrogen: A techno-economic analysis*, "Energy", No. 148.

Mignacca, B., Giorgio L., Sainati, T. (2020), *Deeds not words: Barriers and remedies for Small Modular nuclear Reactors*, "Energy" No. 206.
Milewski, J. i in. (2021), *Hydrogen production in solid oxide electrolyzers coupled with nuclear reactors*, "International Journal of Hydrogen Energy", No. 46.
Nazarko, J. (2013), *Regionalny foresight gospodarczy. Metodologia i instrumentarium badawcze*, Association of Employers of Warsaw and Mazovia, Warsaw, https://depot.ceon.pl/bitstream/handle/123456789/7507/Regionalny%20foresight%20gospodarczy.%20Metodologia%20i%20instrumentarium%20badawcze.pdf;sequence=1 [accessed: 21.03.2023].
NEA (2021), *Small Modular Reactors: Challenges and Opportunities*, https://www.oecd-nea.org/upload/docs/application/pdf/2021-03/7560_smr_report.pdf [accessed: 29.01.2023].
Nucleareurope (2022), *New nuclear solutions: small modular reactors*, https://www.nucleareurope.eu/press-release/small-modular-reactors/ [accessed: 29.01.2023].
OECD (2016), *Small Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment*.
OECD (2021), *Small Modular Reactors: Challenges and Opportunities*, NEA No. 7560.
Pieńkowski, L. (2022), *Wyzwania energetyki jądrowej w KGHM Polska Miedź*, https://www.forum-ekonomiczne.pl/wyzwania-energetyki-jadrowej-w-kghm-polska-miedz/ [accessed: 23.01.2023].
RePlanet (2023), *The Worlds wants new nuclear, Findings from a comprehensive evaluation of the world's understanding and support for advanced nuclear*, https://www.replanet.ngo/post/world-wants--new-nuclear [accessed: 12.05.2023].
Think Atom (2019), *Nuclear District Heating in Finland, The Demand, Supply and Emissions Reduction Potential of Heating Finland with Small Nuclear Reactors*, https://thinkatomnet.files.wordpress. com/2019/04/nuclear-district-heating-in-finland_1-2_web.pdf [accessed: 05.03.2023].
Think Atom (2022), *Shipyard Nuclear in Finland*, https://thinkatomnet.files.wordpress.com/2022/06/shipyard_report_web.pdf [accessed: 05.03.2023].
Tomaszewski, R. (2020), *Ciepło do zmiany, Jak zmodernizować sektor ciepłownictwa systemowego w Polsce*, http://zasoby.politykainsight.pl/pi2/pdf/Polityka_Insight_-_Cieplo_do_zmiany.pdf [accessed: 05.03.2023].
UNECE (2022), *Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources*, https://unece.org/sites/default/ files/2022-04/LCA_3_FINAL%20March%202022.pdf [accessed: 05.03.2023].
Weimar, M.R. i in. (2021), *Techno-economic Assessment for Generation III + Small Modular Reactor Deployments in the Pacific Northwest*, Pacific Northwest National Laboratory, Washington.

(www1) https://wysokienapiecie.pl/krotkie-spiecie/rz-d-przyj-za-o-enia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r/ [accessed: 05.03.2023].
(www2) https://www.world-nuclear.org/information-library/nuclear-fuel--cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx [accessed: 15.03.2023].
(www3) https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs [accessed: 08.03.2023].
(www4) https://www.nei.org/advocacy/build-new-reactors/small-modular--reactors [accessed: 15.03.2023].
(www5) https://aris.iaea.org/sites/overview.html [accessed: 05.03.2023].
(www6) https://www.linkedin.com/posts/maciej-lipka-atom_w-dzienniku-urz%C4%99dowym-usa-ukaza%C5%82-si%C4%99-zatwierdzony-activity-7024505824924295168-rH1k?utm_source=share&utm_medium=member_desktop [accessed: 23.02.2023].
(www7) https://www.nuscalepower.com/en/Products/VOYGR-SMR-Plants [accessed: 23.02.2023].
(www8) https://www.bbc.com/news/business-59212983 [accessed: 13.02.2023].
(www9) https://www.neimagazine.com/news/newsrolls-royce-smr-begins-uk-generic-design-assessment-9598877 [accessed: 13.02.2023].
(www10) https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/bwrx-300 [accessed: 02.02.2023].
(www11) https://www.opg.com/story/opg-darlington-small-modular-reactor-project-passes-significant-milestones/ [accessed: 01.02.2023].
(www12) https://nuclear.pl/wiadomosci,news,21070802,0,0.html [accessed: 03.02.2023].
(www13) https://www.world-nuclear-news.org/Articles/Construction-of-Argentinas-small-CAREM-25-unit-to [accessed: 15.02.2023].
(www14) https://www.world-nuclear-news.org/Articles/Chinese-SMR-project-enters-installation-phase [accessed: 15.02.2023].
(www15) https://www.edf.fr/en/the-edf-group/producing-a-climate-friendly-energy/nuclear-energy/shaping-the-future-of-nuclear/the-nuwardtm-smr-solution/the-solution [accessed: 16.02.2023].
(www16) https://www.world-nuclear-news.org/Articles/European-regulators-to-cooperate-on-Nuward-licensi [accessed: 16.02.2023].
(www17) https://www.nnl.co.uk/2014/12/nnl-publishes-report-on-small-modular-reactor-technology/ [accessed: 18.02.2023].
(www18) https://fermi.ee/en/fermi-energia-chooses-ge-hitachis-bwrx-300-as-the-technology-for-planned-smr-nuclear-power-plant-in-estonia/ [accessed: 17.02.2023].
(www19) https://www.world-nuclear-news.org/Articles/NuScale-marks-SMR-progress-in-USA,-Romania [accessed: 14.02.2023]. (www20) https://world-nuclear-news.org/Articles/Funding-for-demonstration-Swedish-SMR [accessed: 13.02.2023].
(www21) https://biznesalert.pl/synthos-zamowi-dziesiec-reaktorow-pierwszy-w-2029-roku-potem-caly-lancuch-dostaw/ [accessed: 20.02.2023].

(www22) https://www.money.pl/gospodarka/pierwszy-reaktor-jadrowy-bwrx-300-moze-trafic-do-polski-w-2029-r-6799193963879392a.html [accessed: 15.02.2023].
(www23) https://www.wnp.pl/energetyka/obajtek-orlen-ma-bardzo-ambitne-plany-zwiazane-z-reaktorami-smr,672287.html [accessed: 20.02.2023].
(www24) https://forsal.pl/biznes/energetyka/artykuly/8632453,male-reaktory-atomowe-dla-kghm-i-orlen-panstwowa-agencja-atomistyki-analizuje-wnioski.html [accessed: 20.02.2023].
(www25) https://media.kghm.com/pl/informacje-prasowe/kghm-polska-miedz-sa-i-sn-nuclearelectrica-sa-podpisaly-memorandum-o-wspolpracy-przy-rozwoju-smr [accessed: 20.02.2023].
(www26) https://businessinsider.com.pl/firmy/atomowe-plany-spolki-sebastiana-kulczyka-ciech-oprocz-smr-analizuje-tez-magazyny/5m5jse2 [accessed: 20.02.2023].
(www27) https://www.unimot.pl/aktualnosci/nuscale-power-podpisuje-porozumienie-o-wspolpracy-mou-z-getka-i-unimot-w-celu-rozpoznania-mozliwosci-wdrozenia-technologii-smr-w-polsce/ [accessed: 20.02.2023].
(www28) https://respect.energy/respect-energy-i-edf-podpisaly-porozumienie-o-rozwijaniu-projektow-energetyki-jadrowej-w-polsce/ [accessed: 20.02.2023].
(www29) https://www.neimagazine.com/news/newslast-energy-secures-power-purchase-deals-for-34-smrs-in-poland-and-the-uk-10708386 [accessed: 20.02.2023].
(www30) https://zpp.net.pl/stanowisko-zpp-ws-ochrony-polskiego-przemyslu-przed-wzrostami-kosztow-energii-elektrycznej-i-gazu/ [accessed: 20.03.2023].
(www31) https://www.gov.pl/web/rozwoj-technologia/5-mld-zl-rekompensat-za-2022-r-dla-firm-energochlonnych [accessed: 22.03.2023].
(www32) https://www.cire.pl/artykuly/serwis-informacyjny-cire-24/elektryfikacja-hutnictwa-zwiekszy-pieciokrotnie-zapotrzebowanie-tego-sektora-na-energie-elektryczna- [accessed: 20.03.2023].
(www33) https://www.reuters.com/business/energy/us-approves-design-nuscale-small-modular-nuclear-reactor-2023-01-20/ [accessed: 21.03.2023].
(www34) https://ppte2050.pl/platforman/bzppte/static/uploads/04.%20m.st.%20Warszawa_Model%20energetyczny%20Warszawy%202050_L.Drogosz.pdf [accessed: 23.03.2023].
(www35) https://www.power-technology.com/projects/akademik-lomonosov-nuclear-co-generation-russia/ [accessed: 19.03.2023].
(www36) https://www.gov.pl/web/klimat/rekordowe-poparcie--86-polakow-za-budowa-elektrowni-jadrowych-w-polsce [accessed: 12.03.2023].
(www37) https://www.gov.pl/web/klimat/poparcie-spoleczne-dla-budowy-elektrowni-jadrowej-w-polsce---badania-z-listopada-2020-r [accessed: 12.05.2023].

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Seven of the experts who took part in the study asked to remain anonymous

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