CZECH SMR ROADMAP
Applicability and Contribution to Economy

Working Group on the Applicability of Small and Medium-Sized Reactors in the Czech Republic, May 2023

MINISTRY OF INDUSTRY AND TRADE
OF THE CZECH REPUBLIC


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EXECUTIVE SUMMARY

Small and medium-sized reactors (SMRs) will be marketed in the next five to ten years as a tool for transforming the energy system into an emission-free one and may be a solution for the government to guarantee security of electricity and heat supply or hydrogen production in an energy system based on renewables. This Roadmap summarises existing knowledge about SMRs, the results of the dedicated working group. It describes the framework for possible SMR application in the Czech Republic. It outlines approaches to the economic opportunities, provides information on Czech projects and offers of foreign SMR manufacturers, gives an overview of possible sites where SMRs can replace coal-fired units for heat and electricity production, and describes a number of investor models to set equal, attractive conditions for investors; and gives an overview of relevant legislation with an explanation of ongoing measures and proposals for necessary changes.

Governments of the countries of origin of the manufacturers are supporting the emergence of an innovative fleet-based approach to the production and construction of nuclear power plants to make their construction more efficient and accessible, in particular by reducing overall investment and operating costs. For the Czech Republic, joining the supply chain and producing modules in the Czech Republic is a strategic opportunity that would mean the development of a new economic focus, the maintenance of nuclear know-how, a long-term partnership with the country of origin of the manufacturer and the fulfilment of the decarbonisation strategy of the Czech Republic. The current most advanced western SMR project is underway in Canada and is due for completion in 2028. Competing manufacturers expect to complete their first commercial projects in the early 2030s. Manufacturers are now seeking their first orders and concluding memoranda of cooperation with the supply chain, including the Czech one. Despite the potentially higher investment costs per power unit, ranging from 100 million CZK/MWe declared by manufacturers to the more conservative estimates of 165 mil. CZK/MWe, the total nominal investment in SMRs will be significantly lower than for large-scale reactors. Unlike large projects in the past, this will make investment into nuclear in the form of SMRs accessible to a wider range of stakeholders, including private capital involvement. The size of the plant is comparable to today's combined heat and power (CHP) plants, SMRs can therefore be considered as their prospective replacement. SMRs have lower water consumption requirements and dry cooling capability, which is an essential prerequisite for their long-term operation in the context of environmental challenges. The estimated construction time is 3-5 years; with standardized manufacturing and construction, there is a lower risk of changes, repairs and project delays if multiple units are installed in a given country. A unified approach by regulators has the potential to speed up construction and reduce its cost.

If the State is unprepared for the development of SMRs, there is a risk of delaying the first projects, or a decline in the availability of technologies for the Czech Republic and missing out on a strategic industrial opportunity. There is uncertainty surrounding the permitting process. Another risk is the proportionally higher waste production per unit of energy produced compared to large reactors. For some designs, there is a risk of low involvement of Czech companies with regard to the modularisation of construction if the Czech Republic does not take the opportunity to localise production. The SMR sector is now becoming established in Europe and worldwide and the Czech Republic can play an important role in it thanks to its industry and experience not only in the Central European region. Both the European Commission and the European nuclear industry have declared their interest in the new sector in the context of energy transition. Small modular reactors are also currently included in the Net Zero Industry Act's draft regulations as a so-called zero-emission technology. The basic step is a consensus on the inclusion of SMR technology in the State Energy Policy of the Czech Republic. Despite this, some uncertainties persist today with potentially significant implications for the future of the energy sector in the Czech Republic and the possible role of SMRs, from the EU electricity market reform, international efforts to harmonise SMR legislation, to the government's consideration of the nationalisation of energy assets. For this reason, there are tasks at the end of the document that will have to be resolved in cooperation with all stakeholders on an ongoing basis depending on the above-mentioned, especially by finding a consensus on how to finance and publicly support the construction of SMRs for selected investor models, including the possible use of the Low Carbon Act. Without the participation of the State, it will not be possible to use the maximum potential of SMRs in the Czech Republic, which can be an important agenda in terms of ensuring energy security. At the same time, the State must guarantee national security in the context of SMRs, as it does for large nuclear power plants, in terms of nuclear safety, physical security, radiation protection, personnel and competence or other threats to the public interest through existing and new regulatory and legislative instruments.

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1 INTRODUCTION

„The wave of innovation in SMRs has the potential to reshape the way society and industry produces and uses energy. The next five to ten years is going to be pivotal in terms of getting these new technologies to market.

William D. Magwood, IV, Director General of the OECD Nuclear Energy Agency

Small and medium-sized reactors (SMRs) are defined in this document, in line with the International Atomic Energy Agency (IAEA) definition, as nuclear reactors with an electrical output of up to 700 MW[1] with the possibility of modular design. SMRs have the potential to simplify production and construction of nuclear installations and address the demand for lower-capacity plants and lower overall cost of low-carbon energy generation. Outside of Russia and China[2], SMRs have not yet been commercially deployed. One of the first projects is expected to be GE Hitachi's 300 MWe BWRX boiling water reactor project in Canada in 2028. Competing manufacturers declare that they will be ready to start building their prototypes at that time and are already establishing partnerships with energy and industrial companies in the European Union (EU), including the Czech Republic. Although manufacturers differ in their approach to modularity, all designs in the pressurised water and boiling water reactor category are technologically comparable with the only major difference being the size of their power output and, in the case of boiling water reactors, different requirements for radioactive waste management. More than 2 GW of installed SMR capacity can be expected in the EU by 2035 (approx. 10 SMR units), based on the currently available data.[3]

We consider SMR to be a technology applicable alongside large nuclear reactors. According to CEPS's Assessment of resource adequacy of the Czech electricity system until 2040, not even new renewable energy projects together with four new large reactors will cover the self-sufficiency needs of the Czech Republic and up to 3 GWe of additional power will be needed by 2050. According to the National Energy and Climate Plan of the Czech Republic (2023), the expected capacity generated by nuclear new build in 2050 will be ca. 4GWe. This estimation will be refined as the work on the State Energy Policy progresses.

Traditionally, power units with large nuclear reactors have been used to cover the base load of the electricity system; in some countries they are also used for balancing and so-called load following (e.g., in France). SMR power units are also capable of operating in load following mode to provide power control in a grid with a high proportion of intermittent sources and co-generation, and are thus also suitable for heating purposes. About half of the Czech heating industry consists of coal-fired power plants supplying heat to the district heating system. In view of the intention to maintain district heating (DH), SMRs are a suitable substitute for coal-fired sources. In view of the lower heat consumption in the summer months and the European hydrogen strategy, SMR technology is also promising for hydrogen production. The EU taxonomy for sustainable investment currently provides a classification of „sustainable" economic activities and includes the construction and safe operation of new nuclear installations for which the competent authorities of the Member States have issued a construction permit by 2045 in accordance with the applicable national legislation for the production of electricity or heat treatment, including for district heating or industrial processes such as hydrogen production (new nuclear installations), as well as safety upgrades. SMRs are an opportunity to ensure the necessary power and thus energy security of the Czech Republic, a high level of self-sufficiency and to meet decarbonisation commitments in an environment where the applicability of other sources for heat, electricity and hydrogen production is limited.

Given the legal framework, human resource experience and the state of the industry, the Czech Republic has the potential to become a leading country in the energy and industrial application of SMRs in the EU and to be an active player in the entire SMR ecosystem.[4] During 2022, the Czech Republic was actively involved in international initiatives, used the Nuclear Working Group programme to present national approaches to SMRs during its EU Presidency, and provided relevant government representatives with a detailed overview of the status of national preparations and the technology itself. SMRs can be a strategic orientation for the Czech Republic with benefits in energy, industry, supply chains and science. An active leadership role in the EU can bring a competitive advantage to the Czech Republic in the form of the development of existing and the entry of new companies in the nuclear energy sector, including the creation of new direct and indirect jobs.

The application of SMRs in the low-carbon economy of the Czech Republic is expected in the 30s to 40s of the 21st century, when SMRs will be the solution in energy supply for households and energy and industrial enterprises. It can be assumed that the projects would follow one after the other and in the first phase, one or a maximum of two construction projects can be counted on. SMRs are a high value-added opportunity for Czech industry and, due to their high expertise requirements, can play an important role in supply chains and represent a great export potential. At the same time, they can reduce the threat of the relevant part of the Czech energy industry moving abroad (e.g., to Asia). They represent the following opportunities:

- **Developing a new economic focus:** leveraging regulatory and technological expertise and offering it for use in the EU and third countries, creating conditions for Czech companies to join the ecosystem of SMR manufacturers for supply to third countries, high positive impact on the economy with lower investment,
- **Maintaining nuclear know-how:** becoming a centre of competence, i.e., expertise, services and production in the field of SMR, making nuclear education more attractive, localising new science and research projects,
- **Strengthening the Czech Republic's position in the nuclear energy sector:** establishing a partnership with the country of origin of the manufacturer and seizing the opportunity of a long-term partnership,
- **Implementing the Czech Republic's decarbonisation strategy:** accelerating the transition to a low-carbon economy and the associated fulfilment of international commitments and related climate targets.

1.1 Objectives

This document is based on the Programme Statement of the Government of the Czech Republic[5] from January 2022, which states the task: „We will strengthen research and development and international cooperation in the nuclear energy sector and prepare a framework for the use of small modular reactors in the Czech Republic" and the provisions of the Coalition Agreement[6] for the 2021-2025 election period: „We will support the research and development of smaller modular reactors and

[1] The IAEA defines a small reactor as having an electrical capacity up to 300 MWe and a medium reactor as having an electrical capacity up to 700 MWe.

[2] The Akademik Lomonosov floating nuclear power plant with two KLT-40C reactors, each with a capacity of 35 MWe, was commissioned in the Russian Federation in 2019. In China, the Linglong One SMR is under construction with a 126 MWe ACP-100 reactor expected to commence operation in 2026. Both projects use third-generation reactors. In addition, the HTR SMR reactor, classified as a fourth-generation reactor, has been in operation in China since 2021.

[3] Tractebel/ENGIE (2023): SMR-Market analysis in the EU.

[4] The potential of the Czech research and industrial capacities and experience offers the possibility of building production and SMR capacities for the needs of the Czech Republic and other Central European countries.

[5] https://www.vlada.cz/assets/jednani-vlady/programove-prohlaseni/programove-prohlaseni-vlady-Petra-Fialy.pdf

https://www.vlada.cz/assets/media-centrum/dulezite-dokumenty/Koalicni-smlouva-SPOLU.pdf

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the Czech Republic's involvement in international cooperation." It also responds to the International Energy Agency's 2021 recommendation to „develop a plan to identify the potential role of small modular reactors in the Czech energy system, particularly in decarbonising the industrial and district heating sectors."

The Standing Committee for the Construction of New Nuclear Power Sources in the Czech Republic (Czech Nuclear Committee) concluded at its 6th meeting on 20 September 2022 that SMRs should be considered in the context of the State Energy Policy of the Czech Republic (SEP) and assigned the task of preparing this Roadmap. Its main objective is to outline the necessary steps for a decision regarding preparation of a framework for a successful construction and operation of SMRs in the Czech Republic. With regard to energy needs, the Czech Republic will only consider light-water projects with planned commercial availability around 2030 from suppliers whose countries have joined the World Trade Organization's Agreement on Government Procurement (i.e., excluding Chinese and Russian projects, which are therefore not mentioned in this document). Advanced reactor technologies are only considered for commercial deployment after 2040, given their high level of innovation and licensing uncertainties, and are therefore only mentioned in this document in the context of the end of the fuel cycle.

The Roadmap analyses the current state of readiness of the Czech Republic and Czech industry for the use of SMR technology and associated opportunities. It makes recommendations based on consultations with the government, industry, the financial sector, and the research and development sector. The Roadmap will form the basis for decisions of the Czech Nuclear Committee and the Government of the Czech Republic on further steps in the area of SMRs with regards to the update of the SEP and the Spatial Development Policy of the Czech Republic. It recommends creating conditions that will enable the construction of SMRs in the Czech Republic and advance the Czech industry, and setting non-discriminatory conditions for all entities interested in the SMR technology in the Czech Republic.

[7] https://www.iea.org/reports/czech-republic-2021
[8] Fast reactors, salt cooled reactors, gas cooled reactors, etc.

1.2 Sources and authors of the Roadmap

Primary (original) information sources were discussed with stakeholders at the Working Group on the Applicability of Small and Medium-Sized Reactors (WG SMR), which commenced its activities in February 2022 and was formally launched at the 6th Czech Nuclear Committee meeting on 20 September 2022 (the topics of the WG SMR meetings and their conclusions are presented in Annex A). In addition, primary sources included individual consultations, participation in international working groups (see Chapter 2.4) and meetings of the European Nuclear Forum. Secondary information sources were used in the form of background studies (see Chapter 2.1) and European SMR pre-Partnership documents. The Roadmap was written by the Ministry of Industry and Trade (MIT) officials who consulted it at the WG SMR which consisted of Ministry for Regional Development, ČEZ/EDUII, SÚJB, MIT, MoE, Office of the Government, and Nuclear Research Institute (ÚJV) representatives. Consultations with stakeholders were conducted under the leadership of the MIT from February 2022 in a broad forum with a high guest participation (industry associations, energy companies, regions, energy industry suppliers, the banking sector, export and credit institutions). The MIT signed non-disclosure agreements with leading SMR manufacturers in 2021 and 2022 in order to gain access to confidential information about projects under development. As part of the information sharing through a request for information, fact-finding missions to individual manufacturers to get an update on the actual status of projects took place during the spring and summer of 2022. These missions were undertaken jointly with the SÚJB and representatives of the ČEZ Group.

2 BACKGROUND AND CONTEXT

SMR power units have the potential to be a suitable replacement for coal-fired units and large CHP plants with the aim of decarbonising them. In the context of high-performance large-scale nuclear or, conversely, climate-dependent renewables, SMRs are potentially the missing link between the two, capable of providing both stable power output and a degree of flexibility similar to today's coal-fired sources. This implies a degree of decentralisation for SMRs on a local scale at the level of industry, cities and regions, e.g., for the heating sector in conjunction with district heating. In the future, they can, together with renewables, form a „backbone of the European zero carbon energy system", while requiring lower backups and reserves, compared to sources at the power level of 1 GWe and above. Compared to large reactors, SMRs can have a higher comparative investment intensity (mil. CZK/MWe) due to their lower economies of scale. This disadvantage can be compensated by economies of volume. Given the lower overall capital expenditure, investing in SMRs may be more affordable compared to large nuclear power plants. However, the necessary investment will likely still require some form of State aid.

2.1 Available background analyses

a. Small-scale nuclear reactor for heat and power generation in the Czech Republic (TIP programme, FR-TI4/280, completed in 2014)

b. Applicability of small and medium-sized nuclear reactors in the Czech power sector (THETA programme, TK03010119, completed in 2022), hereinafter referred to as „Applicability Study"

c. Interactive seismic hazard map of the Czech Republic (THETA programme, TK03010160, to be completed in mid-2023),

d. The National Energy and Climate Plan of the Czech Republic (MoE/MIT, 2023)

e. Analysis of the system integration of nuclear power sources (SMR and large units) and P2G into the Czech electricity and heating sector (THETA programme, TK04010084, to be completed in 2024),

f. Assessment of decarbonisation of district heating in the Czech Republic (MIT, June 2022),

g. Assessment of resource adequacy of the Czech electricity system until 2040 (MAF),

h. Market framework for financing small nuclear (Expert Finance Working Group on Small Nuclear Reactors, 2018)

i. Small Modular Reactors: A new nuclear energy paradigm (IAEA, September 2022)

j. Annual Energy Outlook 2023 (US Energy Information Administration, March 2023)

k. The NEA Small Modular Reactor Dashboard (NEA/OECD, March 2023)

l. SMR-Market analysis in the EU (Tractebel/ENGIE, May 2023)

m. Projected Costs of Generating Electricity 2020 (IEA, 2020)

n. Questionnaire survey on Czech SMR designs (MIT, February 2023)

2.2 Government documents related to the preparation of SMR construction in the Czech Republic

The Roadmap builds on the objectives set out in the current SEP, which defines nuclear energy as one of the pillars of the Czech Republic's energy mix, with a 46-58% share (by 2040) in the target structure of electricity production. At the same time, the document extends this assumption with regard to the current developments within the framework of European legislation and the Czech Republic's commitments with an emphasis on the decarbonisation of the economy.

Within the framework of the so-called Coal Commission, the Czech Republic expects to move away from coal between 2033 and 2038. The government's programme statement envisages an earlier departure. This assumption is the impetus for finding alternatives to heating and electricity production, and SMRs have promising applications in this respect.

The significance of the document lies in the introduction of the topic of SMR technology into the energy and industrial perspective of the Czech Republic and its subsequent incorporation into the SEP, the National Action Plan for the Development of Nuclear Energy in the Czech Republic (NAP NE) and the Radioactive Waste (RW) and Spent Nuclear Fuel (SNF) Management Policy. These strategic documents are a prerequisite for the inclusion of the technology in spatial development policies and plans.

2.3 Energy needs of the Czech Republic until 2050 and conclusions for SMR construction

2.3.1 Electricity system balance outlook

MAF forecasts the Czech Republic will gradually become more dependent on electricity imports beyond 2025. By 2050, there is a risk of an overall shortage of electricity within Europe and therefore limited import possibilities to the Czech Republic. CEPS evaluated a total of four scenarios until 2040 (respondent, conservative, progressive, and decarbonisation), while the decarbonisation scenario, with the aim of meeting the commitments of the Green Deal for Europe, was evaluated for the MIT until 2050. This scenario leads to a significant increase in electricity consumption. The conclusions of the MAF decarbonisation scenario show that even with the construction of four large nuclear reactors at the Dukovany and Temelín sites with a unit capacity of 1.2 GWe, the use of the maximum allowed electricity imports (i.e., at 90% self-sufficiency) and the deployment of gas-fired plants, there will be a serious resource inadequacy in the electricity system in 2050 which will require timely measures and investment incentives. The capacity deficit in this scenario is approximately 2.8 GWe. According to its analyses, ČEZ also confirms the amount of the required additional supply at the level of up to 3 GWe. The other scenarios presume slower growth in electricity consumption, a lower overall electrification rate and a more gradual decline in coal use, and thus show less severe impacts on resource adequacy in 2040. Projections used in the National Energy and Climate Plan of the Czech Republic foresee lower assumptions of the required output of the total nuclear new build - ca. 4GWe. This is however contingent on a variety of constants and conditions. Projections used in the SEP will therefore be further refined and cross-checked with other studies (including MAF).

If all available energy technologies, including SMR, are not used, simulations confirm a serious risk of the Czech Republic being unable to provide not just energy at affordable prices, but most likely not enough energy for the needs of the economy (even assuming the massive development of renewable energy sources - RES, storage and import of electricity).

2.3.2 Energy balance outlook in the heating industry

Based on the study Assessment of the Decarbonisation of District Heating in the Czech Republic[9], approximately 1.7 million Czech households (about 4 million inhabitants) are currently served by district heating, with coal remaining the dominant fuel. According to current statistics concerning the holders of thermal energy production permits, the production of heat from coal is approximately 55%.

Phasing out coal in the heating industry as early as the 2030s will represent a loss of 52 PJ from the present total of 88 PJ. The main objectives of the Czech Republic are to maintain efficient district heating, to use high-efficiency co-generation, and to emphasize domestic sources (nuclear, RES, waste ...) supplemented by gas. SMRs are a promising clean and efficient co-generation replacement for coal-fired sources connected to district heating networks. Other heating alternatives are emission sources (biomass, biogas); they imply the need to increase the already high demand for electricity (heat pumps) or include unavailable technologies utilising geothermal heat.

2.3.3 Hydrogen economy

The Hydrogen Strategy of the Czech Republic[10] foresees a need for about 1.7 million tonnes of low-carbon hydrogen in 2050 (mostly in transport – 0.8 million tonnes, in metallurgy - 0.4 million tonnes, and in the chemical industry - 0.2 million tonnes). It regards the use of temporarily available electricity from nuclear generation as promising in this respect. However, even the expected temporarily available electrical power may not be sufficient. For the purpose of hydrogen production from nuclear power, it is crucial to set a European framework which, apart from including hydrogen production using new nuclear power plants in the taxonomy of sustainable finance, does not currently consider emission-free hydrogen production in nuclear installations. The first step towards setting the conditions is the delegated act to the Renewable Energy Directive (C(2023) 1086), which includes a calculation methodology to allow the specification of hydrogen from nuclear power plants as green, provided conditions are met. In order to be considered low-carbon, a threshold amount of emissions related to the production of hydrogen must not be exceeded. The legislation presupposes setting a stricter limit on this value after 2031. According to current proposals by several Member States, it is possible that the value of the emission saving will be increased from 70% to the taxonomic value of 73.4%, i.e., 3 kg CO2/1 kg hydrogen. The European Commission envisages the creation of an EU-wide certification system so that different types of hydrogen can be compared. Certification should operate on the basis of a methodological approach that assesses the total life-cycle emissions of greenhouse gases. The European Commission has set the date for the publication of the methodology for calculating low-carbon hydrogen emission savings by means of a delegated act for the end of 2024. There is currently talk at EU level that the rules for low-carbon hydrogen production should be similar to those for non-biological renewable fuels.

Hydrogen production using the electricity generated from the heat of the SMR is possible at load reduction in the energy system and at full reactor capacity. Maximising the reactor power output will support the economic efficiency of the SMR unit. An SMR unit with electrolysers can use the generated electricity to hydrogen produc-

[9] https://www.mpo.cz/assets/cz/energetika/strategicke-a-koncepcni-dokumenty/2022/6/Posouzeni-dekarbonizace-dalkoveho-vytapeni-v-Cesku_final.pdf
[10] https://www.mpo.cz/assets/cz/prumysl/strategicke-projekty/2021/8/Vodikova-strategie_CZ_G_2021-26-07.pdf

tion, thus shifting utilizing the full power of the nuclear reactor. This avoids unnecessary degradation of nuclear reactor technology from power changes. In terms of hydrogen production, the technology under consideration allows the use of low-temperature electrolysers operating at temperatures around 60 °C and controlling the reactions primarily by electrical energy. The heat for low temperature electrolysers does not need to be supplied, only the electricity produced in the SMR. Some manufacturers declare the possibility of expansion by electrically heating the input medium (e.g., solid oxides) to temperatures above 800 °C.[11]

The choice of SMR technology must be complemented by the appropriate placement of the electrolyser. Hydrogen is an extremely flammable gas that will affect nuclear safety. Siting must comply with the requirements of applicable legislation, including the designation of emergency planning zones and other risk protection areas subject to the assessment of the SÚJB. For the sake of completeness, in addition to hydrogen production, other energy storage options such as synthetic low-carbon fuels are also considered, under the same conditions of SÚJB assessment as for hydrogen.

2.4 International cooperation in the preparation of SMRs

Internationally, SMRs can be a tool to secure the national economies of some countries that will seek to develop them in the context of climate change and global energy security. It is clear from the declarations made so far by individual countries and the industry that a competitive environment is already emerging. Interest in the construction of over 80 SMR units has already been declared in the Central European region. Manufacturers here have also started to enter into memorandums of cooperation with the industry. Some regulators have started to cooperate and have signed memoranda of cooperation with a view to jointly assess the designs of specific manufacturers.

In 2022, the IAEA established the Nuclear Harmonization and Standardization Initiative (NHSI), in which the SÚJB participates. The Czech Republic is a member of the SMR Regulators' Forum at the IAEA through the SÚJB, whose working groups also include the SÚRO and the MIT, which is also a member of the SMR Technical Working Group. The OECD Nuclear Energy Agency (NEA) is working with industry on the thematic areas of „technology“, „enabling conditions“, „deployment and markets“ and is publishing an updated design readiness dashboard (NEA SMR Dashboard) and launching the Accelerating SMRs for Net Zero initiative in September 2023 to assist interested countries in accelerating the preparation of the SMR deployment environment, with industry and the non-profit sector participating on a voluntary basis. The MIT monitors 91 SMR-related activities in various NEA working and governing bodies and participates in the NEA Steering Committee. At the European level, the preparation of the so-called European SMR pre-partnership is progressing very slowly and conclusions can be expected in about three years. In addition, there are duplicate structures when mapping the national regulation of participants with possible directions of development. The European Commission is leaving the preparation up to the industry (nucleareurope and the Sustainable Nuclear Energy Technology Platform); it has not yet assessed progress since the discussion started in June 2021 and Member States have not yet been invited to the negotiations. The SÚJB participates in the working group for the permitting process. Czech industry was involved in the introduction of the pre-Partnership. In April 2023, the European Commission, together with industry, declared that SMRs are an opportunity to further improve nuclear safety (through the inherent safety features of SMRs) and increase grid stability in the context of the growing presence of renewables.[12] Small modular reactors are also currently included in the proposed Net Zero Industry Act (COM(2023) 161) among the so-called zero-emission technologies. As a result, the regulation should have a positive impact on increasing the required production capacity, the faster deployment and expansion of small modular reactors by simplifying the necessary administrative procedures and licensing processes, and possibly other instruments included in the Regulation. In the research field, effective activities are ongoing in the framework of ELSMOR (Euratom project 847553, until the end of 2023) or TANDEM (Euratom project 101059479, until the end of August 2025) and general coordination in the framework of the SET Plan (IWG 10 with a representative of the MIT). The EU started a political dialogue on SMRs with the US in 2019, but there is no concrete cooperation and no targets have been set.

Cooperation on permitting or pre-licensing information exchange between the regulator of the country of origin and the regulator of the country of construction or the regulator of the country where the first design permit will be granted will be essential. The cooperation of the SÚJB with the French ASN and the Finnish STUK on a test case for possible future cooperation in the evaluation of designs prior to the licensing phase and comparison of legislation and approaches for the Nuward design under development was initiated. Discussions are underway with SÚJB on the possibilities of cooperation with other foreign regulators.

[11] For real projects, it will be useful to perform a verification analysis to calculate which method will be more cost-effective in the context of SMR unit operation modes.
[12] Declaration on EU SMR 2030: The role of Research, Innovation, Education and Training in the safety of Small Modular Reactors (SMRs) in the European Union

To accelerate the progress of cooperation, there is the possibility of an intergovernmental agreement to establish a structure for governments to collaborate on a specific project with specific objectives, to cover the use of the supply chain and the selection of technology. An intergovernmental agreement is not required for the actual use of export financing. Export banks have their own rules and thus the ability of the government to interfere in their terms and conditions is limited.

Cooperation between countries or concerns on a cross-border fleet approach, i.e., implementing synergies in the construction and operation of multiple SMR units in countries within a region, is not yet a topic. Each non-state investment will be consistently examined in terms of ensuring the security interests of the Czech Republic in accordance with Act No.34/2021 Coll., on the examination of foreign investments and on amendments to related acts (Act on the Examination of Foreign Investments).

2.5 SMR licensing in the Czech Republic

SMR technology represents an innovative direction in nuclear power, responding to the need for smaller nuclear source capacity, non-electric applications, easier construction and lower cost of the plant as a whole. Below are the main characteristics, specifics and expectations. An overview of selected designs including parameters is given in Annex B.

The benefits of SMRs are anticipated in the following areas:

a. Modularity and standardisation enabling serial factory production - the possibility of off-site preparation of components and technology in controlled conditions of the production plant, including testing and quality assurance with subsequent import and assembly of finished parts to the site with a positive impact on the length and reliability of construction (mitigation of construction risks).

b. Investment intensity - despite potentially higher unit investment costs, the total nominal investment in SMRs will be significantly lower than for large sources. This will allow investment in the project by a wider range of stakeholders, including the involvement of private capital.

c. Dimensions - the size of the modules and other components is typically optimised for transport, although some manufacturers specify significantly large and heavy components, and the size of the plant is comparable to today's CHP plants, i.e., they are a prospect for replacement.

d. Environment - lower water consumption and the possibility of dry cooling.

e. Safety - one of the objectives is to reduce the need for emergency protective measures so that the Emergency Planning Zone (EPZ) is required only at the boundary of the nuclear installation site due to the lower risks associated with operation. Lower probability of a severe meltdown accident and a large release of radioactive materials outside the reactor safety envelope. In most cases, passive security systems are common.

f. Construction duration and schedule adherence - construction is expected to take 3-5 years; given the standardised production and construction, there is a lower risk of changes, repairs and project delays in the case of multiple installations (NOAK in a given country) than in the case of large units, which take at least 6-7 years to build if there are no delays.

g. Low-emission power generation - nuclear sources have emissions at the level of wind power plants.

h. Stability of electricity supply and flexibility - SMRs allow a degree of power flexibility and have the potential to stabilise the grid, especially when combined with hydrogen generation.

i. More efficient use of human resources in construction - SMRs require a lower overall number of construction professionals. Factory production allows for greater long-term productivity of the workforce 24/7 compared to one-off construction projects.

j. More efficient use of human resources for operation - SMRs, thanks to their passive systems and higher levels of automation, require fewer staff to ensure operations.

k. Non-electrical applications - SMRs enable combined heat and power generation, hydrogen production, and to some extent (due to the power range) the provision of ancillary services to the transmission system.

Prerequisites for the applicability of SMRs in the Czech Republic

a. Compliance with the security interests of the State

b. Public support

c. State and regional support

d. Suitable natural conditions and absence of sources of danger, distances from other countries, demographic conditions

e. Stable and transparent investment conditions (legal and regulatory framework, possible public support in case of market failure, etc.)

f. Modification of the current nuclear legislation, and timely completion of the licensing procedure (foreign projects) and the ability of suppliers to successfully complete it in the Czech Republic or prepare for it

g. Timely commencement of production and delivery of all necessary long-lead items, such as the reactor vessel

h. Securing financing, especially for the first projects in the Czech Republic

Risks of the technology

a. Technology readiness - risk of delays in first projects or changes in the economic and technical parameters of construction and operation compared to assumptions.

b. Legislation & Regulation - uncertainty in the regulatory approval process for new technology - especially for conceptually significant innovative designs.

c. Securing nuclear fuel supply - unreliability of the supplier, unavailability of diversification.

d. Radioactive waste - the risk of proportionally higher waste production per unit of energy produced compared to large reactors, or radioactive waste generated during non-standard (emergency) operational events.

e. Economic risk - with regard to the modularisation of construction, there is a risk of a low involvement of Czech companies if the Czech Republic does not take the opportunity to localise production.

f. Excessive interest - in view of the interest declared globally, there is a risk of overloading production capacity and postponing construction in the Czech Republic beyond 2040.

g. Lack of relevant experience - risk of new, untested and unproven design elements that place increased demands on component manufacturing, construction, and subsequent operation, including in terms of the required expertise of the operator's personnel and its suppliers

h. The human factor - new technology places increased demands on human resources, both qualitative (lack of expertise and experience with the new technology) and quantitative (the required experts may not be sufficient at the time, also due to parallel demand for human resources across the EU and elsewhere

Aspects of choosing a particular design:

a. Investor preferences and their willingness to bear the risks associated with the permitting process and construction

b. Readiness and ability of the technology supplier to meet the conditions set by the investor, especially in the areas of risk sharing, licensing, technology transfer, financing, etc.

c. Technological readiness, e.g., according to the Technology Readiness Level methodology proposed in the Applicability Study[13] (see Annex C), licensing status, etc.

d. Possibility of licensing in the Czech Republic - close link to Czech experience in the field of nuclear technology

e. Safety features - proven technologies, passive systems

f. Benefit for the Czech economy - securing energy supplies for industry, involvement of Czech companies in the supply chain of a supplier, or production localised in the Czech Republic

g. Project economics and cost of energy produced - various designs can achieve significantly different parameters depending on the specific technical solution

h. Suitability for the site in terms of infrastructure (connectivity, transportability, environmental impact)

i. The ability of the contractor to provide the investor's preferred delivery model (e.g., declared turnkey implementation)

j. Human resource requirements and provision

k. Market potential of the technology - sufficient demand to enable the creation of the necessary production base

The SÚJB is limited in its ability to draw on older experience as SMRs are still under development. At the international level, the SÚJB cooperates on all available platforms for sharing and exchanging information (SMR Regulator's Forum at the IAEA, NHSI, WENRA, NEA/OECD Innovation Working Group, cooperation with France, Finland, contacts with Canada and other countries at the bilateral or multilateral level) and tries to obtain and use as much relevant information as possible. The WG SMR discussed the problem that the Czech Republic does not have a legally established institute of SMR design approval or certification. However, the use of a similar institute of conformity assessment and mutual recognition applying to safety critical systems and components that will include systems under the SMR is not excluded. The current legislation on nuclear energy is applicable to light-water SMRs, which are based on well-known technologies and have a similar life cycle to large reactors, but will require modifications mainly at the level of decrees under atomic law, see Chapter 9. Given the factory nature of SMR production, the mutual recognition institute would be beneficial to avoid the need for repeated assessment and licensing of identical technology. Another possibility for speeding up the process without changing the legislation is, in the case of repeated evaluations of the same design, to shorten them within the existing administrative time limits, which are defined as the maximum, not as fixed. The question remains how many different SMR designs it is possible and sensible to allow in the Czech Republic. Coordination at the WG SMR level will avoid inefficiencies in the design selection process. A larger number of different SMR designs may be limited by professional and other capacities within the Czech Republic.

[13] Different organisations use different definitions, e.g., the EU or IAEA

2.6 Economics of SMRs

According to the latest data from the Annual Energy Outlook of March 2023, the SMR's comparative investment (i.e., per unit of electrical output) at the level of overnight costs (the amount of investment assuming that the power plant would be built overnight, typically not including financing costs) is in the range of approximately 125 to 165 million CZK/MWe. The data provided directly by the manufacturers and available to the MIT most often indicate values of around 120 million CZK/MWe. However, due to the absence of the first unit of its kind (FOAK), only the first projects will show the real price, which is also true for the effect of repeated construction on price reduction (results of the construction of more units).

	SMALL AND MEDIUM REACTORS	LARGE REACTORS
Module production [1/year]	1–2	-
Duration of construction [years]	3-4	6–7
Power [MWe]	up to 700	700 and above
Locations	current nuclear, brownfields	current nuclear
EPZ [km]	At the level of the power plant site	20 (EDU), 13 (ETE)
Size of the site [m^2]	26 000 - 141 000	1 230 000 (ETE)

Tab. 1 Indicative comparison of typical parameters of nuclear sources

According to a review by the International Energy Agency, nuclear power is generally able to compete with other types of electricity sources, as assessed by the LCOE (Levelized Cost of Electricity) indicator. We assume that SMRs at the LCOE level can reach values[14] close to the production cost of electricity from large reactors (the negative effect of possible higher comparative investment costs due to the absence of economies of scale, i.e. higher cost per plant, can be offset by economies of volume, i.e. more plants constructed, shorter construction time or co-generation use). The Applicability Study presents LCOE values for light-water reactors in the range of 1.4 to 2.1 thousand CZK/MWh (median 1.9 thousand CZK/MWh), which corresponds to 60 to 90 EUR/MWh (median 79 EUR/MWh). Depending on the sensitivity analysis of the individual parameters, in the case of WACC = 8% and an 85% capacity factor, it can reach a median of around 2.6 thousand CZK/MWh, which corresponds to roughly EUR 110/MWh. The results of the sensitivity analysis on the individual parameters according to the Applicability Study are presented in Annex D. These parameters and assumptions are analytical expectations, as there are no projects that have been implemented to date to confirm them in practice.

It must be stressed that the comparison of nuclear sources with intermittent sources of electricity is not objective on the basis of LCOE because they are characterised by different costs from the point of view of the system as a whole (need for backup, investment in grids, ancillary services, etc.) From this perspective, SMRs as dispatchable power sources with stable power output are less demanding and potentially more efficient than renewables.[15] The benefits of small, medium and large nuclear reactors will be taken into account in the SEP update.

The price of hydrogen produced through SMRs will be highly dependent on the actual cost price of electricity. However, according to the

[14] With a WACC of 5% and an overnight cost of 165 million CZK/MWe

[15] More appropriate comparisons can be provided by the International Energy Agency's VALCOE (Value-adjusted LCOE) methodology - an extension of the LCOE indicator to include terms reflecting the impact of the source on the grid, or (ii) LACE (Levelized avoided costs of electricity) - representing the value of the power plant to the grid and usually reported together with the LCOE; the methodology is used by the Energy Information Administration in the United States.

Applicability Study, the investment in a higher efficiency electrolyzer has a positive impact on this hydrogen price.

In terms of the total investment costs for SMR, the above-mentioned 2.8 GW of capacity will cost about 350-470 billion CZK (overnight costs at 2022 price level) based on the aforementioned data from the Annual Energy Outlook 2023 (these are current assumptions, actual values may vary). When considering designs at a high stage of development, the capacity is about 5-15 SMR units gradually connected to the grid in the 2030s and 2040s.

In view of market failure and the generally necessary State intervention in the construction of low-carbon sources (RES, new nuclear sources, etc.), or international recommendations in this sense to ensure financing and returns, it is recommended to examine public support mechanisms to ensure the construction of SMRs in the Czech Republic, both the existing institutes contained in Act No. 367/2021 Coll., on Measures for the Transition of the Czech Republic to Low-Carbon Energy (hereinafter referred to as the Low Carbon Act), and other institutes and instruments.

2.7 SMR applicability

2.7.1 Transportability

According to SMR manufacturers, the designs are developed in a way that will allow for transport to an assembly site, given the future factory production of the components. The components of SMRs analysed in this Roadmap are prepared with the possibility of transport by land, rail, and water in mind. Some manufacturers declare significant size and weight, with maximum size of ca. 6x8x28 metres for the largest components and maximum weight of between 200-600 tonnes, depending on the specific design. A prerequisite is therefore the safe transportability of all components to sites where SMRs are to be used, in particular current sites of CHP plants and coal-fired plants, where the necessary infrastructure is already in place. Any specific project must be examined in this regard, including any additional costs for permanent or temporary measures related to transport to the sites.

2.7.2 Aspects of the possible use of SMRs in terms of the „3S"

The „3S" concept, philosophically, legally and politically based on IAEA recommendations and international conventions and Euratom law, requires for all activities or facilities related to the use of nuclear energy or ionizing radiation to ensure Safety, Security and Safeguards, provided for in the Czech context by legislation on nuclear safety, radiation protection, radiation emergency management, security and the non-proliferation of nuclear weapons. These principal requirements apply not only to power nuclear installations, but also to nuclear research facilities and sites with sources of ionising radiation, so it is beyond doubt that they will also be applied to small and medium-sized reactors of all generations. It is likely that the approach to their implementation will be graded according to the level of risk associated with these facilities or activities, as is already the case, but certainly these principles and requirements will not be eliminated or minimised to a negligible level in the case of SMRs. SMRs will undoubtedly bring a number of simplifications in terms of the 3S, but overall, the need for safety, security and safeguards will remain. Below is an elaboration of the areas of security and safeguards, as the area of safety is a central focus of SMRs and does not require further commentary.

Security

Security is aimed at protecting nuclear materials and nuclear facilities against misuse, theft or sabotage, the ultimate goal of which is to cause an accident or to misuse them for terrorist or other unlawful acts. The purpose of security measures is typically to deter, detect, delay, defend/respond to such an attacker, and security uses various tools to achieve this purpose, typically various warning devices, detection systems, fences and other barriers, access control and registration, industrial television, guard services, etc. Any nuclear material or radionuclide sources are effectively exploitable in this manner (e.g., for the contamination of food sources, production of explosive devices that do not use fission – a so-called „dirty bomb", disruption of energy security by sabotage, etc.) as well as all nuclear facilities, albeit to varying degrees. Measures used to ensure safety pursue a different purpose and are not immanently simultaneously utilisable for security. Safety and security elements even often work against each other.

Security is based on assessing risks and then setting the appropriate level of measures and choosing specific tools accordingly. International requirements (also legally binding, e.g., the Convention on the Physical Protection of Nuclear Material and Nuclear Facilities) divide nuclear materials and nuclear facilities into categories and associate specific levels and intensities of safeguards with them. The basic element is the division of the surroundings of the material and equipment into concentric zones, to which access is controlled and increasing detection and protection measures are established. The risk assessment, based on the State-defined baseline project threat, must then be used to select the appropriate specific tools. In doing so, basic principles must be taken into account, such as limiting access to and protecting information, protecting against insiders, in particular by verifying and ensuring the trustworthiness of personnel, ensuring cyber security, management systems, quality and security culture, etc.

In the case of SMRs, the above-mentioned elementary assumptions apply without exception, because they are also nuclear facilities, can be misused in the ways described above and must be protected against such attacks. The same applies to nuclear-related materials, especially fuel, whether fresh or spent. Some safety design features that increase the level of safety compared to conventional nuclear installations can play a positive role from a security point of view, e.g., the compact and hermetic sealing of the primary circuit in the reactor vessel, which also forms the containment. However, even with such a solution, sabotage of the installation cannot be ruled out, e.g., by exposing it to explosion, fire or corrosive action, or by using personnel to deliberately damage the installation through its normal operating systems. Therefore, it is also true that SMRs will require adequate evaluation and follow-up in the area of security. These are unlikely to be identical in detail to the measures for conventional nuclear sources, but they will not differ in principle from them and will require all the elements mentioned above, as SMRs do not in principle deviate from the risks they are intended to prevent. These facts need to be dealt with, in part, at the design stage of the SMR.

Safeguards (non-proliferation of nuclear weapons)

Safeguards, in simple terms, are aimed at preventing the misuse of nuclear materials and certain other items used in the nuclear industry, e.g., to manufacture or operate nuclear installations for the purpose of developing or producing nuclear weapons. This is a very closely monitored international area of regulation of nuclear and related activities, which is based mainly on a set of international treaties consisting of the Treaty on the Non-Proliferation of Nuclear Weapons and the Safeguards Agreement and its Additional Protocol, which serve to implement it, as well as on international recommendations of the IAEA and its advisory bodies. In the field of Euratom law, the area is strictly regulated in particular by Commission Regulation (Euratom) No 302/2005 on the application of Euratom safeguards.

The essence of safeguards is the continuous control of where the abusable items are located, who has access to them (or preventing it), keeping records of them, controlling their movement, and verifying and ensuring that they are not handed over to unauthorised persons or entities that could abuse them. The basis of this control system is a precise definition of the items thus monitored. These fall into several categories (nuclear materials, selected items, dual-use items) and their lists are categorically legally established, with no distinction made as to which type of nuclear facility they relate to. For these items, the State must have an accurate overview of their location, movement and method of handling and decides to whom they are transferred. This places considerable demands on those who manufacture, import, distribute and use such items. In the safeguards area, therefore, not only designers, engineers and operators of nuclear facilities are regulated, but also a large part of the supply chain, as the items under review include not only systems, structures and components of nuclear facilities, but also machine tools, packaging assemblies, some measurement equipment, parts of such items, technology, the software and hardware used for these purposes, etc.

Requirements in terms of safeguards impact the SMR area without exception. The specifics of their technology, which are primarily security-related, do not inherently preclude or limit the abuse of such devices or their individual systems, designs and components for the development or production of nuclear weapons. For some of the designs under consideration, the opposite is even true. The same applies to the supply chain, which is essentially similar to that of traditional nuclear facilities. Proper non-proliferation of nuclear weapons necessitates that the requirements for such assurance be considered at the design stage, e.g., that the required monitoring equipment, seals, etc., be placed on the nuclear device. This may in turn place higher demands on some types of SMRs under consideration, particularly for designs that opt for compact and modular solutions. Future SMR deployments must also deal with these requirements.

The State must ensure a timely reporting obligation based on the requirements of the above-mentioned international law, which takes into account the requirements of Commission Regulation (Euratom) No 302/2005, arising from both the Safeguards Agreement and the Additional Protocol to that Agreement. Under the Safeguards Agreement, in particular, the timely obligation to provide information on the design of the planned and then already constructed SMR using the relevant form is required, which is sent to the IAEA and the European Commission within a predetermined timeline. The Additional Protocol then requires the transfer of information concerning research and development in the field of SMRs in the Czech Republic, as well as information on planned SMR construction in the Czech Republic to the IAEA, all within a predetermined timeline.

2.7.3 Liability for nuclear damage

Future deployment of SMRs in the Czech Republic must also respect the requirements associated with nuclear liability. The Czech Republic is currently a party to the Vienna Convention on Civil Liability for Nuclear Damage and related international treaties. These make demands in terms of compensation for damages that the operator of a nuclear installation is obliged to pay in the event of an accident. A similar regime applies to shipments of nuclear materials. The operator of a nuclear installation must compensate for damage up to a specified amount and have adequate liability insurance. In the Czech environment, this international legal regime is regulated by Act No. 18/1997 Coll.

From the perspective of SMRs, the current Vienna nuclear liability regime does not provide exceptions to standard nuclear installations. The future SMR operator should meet the same legal requirements and be prepared to invest accordingly in compulsory insurance. A higher SMR security level or a lower capacity level do not play a role in this respect. It should be noted that, internationally, there are other nuclear liability regimes which differ in the level of liability limits, mandatory insurance requirements, the compensation procedure, etc. (namely the so-called Paris regime).

From a practical point of view, a situation may arise in the future when designs from countries of origin applying different liability regimes (typically Western European and North American countries) will be deployed in the Czech Republic. Technology suppliers or investors, or even foreign-domiciled operators, may find the Vienna regime inconvenient for various reasons, or may be concerned about the incompatibility of their domestic regimes with the Vienna regime, which could place higher financial demands on them. The fact that some EU Member States reject these international regimes altogether and apply a general liability regime in the event of nuclear damage, i.e., unlimited and broadly procedural, may also pose a risk. This may be important in the event of accidents with cross-border impacts, which cannot be absolutely excluded given the position and size of the Czech Republic. These aspects could be overcome by a general international consensus, but for political reasons this cannot be achieved. Future SMR deployments must therefore take these circumstances into account.

2.8 Spent nuclear fuel and radioactive waste management

Responsibility for the safe management of radioactive waste (RW) and spent nuclear fuel (SNF) in the Czech Republic is divided between the holder of RW management licence (collection, sorting, processing, treatment and storage of radioactive waste) and the State, represented by Radioactive Waste Repository Authority (SÚRAO), which is responsible for the safe disposal of RW. The SMR operator must base its RW management strategy on applicable legislation and take into account the principles, objectives and recommendations set out in the Radioactive Waste and Spent Nuclear Fuel Management Policy. The operator must inform SÚRAO about its management strategy, that is, the expected quantity and nature of the RW generated. SÚRAO operates Czech radioactive waste repositories and is preparing a project for a deep geological repository of radioactive waste, including spent nuclear fuel. The method of treatment and processing of RW and management of SNF from nuclear new build will depend on the selected supplier of reactors.

2.8.1 Management of SNF

In terms of quantities of SNF and operational waste, predictions for storage capacity requirements from SMRs will need to be continuously refined and updated once the technology supplier (pressurised water and boiling water reactors) is known. To illustrate, the amount of SNF expected to be disposed of from SMRs, i.e. after the cooling phase and its declaration as RW, should not be problematic for disposal in a deep repository at an operation length of 60 years and at a total expected installed capacity of 2.8 GW with an annual electricity production of 21 TWh (85% utilisation factor), but the refinement of inventory estimates is desirable for the deep repository design (illustratively derived from data for large reactors, this is a mass of approx. 5.5 tonnes and a volume of 250 m^3 over the lifetime of the indicated capacity). The estimated amount of SNF that could be declared as RW and deposited in a deep repository is not negligible in terms of quantity; on the contrary, after the storage process (dry cooling), it is a significant contribution to the inventory, which will be reflected in the sizing of the deep repository and may even play a role in the evaluation of sites for the final location of the repository. However, from the point of view of the four identified deep repository sites, this requirement for repository capacity should be provisionally valid[16]. Nevertheless, the characteristics of these wastes (or the radionuclides contained therein) will need to be specified in the future in order to meet the limits and conditions for safe operation of the repository. Should the operator decide to reprocess the SNF (MOX fuel, REPU fuel, or the preparation of a Generation IV SMR reactor with a different fuel cycle than PWRs and BWRs) based on economic analyses and availability of uranium stocks, an inventory of the RW generated after reprocessing will need to be defined.

For SMRs based on Generation III reactors, typically, according to the manufacturers' information, after wet cooling of the SNF, it is expected that it will be stored in a warehouse (dry cooling) before expected storage in a deep repository or reprocessing, as is the case for large reactors. Existing SNF storage facilities in the Czech Republic are located on the premises of nuclear power plants owned by ČEZ with new ones under construction. The construction of an SNF storage facility in the vicinity of each SMR represents an inefficient increase in costs for its construction and security, permitting procedures and risks associated with public opinion. In addition to the possible use of the existing on-site warehouses in ETE and EDU (or expansion of their existing capacity), the possibility of building a central warehouse exists; such a location may be the ČEZ back-up option „CSVJP Skalka" south of the town of Bystřice nad Pernštejnem in the Žďár nad Sázavou district - see Article 169a Sk2 of the Czech Spatial Development Policy and Diagram 10. The possibilities of implementation, expansion and operation of the Skalka warehouse or preparation of a new central warehouse need to be analysed. It will also be necessary to analyse the conditions for transporting SNF from power reactors, which are not yet implemented in the Czech Republic.

2.8.2 Radioactive waste management and storage capacity

From the perspective of RW management, a far more significant obstacle to SMR implementation in the Czech Republic is the provision for storage capacity for RW from the operation and decommissioning of these facilities (very low-, low- and intermediate-level RW). It is clear from the RW and SNF management policy, that the Dukovany repository will not have the capacity to accept waste from more than one new plant. Boiling water reactors are expected to produce larger amounts of liquid RW and activated material per reactor capacity during decommissioning. Thus, there is still a need to prepare and assess options for providing additional capacity (by expanding the existing Dukovany repository under the management of SÚRAO, or by building new repository facilities, or by building these facilities on the site of the planned deep geological repository). The operation of nuclear reactors during decommissioning generates RW that cannot be disposed of in near-surface storage. This is a part of the activated material stored for the entire period of operation at the NPP site. This waste will be treated as part of the decommissioning of nuclear installations so that it can be accepted into a deep repository together with any SNF after it has been declared RW in accordance with the legislation. Concrete containment units with outer and inner steel cladding (so-called concrete containers) were designed for their placement. The RW and SNF Management Policy takes these into account both in the decommissioning of existing nuclear sources and in the preparation of new large sources.

Ensuring capacity for any new nuclear installation, including SMRs, is one of the technical screening criteria of the European Commission regulation on the EU Nuclear Energy Taxonomy for the radioactive waste management system. The issue of providing capacity for operational RW is addressed by the task given by Government Resolution No. 24/2023[17], whereby the adoption of this study will also require the assumed inventory to be expanded by a contribution from the SMR on an ongoing basis when updating the RW and SNF Management Policy.

2.8.3 Radioactive waste storage and decommissioning costs

The holder of the RW management permit or the operator will contribute a regular fee to the so-called nuclear account, the amount of which is determined by Title V of the Atomic Act and should be continuously updated in relation to the applicable SEP and the RW and SNF Management Policy. Thus, the permit holder bears all costs associated with the management of RW after its disposal, including the monitoring of the repository after its closure. This fee generally applies to power nuclear sources that are used primarily for the production of electricity; in the event that a co-generation SMR source is built primarily to perform the function of providing heat during the heating season, a new category of fee derived from the heat produced needs to be defined in the provisions of Section 121 of the Atomic Act.

From the time of the issuance of the SMR reactor physical start-up permit, the operator will continue to build up reserves for the decommissioning of the nuclear installation in an escrow account until power generation is terminated. The method of establishing these reserves and the proceeds thereof is governed by the Atomic Act and Decree No. 250/2020 on the method of establishing a reserve for the decommissioning of a nuclear installation and Category III and Category IV workplace, as amended.

[16] Butovič et al. (2020): Evaluation of potential deep repository sites in terms of key technical feasibility criteria. - TZ 457/2020, SÚRAO, Prague.

[17] Vondrovic et al. (2022): Evaluation of the impact of the Commission Regulation on the EU Nuclear Energy Taxonomy on the radioactive waste management system in the Czech Republic in relation to the activities of SÚRAO. - TZ 601/2022, SÚRAO, Prague.

3 ECONOMIC BENEFITS

A nuclear power plant project has an impact on the country's economy on two levels: (i) economic activity during construction and (ii) economic activity during its operation, including the decommissioning phase. The economy is further impacted by the export potential of existing local industry abroad. The prerequisites for maximizing the economic benefits of SMR construction and production in the Czech Republic are (i) the localisation of production for both domestic and foreign projects, (ii) readiness of Czech suppliers to participate in projects, and (iii) sufficient competent human resources. The following table illustrates the economic impact of the Czech nuclear industry:

ECONOMIC IMPACTS OF THE NUCLEAR INDUSTRY IN THE CZECH REPUBLIC IN 2019 [BILLIONS OF EUR]	GDP	HOUSEHOLD INCOME	REVENUE OF PUBLIC BUDGETS	NUMBER OF WORKERS
Total	11,7	8,6	5,5	29 600
of which				
direct impacts	3,1	3,2	1,7	11 200
indirect impacts	8,6	5,4	3,8	18 400

Tab. 2: Economic impacts of the Czech nuclear industry in 2019[18]

The economic impact of the industry associated with SMR, i.e., the construction itself, possible factory localisation of production in the Czech Republic and export abroad requires further analysis.

For the Czech Republic, SMR technology is an opportunity on two levels:

a. **Energy benefits of SMRs -** Given the above-mentioned risk of electricity shortages, SMRs are likely to be one of the few options to increase self-sufficiency in electricity generation beyond the development of other energy sources. For context only, the value of undelivered electricity (reflecting customers' willingness to pay for uninterrupted supply in the short term) is 4 016 EUR/MWh, according to MAF 2022. MAF also simulates market prices of electricity up to 2040, estimating a gross margin of electricity producers at 700 to 7 800 CZK/MWh, which indicates the need for resourcing and a high probability of return on investment in new resources.

b. **Economic contribution of SMR -** The Czech Republic has the potential to play a significant role in the regional or global context of SMR, thanks to its historical experience in the nuclear sector. The production of SMR in the Czech Republic or the involvement of Czech companies in supply chains is an opportunity for the Czech economy due to the high added value of production in the sector.

With regard to the origin and location of production of the technology, SMRs in the Czech economy can be considered on the following levels:

3.1 Scenario 1: Purchase of a foreign SMR without the involvement of Czech industry

This means selecting a foreign design to meet the energy needs of the Czech Republic without requiring significant involvement of Czech industry in the production of the technology. It is probably the simplest option, although it represents a missed opportunity to be a leading country in the emerging SMR sector. The most advanced foreign projects of power plants with light-water reactors, which can potentially be permitted under the current nuclear law, are usually with a capacity of more than 300 MWe (i.e., approximately the capacity of the current Czech coal-fired power plants and CHP plants, which will need to be decommissioned and replaced in the next 15 years), with the exception of the SMR-160 project of Holtec International, which has a lower capacity of 160 MWe. Another advanced light-water concept is the GE-Hitachi's boiling water design whose licensing is however potentially problematic under current legislation. The ČEZ Group expects to select from these projects, i.e., those with a high probability of commercialisation, for its first SMR projects. The question remains as to what extent these foreign designs will be available if the high demand indicated by for instance neighbouring Poland materializes (sources hint at plans for 79 reactors from GE Hitachi, up to 8 GW from Rolls-Royce SMR and others).[19]

3.2 Scenario 2: Production of part or the whole of the SMR in the Czech Republic

Bilateral negotiations show that SMR manufacturers have made enquiries with Czech companies regarding the production of their SMR components. Some of them also offer to build factories for module production in the Czech Republic. Assuming a regional approach, this is an opportunity for the Czech industry to supply projects in neighbouring countries and influence the selection of the SMR design if the Czech Republic takes a leading role from the outset. Production in the Czech Republic also offers the opportunity to create a regional service and training centre and to further develop its research and development capabilities. Within this scenario, the possibility of involvement in the development of foreign design is also considered, should any of the manufacturers of advanced projects show such an interest; however, such a scenario has not yet emerged from bilateral negotiations.

Typical components that foreign manufacturers are interested in are raw materials and other materials (carbon steel sheets), pressure vessel fabrication including the build-up, equipment for the handling of material (cranes/lifting equipment, etc.) and fuel, including fuel assembly control, primary circuit components (piping, valves, pumps, exchangers), secondary circuit components (turbines, generator, power outlets), simulators, instrumentation, measurement and control, diagnostic systems, cooling systems, the provision of chemical regimes, refuelling systems, radioactive waste treatment and disposal.

Due to the high interest of neighbouring countries such as Poland, the Czech Republic has the opportunity to exploit the competitive advantage of its existing nuclear industry and to be an active and leading country in the SMR area, including in the production and provision of services mentioned in the following chapters.

The Czech Republic does not currently have the capability to produce nuclear fuel, even at the level of assembling fuel assemblies under the licence of an established supplier using enrichment capacities abroad. In case of localisation of production in the Czech Republic, it would be appropriate to also consider the localisation of nuclear fuel production.

3.3 Scenario 3: The development and deployment of a Czech design

The Czech Republic has a well-developed scientific research base in nuclear energy, which is financially supported mainly by the Technology Agency of the Czech Republic (TACR), through institutional support and earmarked support from the MEYS to cover the operating costs of the CICRR large research infrastructure project (formerly Experimental Nuclear Reactors LVR-15 and LR-0 and JHR-CZ).

Dedicated support from the MEYS for the operational costs of the CICRR large research infrastructure project, one of the main objectives of which is to provide a comprehensive platform of technological and experimental facilities, equipment and capabilities for research and development in the field of nuclear and power equipment, including small modular reactors will exceed 760 mil. CZK in 2023-2026. Through TACR, projects related to nuclear energy were supported in the THETA (e.g., SMR applicability) or DELTA (intended for international cooperation) programmes, as well as in the National Centres of Competence programme (for the current period, the Centre for Advanced Nuclear Technologies II, where support in excess of 500 mil. CZK is allocated for the period 2023-2028).

There are already Czech SMR projects in the development phase that have the potential for commercial and industrial application. In the context of Czech atomic law and technological readiness, there are two time horizons in which Czech SMR projects are applicable today:

a. 2030s: in the Czech Republic, three projects of light-water reactor power plants are being developed at an early stage, with declared availability in the 30s in case of implementation:

PROJECT	POWER (MWE | MWT)
ZČU/CIIRC Teplator	n.a. | 200
SMR Witkowitz David	50 | 175
CVŘ CR-100	< 50 | 100

Tab. 3: Czech SMR Generation III projects

[18] Deloitte for FORATOM: Economic and Social Impact Report, April 2021.

[19] https://ekonomickydenik.cz/polsky-jaderny-sen-sef-koncernu-pkn-orlen-chce-do-15-let-postavit-az-79-modularnich-reaktoru/ or https://www.world-nuclear--news.org/Articles/Poland-s-Industria-selects-Rolls-Royce-SMR-for-hyd

b. 2040s: projects of advanced reactors Energy Well, HeFASTo, or demonstrator Allegro are running in the Czech Republic. These projects are nowadays usually supported by TACR programmes. Their applicability is at least a decade further away than that of light-water reactors, but they are important today in terms of building a knowledge base and maintaining world-class know-how for the future use of Generation IV reactors in the Czech Republic and abroad.

Czech projects of power plants with light-water reactors are in the power range of 50-100 MWe, respectively 100-200 MWt, and offer a complementary alternative to developed global SMR projects, i.e., there is a hypothesis of simultaneous use of global and Czech designs depending on the energy needs of localities. Representatives of all Czech designs declare interest in locating production in the Czech Republic. At the same time, however, none of the potential investors in the Czech Republic, including ČEZ, which is the majority owner of ÚJV Řež, has shown serious interest in these Czech designs. None of the projects have presented a financing plan or its provision, nor a specific plan for project implementation, including the investor.

3.4 Czech SMR projects

As part of the preparation of the plan for small and medium reactors, a mapping of Czech projects developing their own SMR design with a view to applicability in the 2030s (Generation III reactors) was carried out. During 2022 and 2023, meetings were held with project representatives and a questionnaire survey was conducted to obtain data on the status of project development. All projects are at a very early stage of development and provide only basic information indicating a lower or higher degree of realism of successful completion. The projects foresee the construction of prototypes during the 2030s, with the exception of the TEPLATOR project, which aims to present a demonstration unit before 2030. In terms of schedule, despite the use of proven technologies in some of these projects, it is still necessary to consider the experimental verification of relevant parts of the reactor during its development.

3.4.1 CR-100

The CR-100 uses a pressurised water reactor type with a thermal capacity of 100 MWt. This project focuses on the co-generation of heat and electricity. The project is proposed as a replacement for fossil sources used for central heating supply. If the project is successfully developed, its construction is planned for the 2030s. The size of the plant can be increased by configuring two or more reactors. The use of commercially available fuel already used and proven elsewhere is a positive. The project expects mainly the participation of Czech companies in the supply of all necessary components for the implementation of the project and the application of SMR in the Czech Republic. The exception is nuclear fuel, where supply is expected from one of the proven suppliers of ETE and EDU.

The investigating organisation has extensive experience in nuclear technology issues. The investigator has at least the minimum necessary in-house human resources to design this nuclear facility. According to the information provided, the project seems realistic; a typical Generation III reactor with a few innovations. The technical parameters of operation and output are within limits that do not deviate from the existing experience with pressurised water technologies, will not require significant changes in the materials used and are a good prerequisite for the realism of the solution. Unlike some other SMRs in the world, the CR-100 project does not consider a high proportion of passive safety features, but declares a certain level of passive safety due to the low capacity and the possibility of the passive dissipation of residual heat.

The concept seems to be feasible and, with its relatively conservative design, safety-consistent with the current generation of NPPs with the advantage of low specific capacity. Certain elements of the project will require additional safety analyses and safety clearances, which will place demands on resources and introduce uncertainty into further development. The timetable is ambitious, but with the right inputs and anticipated resources it is not unfeasible, although some delays are to be expected, especially at the beginning. Given the early stage of development, the economic parameters of the project are at the level of preliminary estimates.

3.4.2 DAVID

SMR DAVID is based on a pressurised water reactor with an installed capacity of 50 MWe or 175 MWt. The plant's output can be increased by configuring up to eight reactors. This design is intended to use similar technology, components and the core from the fuel assemblies used in current VVER reactors. The project considers placing the entire core in a spent fuel assemblies storage container after the fuel assemblies have burned out. The DAVID SMR project is designed as a low-carbon co-generation source for district heating or hydrogen production.

The information provided in connection with this project is general. The Witkowitz Group has experience mainly in the most nuclear part of the technology, i.e., in engineering production. However, Witkowitz Atomica itself provides only minimal information on past projects and management. The research team includes academics experienced in nuclear technology. The company introduces cooperation with the Slovak company VUJE, which has know-how in the nuclear safety assessment field. The project contains a number of innovative ideas. The information is still rather general. In particular with regard to safety risks and related safety analyses, the impact on nuclear safety and radiation protection cannot be assessed in advance. The project schedule seems ambitious. The investigators foresee an international application of SMR David. However, there is now only a rough estimate of the costs associated with the project and the economics of the SMR.

3.4.3 TEPLATOR

The core of the TEPLATOR project is a heavy water reactor with a thermal capacity of 50 to 200 MWt, in which the use of fresh or used fuel assemblies for heat production (exclusively) is envisaged. The information in the document is often very brief and it is not possible to evaluate it in terms of its realism and potential challenges in the field of nuclear safety. It is a design inspired by the proven CANDU reactor technology, which also assumes the possibility of using spent fuel to improve the economics of the heat produced. In the case of fresh fuel loading, the design is close to the proven CANDU concept. A prerequisite for the application of the design is the timely mastering of some areas not yet addressed in the Czech Republic, which are, however, mastered in countries that have experience with heavy water reactors. In the case of used fuel, the handling and verification of its condition prior to loading into the reactor will be a major challenge. A further challenge may be obtaining an operating licence from the fuel producer, given that no global fuel producer has so far granted such a licence for irradiated fuel. The authors state that fresh fuel is now primarily considered.

The project leaders have experience and background mainly in academia. It is not clear whether and at what stage the researchers are in negotiations with the project contractors. The project introduces a number of atypical features that may pose a safety challenge, even without the anticipated use of irradiated fuel. The project timetable looks ambitious.

3.4.4 Conclusions of the Czech Generation III SMR development

The projects evaluated are small modular reactors, which will certainly be suitable for replacement, particularly in the CHP sector, but it can be assumed that reactors of this capacity will be developed faster in other countries. As this area is subject to market conditions, there is a risk that users will use solutions already available on the market that have been developed abroad.

The submitters did not provide sufficient data from which it would be possible to assess in detail the overall financial intensity of the development of Czech designs. Given their very early stage of development and the later expected availability of prototypes, there is currently doubt as to whether investing in the development of Czech design is an appropriate choice.

Based on the information received from the individual projects, it is questionable that the Czech Republic would finance the parallel development of several small modular reactor technologies without cooperation with foreign entities. There are doubts regarding the early stage of development of Czech projects compared to other countries, with regard to the possibility of applying this technology in the Czech Republic.

SMR technology should continue to be supported through the current research and development instruments. The Czech projects ought to be supported under the other Programmes for the Support of Applied Research, Experimental Development and Innovation of the National Centre of Competence (now called the Advanced Nuclear Technology Centre II) and the priority research objectives for the THÉTA II calls.

4 SITES AND STATUS OF THEIR PREPARATION FOR AN SMR LOCATION

Just as SMRs are close in capacity to the current CHP plants and coal-fired sources, it is logical to expect that they will be the solution for replacing them. The prerequisite is therefore to use mainly brownfields, which will be created by existing coal resources. The SMRs would thus be used primarily for co-generation, i.e., heating (while maintaining district heating) and electricity supply, if the sites meet the conditions for the siting of a nuclear installation.

An overview of the sites examined in the Applicability Study is shown in Fig. 1 and detailed in Appendix E. The study focused on site selection at three levels: (i) sites of current coal-fired power plants and heating plants (in the case of heating plants, only sites with developed district heating networks), (ii) sites of current nuclear sources at Temelín and Dukovany and the reserve nuclear site Blahutovice (a so-called greenfield) and (iii) sites without significant central heating sources, but with the potential to create them.

Fig. 1: Map of significant non-nuclear power and heating sources in the Czech Republic

It is important to emphasise that this overview only includes the locations of existing coal resources and might not be a complete itinerary for potential SMR locations in the future. Any site under consideration for SMR construction, including new (greenfield) sites, is subject to an individual assessment based on the requirements of the Atomic Act before a decision can be made on the suitability or unsuitability of the site. The application of SMR technology shall not be achieved at the expense of public safety and security. In order to confirm the acceptability of a particular site or to exclude it due to its unsuitability, it will be necessary to carry out detailed field surveys for that site and to analyse in detail the seismo-tectonic and hydrological conditions and other site characteristics. In addition, the feasibility of connecting to the electricity and heating system will need to be assessed for a specific project in a specific location should it differ significantly from the capacity of the existing source. The same applies to the water analysis.In addition to the above, the Applicability Study assessed the possibility of connecting SMRs to the electricity grid in the current situation (i.e., without taking into account the possibility of future developments) at the following points in the transmission and distribution system:

TRANSMISSION SYSTEM (SOURCES BEING DECOMMISSIONED)	110 KV DISTRIBUTION SYSTEM (SOURCES BEING DECOMMISSIONED)	ON A GREENFIELD
• **Rozvodna R420 kV Hradec** (Prunéřov, Tušimice, Počerady)	• Verneřov	• Kletné
	• Komořany	• Chrást
	• Koštov	• Přeštice
• **Rozvodna R420 kV Vítkov** (Tisová, Vřesová)	• Chotějovice	• Rohatec
	• Poříčí	• Krasíkov
• **Rozvodna R420 kV Týnec.**	• Opatovice	
Alternativa velkých bloků je:	• Třebovice	
• **Temelín**	• Dětmarovice	
• **Dukovany**		

Tab. 4: Currently connectible SMR capacity at distribution and transmission system locations

According to CEPS, SMR connectivity is possible anywhere, it is a question of cost. CEPS also allows for the non-application of the N-1 criterion in the case of SMRs. The purpose of the list of sites is to enable their inclusion in the Czech Spatial Development Policy and spatial planning in relation to the upcoming update of the SEP. The assessment and preparation of non-nuclear sites for the siting of a nuclear facility is a long process that must begin as soon as possible for the success of SMR construction in the 2030s, see the permitting process in Chapter 9. A prerequisite for the possibility and preparation of a site for the construction of a nuclear facility is its inclusion in the SEP, or the policy and principles of spatial development or spatial and regulatory plans. The investor then applies for a new land use plan for the nuclear facility in accordance with the above-mentioned, or an amendment to the land use plan if it is an industrial site but the source is not specified. In this phase, the regions and municipalities will have a significant role to play, as they are responsible for the spatial development principles and land use plans and have declared their willingness to cooperate in the preparation of sites and related infrastructure at the WG. The cost of site preparation is in the tens of millions of CZK depending on the specific case. The MIT has mapped the possibilities of co-financing from public sources and funds, but there is currently no suitable instrument that could be used, see Chapter 7.

5 PUBLIC OPINION

The Czech Republic is a country with a long-standing high level of public support for nuclear power, amounting to 70%. Based on the current public opinion poll conducted by the Academy of Sciences of the Czech Republic in 2022, 56% of respondents answered positively and 9% negatively to the question whether the share of nuclear energy in the Czech Republic's production should increase.

When asked about the acceptability of building SMRs near the respondent's residence, the so-called NIMBY (not in my backyard) effect is visible. In the case of developments more than 50 km away from the residence, respondents answered positively in 51% and negatively in 34% of cases. For developments closer than 10 km from the residence, the ratio of negative to positive responses was 55% to 28%. At the same time, people are more likely to respond positively to the question of building on the sites of current nuclear power plants (66% positive responses) compared to building outside them (46% positive responses). People were mostly positive about the possibility of the Czech Republic supporting research, development and education in nuclear energy. In the case of SMRs, this was true in 69% of cases.

The public acceptability of SMRs may be higher with respect to specific parameters compared to other sources:

- Significantly smaller emergency planning zone compared to large nuclear sources,
- Declared higher safety of equipment and operation compared to large reactors,
- Plant size comparable to existing thermal and coal-fired power plants,
- Lower long-term impact on the environment (e.g., lower demands on water resources and dry cooling) and public health when replacing existing fossil sources.

It is desirable to communicate these positive features clearly to the general public, especially when developing spatial policies and plans for the potentially affected localities. Particularly in the locations of existing coal-fired power stations, these are benefits in terms of employment, added value to the sector, decarbonisation and securing energy supply, especially heat.

The issue of public opinion also has an international overlap due to the involvement of the public from countries neighbouring the Czech Republic in the EIA process.


Foto: Shutterstock

6 INVESTMENT MODEL

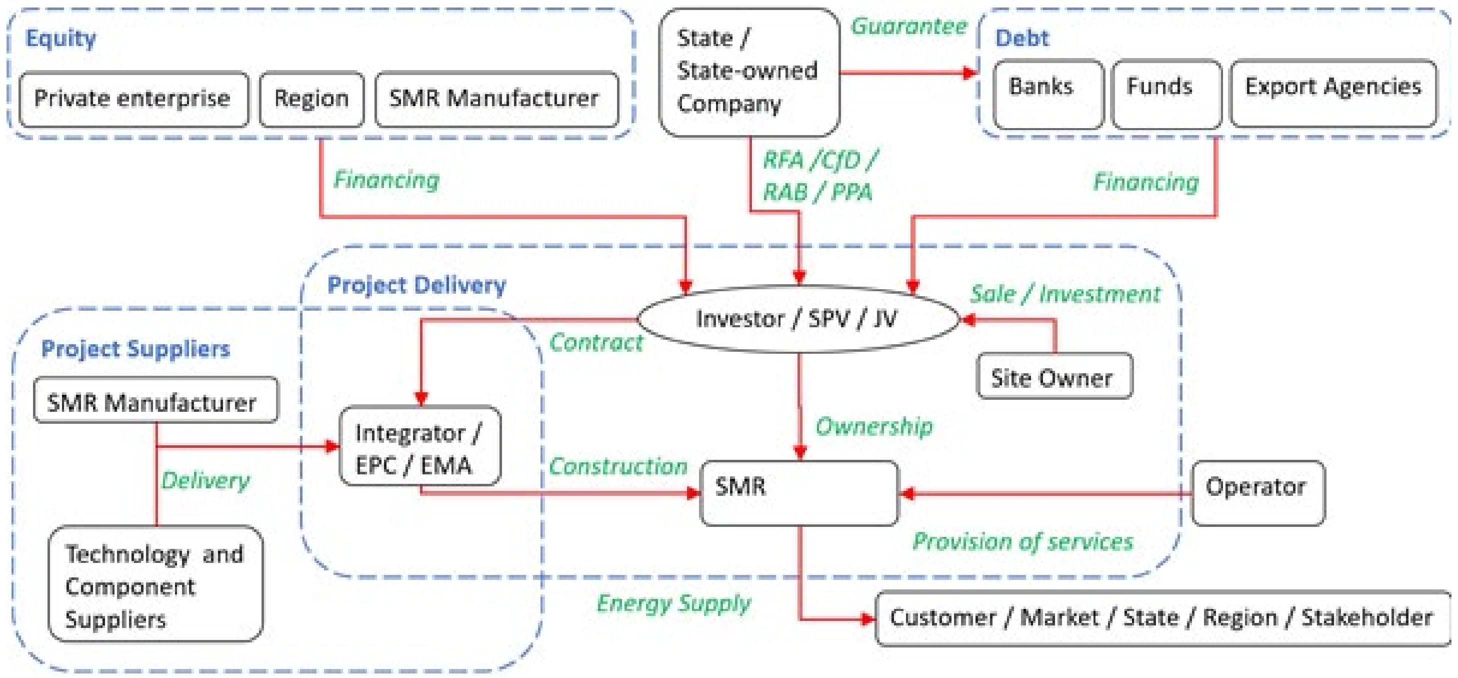

Fig. 2: General diagram of the individual roles and relationships in the construction and operation of SMRs

The investor model for the construction of SMRs can take many forms. A general diagram showing the main roles and relationships within construction and operation is shown in Figure 2. Depending on the specific scenario, the actors involved are different and the tools used vary. The four main scenarios for the investor model are defined and described below. Investors expect a higher return on investment with a higher level of risk also in the construction of nuclear power plants. Given the long investment horizon, high costs and uncertain future assumptions in terms of market, political, technological and other risks, nuclear projects have a higher risk premium and thus a higher required return from the investors' perspective. Therefore, it is necessary to allocate risks effectively to the parties involved so that the associated costs are minimised and the project is feasible. This typically occurs at large nuclear power plants through government interference. In this respect, SMRs differ primarily in terms of lower overall investment costs, shorter construction time and thus availability to a wider range of investors. Yet in the context of Chapter 2.6, they are still an investment in the order of 30-80 billion CZK per project. The risk levels of SMRs compared to traditional nuclear projects, inter alia with regard to different capital requirements and expected preparation/construction times, are analysed e.g., in a study prepared for the UK Department for Business, Energy and Industrial Strategy.[20] This has implications for the shape of possible investment models in which the need for a State role must be assessed. The following models describe the project phase after the final investment decision and do not address pre-project or preparatory work.

[20] Expert Finance Working Group on Small Nuclear Reactors (2018): Market framework for financing small nuclear, p. 19.

6.1 Option 1: Private company or consortium

The market approach presumes minimal or no involvement from the State beyond stating the role of SMRs in the energy mix within the SEP. The project should be implemented and financed on a purely market basis with the help of commercial loans and the investor's own resources, possibly through project financing. This option represents the highest cost of financing given the level of risk and uncertainty associated with the nature of the new technology, political, regulatory and market risks, and the long investment horizon. In the conditions of the Czech Republic, but also with regard to a number of market failures within the internal electricity market, it is not possible to expect a wide range of investors, if any, who would be able to implement such an investment-intensive project within their own balance sheet without a significant negative impact on their own rating, or without any public support. For these reasons, this option is highly unlikely.

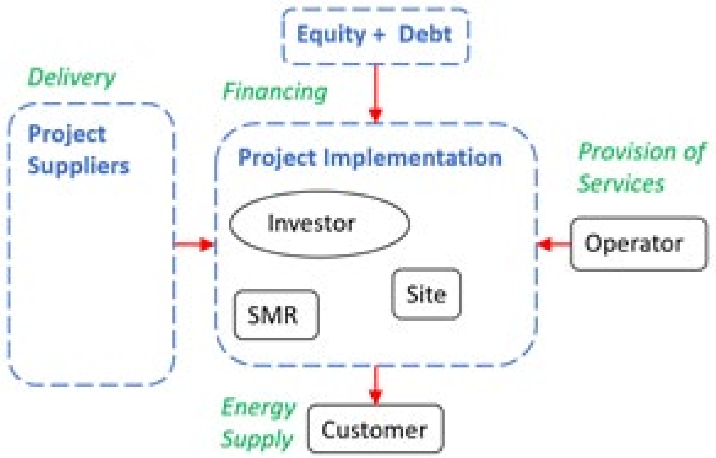

Fig. 3: Simplified diagram of the O1 investor model

6.2 Option 2: Private company or consortium with State aid

This model presumes an initiative by the private sector, especially the energy-intensive industry and energy companies, with some form of public support to enable or improve the conditions for financing.

Public support instruments are mainly (i) credit guarantees from the State[21] (enabling export financing), (ii) business models ensuring returns, i.e., long-term contracts for electricity purchase (power purchase agreement, differential contract, etc.) or alternative business models (e.g., Regulated Asset Base, etc.), (iii) financial assistance from the State[22] and (iv) provision of sites available to the State for the construction of SMRs.

A suitable model with regard to the lowest possible exposure of the State may be primarily state guarantees to credit institutions to achieve lower financing costs, or the provision of a long-term contract for electricity consumption - the simplest application is currently the Low Carbon Act, in the form of a purchase of electricity by the state trader, while this is public support subject to notification by the European Commission for individual projects. The specificity for SMRs may be with regard to the lower (yet still high) investment intensity to provide buyout for a limited period of time, which will allow to overcome the riskiest phases of the project and then refinance the loan with the possibility of limiting or terminating State aid after successful commencement of operation of the source.

[21] In the case of a consortium, guarantees for the individual shareholders, including compensation payments in the event of the insolvency of any of them.
[22] Some of these forms of support are currently allowed under the Low Carbon Act

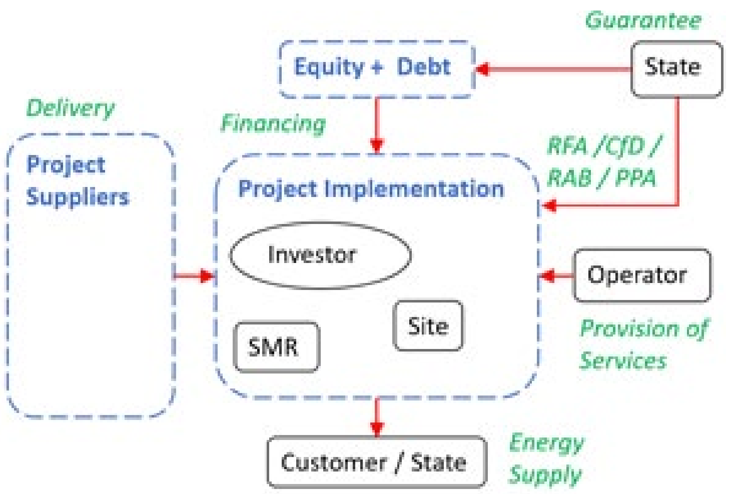

Fig. 4: Simplified diagram of the O2 investor model

6.3 Option 3: State-owned company

This option is in line with the strategic importance of nuclear resources for the energy security of the country and is related to the possibility of the State acquiring all of the existing and future nuclear installations into its exclusive ownership. It may be perceived as a maximalist interpretation of the Security Strategy of the Czech Republic with regard to security threats and sources of instability related to internal and external safety, physical, personnel, and administrative security. Exclusive application of this option would, given the possible lack of effective legislation (screening of foreign investments, Critical Entities Resilience Directive implementation, etc.), limit private investment in nuclear installations.

Assuming partial acquisition of ČEZ, including nuclear assets, by the State or another state-owned entity, the Czech Republic can become a direct investor into SMRs. A specific feature of this option would be the possibility to use existing coal-fired plant sites if they were included in the potentially nationalised part of the company.

This option offers the possibility to use instruments of the Low Carbon Act for a predetermined scope of construction of the SMR, i.e., providing repayable financial assistance with the lowest possible financing costs of all options discussed in this Chapter, loan guarantees, or purchasing electricity through a state electricity trader at a predetermined strike price. Alternatively, other business models (CfD, RAB, SaHo, etc.) could be considered, but in the view of WG SMR it would be preferable to use proven methods. With regard to the impact on public budgets, public support options call for an impact assessment by the Ministry of Finance given the scale of construction. In addition, this option would constitute public support with regards to European procurement law and would be subject to notification.

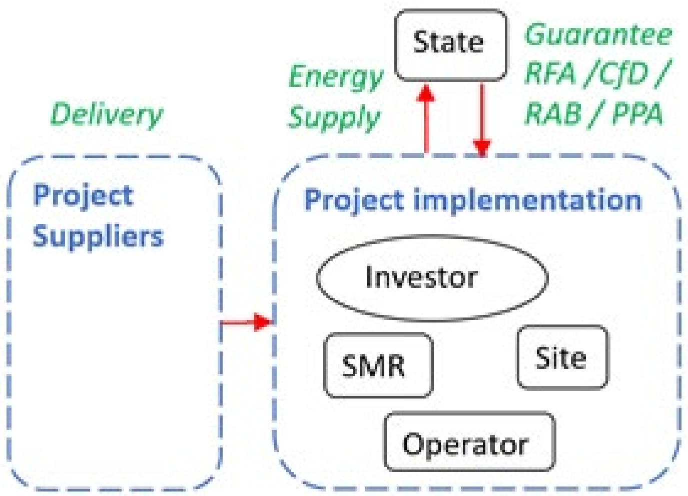

Fig. 5: Simplified diagram of the O3 investor model

6.4 Option 4: Alternative investment and cooperation models

This option represents models of a group of investors working together to finance and implement a primarily non-profit project to meet their own energy needs. Stakeholders finance the project with a combination of their own capital and, where appropriate, foreign capital, and once the plant is operational, they are entitled to receive electricity at a cost price corresponding to their share of the project. Examples of such a model include Finland's Mankala, which brings together energy-intensive companies, and France's Exeltium, which brings together industrial investors and banks, or Poland's SaHo model, which combines the implementation of a project on the part of the state and the subsequent sale of shares to those interested in purchasing electricity before the plant is commissioned. These models could be attractive for investors in the Czech Republic. Here again, the role of the state potentially makes projects more attractive and accessible to more investors, especially if guarantees are provided.

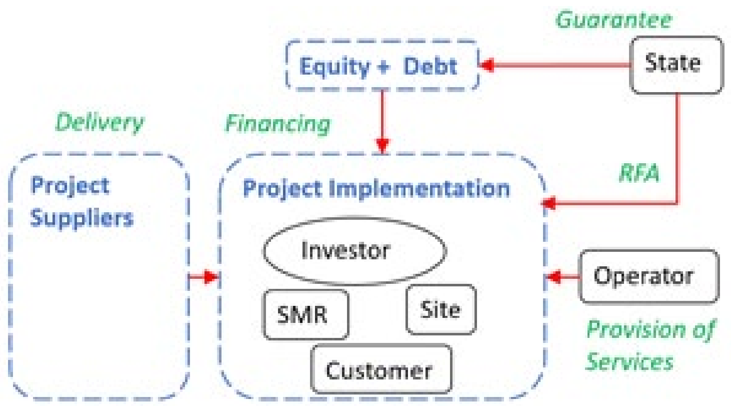

Fig. 6: Simplified diagram of the O4 investor model

7 FINANCIAL MODEL

Due to the high complexity of nuclear projects, there are various financing models that combine different approaches in terms of risk allocation for the stakeholders, with a significant impact on the cost of capital, hence the return on the project and consequently the price of the energy produced[23] .

Thus, the design of a business model (assumptions about future costs and revenues, or, amount of investment; operating and fuel costs; sale of electricity, heat or hydrogen production; or provision of ancillary services) is crucial for project financing. In this context, a positive prerequisite for the cost of financing is the designation of nuclear power as a sustainable activity within the sustainable finance taxonomy. [24]

Given the strategic importance of nuclear power plants in ensuring energy security of the country, various forms of public support for construction are common practice due to market failures that have co-created underinvestment in new generation capacity over the last decade. For example, securing electricity supply contracts through long-term or differential contracts abroad, or in the Czech Republic through the Low Carbon Act, see below.

In the case of SMRs, the total investment is typically in the order of tens of billions of CZK per SMR, depending on the design, in terms of overnight costs. The entity for the construction of the SMR should have a rating of at least BBB+[25], but more likely higher in order to attract private capital, with the understanding that a higher rating will allow for lower financing costs.

The first phase of the project before the final investment decision (including the financing of site preparation, see the lack of suitable instruments as described in Chapter 4) is currently only possible from the investor's resources. This is not as investment intensive as the next phase of the project. In the next phases it is desirable to provide some form of support from the State, see Chapter 6 Investor Model, to make the construction of SMRs available to a wider range of interested parties. Based on the discussions of the WG SMR, SMR construction projects in the Czech environment represent such an investment-intensive activity that it is not possible to implement projects without some form of State aid.

The Czech Republic or the EU can take inspiration from, or use the experience of the USA with the anti-inflationary package.[26] The aim is to make investment in (not only) SMRs by existing coal-fired power plant operators more attractive. According to the U.S. Nuclear Energy Institute (NEI), small reactors can benefit from the package through the Clean Power Production Tax Credit, a technology-agnostic production credit that can be applied to emissions-free electricity generation that will be in operation after 2025. The clean energy credit is a minimum of $25/MWh for the first ten years of the plant's operation, adjusted for inflation. According to the NEI, the credit will be phased out when carbon emissions from electricity generation fall 75% below 2022 levels. There is a 10% bonus if the plant is built on a brownfield site or in a region affected by coal mining and burning, ensuring social and energy justice.

7.1 Ensuring returns

Business models for SMRs must take into account four main parameters - investment costs, operating costs (operation, maintenance, fuel, overheads, decommissioning, RW storage costs), revenues (mainly sales of electricity, heat and, prospectively, hydrogen with ancillary services) and financing costs. The most significant component of the electricity price (expressed as LCOE) is the investment cost. On the other hand, long-term returns from all these commodities must be secured to achieve the required returns and competitiveness with other energy sources. In order to meet the energy needs of the State, different models of securing returns through mechanisms guaranteeing the achievement of the required returns may be attractive to investors. The most discussed models are:

- **Power Purchase Agreement (PPA):** a long-term contract for the supply of electricity without the need for a reference to the electricity market. The customer assumes the market risk, but is guaranteed a supply of electricity in a pre-agreed quantity at a pre-agreed unit price without market volatility. This type of contract can be an important factor in the creditworthiness of a project.
- **Contract for Difference (CfD):** a specific case of a PPA where the off-taking party, typically a government entity licensed to trade electricity, assumes the market risk and realizes a profit or loss against the agreed electricity price depending on the market price of electricity. It is possible to distinguish a one-way or two-way differential contract. The European Commission's current proposal includes measures to introduce and incentivise the use of this type of contract to stabilise electricity prices and create long-term investment signals. The usability of this tool will depend on the final form of the proposal that is adopted. A unique form of CfDs are some of the instruments of the Low Carbon Act, in particular the mandatory feed-in and the two-way differential contract, which is consequently reflected in the transmission and distribution tariffs of customers.
- **Regulated Asset Base (RAB):** a model used in infrastructure projects (in the Czech Republic typically for network operators). Its main disadvantage is the lack of experience in applying it to nuclear projects (the first such project would be the Sizewell C power station in the UK). This model is subject to political risk and the disadvantage is the regular revision of model assumptions with an impact on the return (in the Czech Republic, usually 5 years for network operators). Further, from an electricity hedging perspective, the nature of the revenue determination is a fundamental flaw, which theoretically allows for the generation of profit even in a situation where the plant does not supply electricity to the grid and does not incentivise the supplier to be efficient during construction. The rationale for using this model was to incentivise private investment in public projects through a set rate of return.

The above measures are a form of State aid that would be subject to notification to the European Commission by the Czech Republic in accordance with the Treaty on the Functioning of the EU (Article 108(3)) and Council Regulation (EU) No 2015/1589. It is desirable to start early communication with the European Commission on the setting of public support, and after the initial consultations (pre-notification), proceed to the official notification. The notification is submitted by the administrator of the support measure (MIT) through the Office for the Protection of Competition. The formal notification is followed by a so-called notification procedure, the length of which depends on the quality and completeness of the notification documents and the significance of the project in question. It can be assumed that the project will be examined in a formal investigation procedure in which third parties will have the opportunity to comment on the aid measure in question. We expect that the total duration of the procedure from the notification to the final decision of the European Commission may take about two years in an optimistic scenario. The Commission's notification decisions on public support for new nuclear power projects have been challenged in the past by another Member State, which is also expected to be the case in the future for public support for SMRs.

7.2 Funding

The financial structure of the project and the allocation of risks to stakeholders has a direct impact on the cost of financing, which is a critical parameter impacting the return on the project. Given the new technology sector with its lack of experience, there will also be a higher perceived risk for the finance provider in the case of early-stage projects. The appropriate financial structure should thus reflect primarily the provision of a return to the investor with state involvement in the completion and commissioning of the project, with the potential for the State to play a role (either a loan guarantee or a long-term contract) in the refinancing of the revenue-generating project.

European funds and national funds

The WG SMR has examined all currently available options for public financing of SMR projects or their preparatory phases.

- **Modernisation Fund** - In its current form there are obstacles that do not allow the qualification of Czech nuclear projects. In particular, the project completion horizon to 2033, along with a project duration of 5 years from its commencement. The preparatory phases cannot be financed due to the requirement to reduce CO2 emissions within the time frame.
- **The Just Transition Fund** - Not applicable.
- **National Renewal Plan and REPowerEU** - The time frame is a barrier to use, namely until 2026, including the requirement to reduce carbon emissions. The nature of the tool does not allow it to be used for site preparation.
- **European Commission Technical Assistance Facility** - The MIT prepared an application to use the facility for site preparation and survey purposes, but the application was not accepted because it was not assessed as an appropriate structural reform.

Intergovernmental treaties and financing

The possibility of foreign investment or intergovernmental loans under an intergovernmental agreement presupposes an interest of both parties in implementing common goals and projects. One risk, but also a benefit, of an intergovernmental agreement and the resulting financing options may be limited technology choices, which could lead to a lack of healthy competition and consequent price increases across the supply chain. Unexpected geopolitical events during the contract are also a risk. On the other hand, negotiating the localisation of production into the Czech Republic may be an advantage. Based on preliminary discussions, this option is not currently being considered for SMR projects.

[23] The sensitivity of the electricity price represented by the LCOE parameter to the weighted cost of capital - WACC - and the capacity factor of the resource is shown in the graph of the International Energy Agency in Annex F

[24] Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific disclosures in relation to those economic activities (Text with EEA relevance)

[25] DBEIS Market Framework for financing small nuclear

[26] Inflation Reduction Act - https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

Loan guarantees

In a loan guarantee, financial support is provided by the government in the form of a guarantee to repay part of the debt to the lender. From the point of view of the guarantor, no allocation of funds is required if the risks are not met. Guarantees can lead to lower interest rates because a guaranteed loan carries a lower risk.

Supplier financing[27]

The supplier's involvement in the financing of an SMR project can be in the form of a loan negotiated by the supplier with its own bank(s) or export agency, where the supplier operates the plant itself after completion (Build-Own-Operate) and decommissions it at the end of its life (e.g., Akkuyu project in Turkey in cooperation with Russia, which finances 99%).

Another form is a loan provided by the contractor, with the host country or company operating the plant after completion (e.g., Rosatom's loan to Hungary for the construction of Paks II nuclear power plant).

The final option is for the supplier(s) to enter the project with its/their own capital, thereby acquiring a stake in the plant and operating it. In terms of risk, entry with the supplier's own capital is the riskiest option, so it should be combined with, for example, a long-term power purchase agreement - PPA (e.g., the Hinkley Point C project in the UK).

However, in the case of large-scale investment projects, there is also an indirect support for the project from the supplier - through negotiating offset programmes that have an economic benefit for the project investor's country of origin.

Supplier financing can be a potentially expensive option compared to others, and can also limit localisation possibilities.

Based on the findings and discussions to date, there is no interest from suppliers to participate in the financing of the SMR project in the Czech Republic, but it remains a potentially open option.

Investor financing

This financing model presumes a group of investors raising sufficient funds to implement the project, coming either from external sources (loans from banks or export agencies, bonds, etc.), or from their own sources, such as shareholders. The investment plan and risks are shared between shareholders, lenders and suppliers, which is why this model is often referred to as the collaborative model. Its concrete application can be seen in the Mankala model. Given the volume of each transaction and their number, it can be assumed that investor financing would only be considered as a supplement to overall funding - probably not more than the amount of equity expected. Ultimately, without additional collateral, investor financing would work like a commercial bank financing.

Export financing

OECD rules apply to export financing. Typically, an export agency can provide up to 85% of the contract value, subject to a certain proportion of supply from the provider country. The maximum repayment period of 18 years may be an obstacle. It is a project-specific question whether the amortization period will be sufficient or whether refinancing will be necessary. Export financing is offered by the UK or the USA for their manufacturers, see Annex G; no information was provided for France or South Korea.

European Investment Bank (EIB)

The last time EIB supported a nuclear construction project (with Euratom grants) was in 1987. Its recent projects were „only" aimed at security upgrades in Finland and Slovakia. The EIB's objectives are in line with the European Commission's policy; the EIB's internal documents include the objective of climate neutrality. The main instrument is renewables, but nuclear energy remains as one of the sources, i.e., nuclear projects are not excluded, but depend on the political consensus of all the national representatives in the EIB - there is no consensus at the moment. Financing may be considered, if there is a positive attitude from the Commission, under Articles 41-43 of the Euratom Treaty. At the same time, the project must be economically, financially and technically feasible. For nuclear investment, political support and an existing prototype are needed, the EIB would then be able to provide up to 50% CapEx. The key to EIB support is the location of the project in the EU, not in the country of origin. The EIB screening criteria for major projects are: the legislative, regulatory and institutional framework, technology, design and operational capability, spent fuel and radioactive waste management, economic analysis and environmental impact.

Repayable financial assistance

A possible form of State financing is the institution of repayable financial assistance with costs at the level of servicing the state debt increased by one percentage point under the Low Carbon Act. With regard to the objective of using this instrument for the construction of up to four conventional nuclear power plants, the possibility and scope of this financing for SMRs (including the option of full financing through Repayable Financial Assistance) is subject to further analysis.

National Development Fund (NDF)

This is a Czech regulated financial institution that pools resources from investors and uses them for investments with a certain expected return. It is complementary to commercial banks and targets riskier projects. As part of the financing, it provides a subordinated loan, called a pseudo-equity. The NDF considers the SMR as a type of project where it can be an effective part of the financial structure.

Commercial banks

Loans from Czech commercial banks are limited to the total amount of investment in SMRs. Loans may be part of the financial structure, but according to the WG SMR, they are a fraction of the funds needed even in the case of a multi-bank syndicate.

Pension and other funds

Consultations indicate that some funds with nuclear projects in their portfolio would potentially be interested in investing in SMRs in the Czech Republic, although we foresee their role more in the later stages of the project and in the refinancing of the completed project.

[27] In line with the approach to the selection of the supplier for the new unit at Dukovany, companies from Russia and China are not considered for the SMR, i.e., neither is financing from these countries. The examples in the text are for illustrative purposes only.

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8 DELIVERY MODEL AND BUSINESS ASSURANCE

SMR projects are expected to simplify the delivery model compared to large nuclear power plants, but at the same time, SMRs may represent a lower level of involvement of Czech entities in construction if foreign designs are chosen. Thanks to factory production, site work should be minimised and the SMR should be constructed, literally assembled, relatively quickly after transport from factory to site. In order to make the technology available to a wider range of interested parties, it will be a competitive advantage for the supplier if it is able to deliver the project on a turnkey basis, or if the Czech Republic has a company capable of integrating the project as a whole. SMR manufacturers declare the ability to offer a turnkey contract that includes delivery and plant operation guarantees. However, they expect the integrator and investor of the project to have the appropriate level of technical competence. The contractor model is also related to other factors, such as the way project documentation and budget are prepared and the mechanism for authorising payments to contractors during construction.

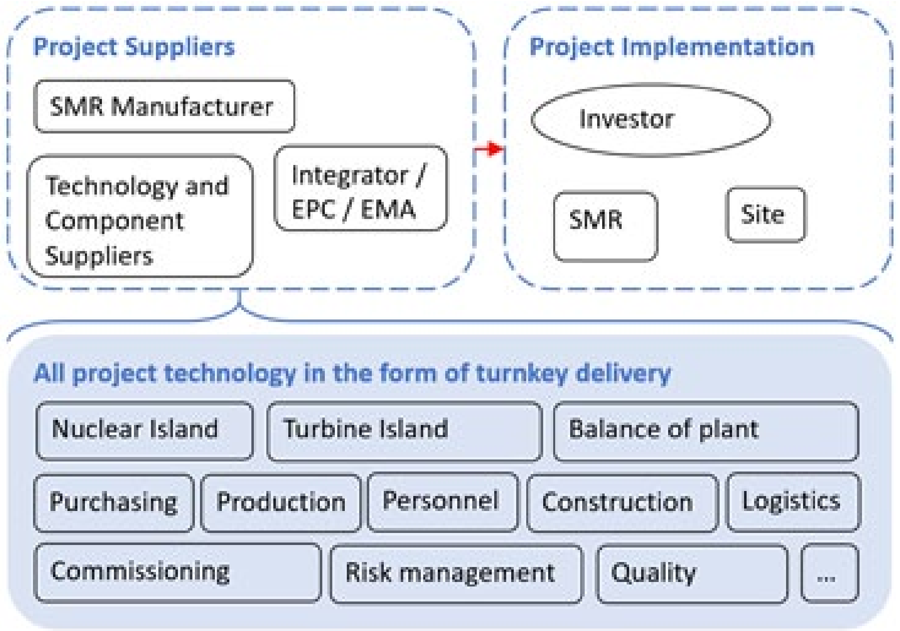

Fig. 7: Scheme of the SMR „turnkey" delivery form

In the Czech Republic, there are now possibilities for partial integration, but negotiations and preparations are needed for full integration:

1. Identified capabilities of the integration role within the Czech industry

- Nuclear Island - integration of the technological deliveries of the nuclear island (NI) including related complete engineering and design work
- Turbine Island - integration of the turbine island (TI) technology supplies including related complete engineering and design work
- Balance of plant / auxiliary operations - integration of process supplies, power and cooling systems, including related complete engineering and design work
- Management and control system - integration of HW and SW deliveries and related complete engineering and design work
- Electrical engineering - integration of technological supplies and related complete engineering and design work in the scope of the entire electrical part
- Construction works - integration of the construction part and related complete engineering and design work
- Simulation - integration of delivery and complete engineering and design work in the scope of simulation/training systems/equipment

2. Overall EPC integrator role

Czech industry is capable of forming a consortium of companies that is able to take on the role of integrator of the whole, if there is such a demand from the partner, and is ready to negotiate intensively on this variant of cooperation in case of interest.

The discussions of the WG SMR show that the last time a complete nuclear power plant project was integrated was in the 1980s in the case of the Dukovany power plant. The most recent experience of the Czech contractors is from the Mochovce NPP, where it was the role of integrator for the primary part, not the complete construction. Therefore, the risk that some Czech companies may have problems meeting the commitment, mainly due to a lack of manpower or lack of experience resulting from the break in continuity since the last integrated project, should be taken into account.

Some foreign manufacturers have already made contact with Czech companies and signed agreements of understanding. Within the WG SMR, representatives of Czech companies stated that they are now reactive in relation to possible production and do not see supply chains as a weak point for the deployment of SMR technology, both in terms of personnel capacity and adaptation to different standards and the regulatory environment in the Czech Republic. The entire supply chain is capable of producing components for SMRs immediately on demand.

Commercial support

The commercial support of SMR delivery would depend on the investor and supplier model and the fulfilment of the definition of a contracting authority or a public contracting authority according to Article 4, paragraph 2 of Act No. 134/2016 Coll., the Act on Public Procurement. Compliance with EU public procurement law is also one of the preconditions for the granting of public support.

When preparing a project, it is necessary to evaluate the optimal procedure, including the economic considerations of the contracting authority, but also the security interests of the state and the risks of possible contractor selection procedures. Precedents for large blocks can be followed, although SMRs may include specific investor models or conditions.

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9 LEGISLATION AND THE PERMITTING PROCESS

9.1 Overview of basic legislation

In the time frame of the expected implementation of the SMR project, the related permitting procedures will be regulated mainly by the following fundamental laws:

- Act No. 263/2016 Coll., the Atomic Act, as amended, which regulates the conditions for the peaceful use of nuclear energy, specifies the procedure and conditions for obtaining a licence from SÚJB for the siting of a nuclear installation, its construction, commissioning, operation, decommissioning and modification. An amendment is currently being drafted and should come into force at the beginning of 2025;
- Act No. 283/2021 Coll., the Building Act, as amended, which regulates the authorisation of the project from the point of view of the Building Code (New Building Act, NBA);
- Act No. 148/2023 Coll., on the Single Environmental Opinion, which regulates the procedure and competence of administrative authorities in issuing a Single Environmental Opinion (SEO) in order to ensure the public interest in the protection of the environment as a whole and to contribute to sustainable development when making decisions in proceedings for the authorisation of a project under the Building Act or in subsequent proceedings under the Environmental Impact Assessment Act;
- Act No. 100/2001 Coll., on Environmental Impact Assessment, as amended;
- Act No. 416/2009 Coll., on Accelerating the Construction of Transport, Water and Energy Infrastructure and Electronic Communications Infrastructure (Line Act), as amended;
- Act No. 458/2000 Coll., Energy Act, as amended - addressing the issue of expropriation;
- the draft of the Act on Expropriation, according to the approved substantive plan of the act, envisages the merging of the issue of expropriation under one piece of legislation with the procedural provisions being completely deleted from the Line Act.

Atomic Act

SMR projects presume a completely new approach to the construction of nuclear facilities, the manufacturing of their components and equipment, and end-of-life decommissioning. These include the compactness of SMRs, the integration of systems and components within production units assembled in the factory, the unification of components and production in larger series. From the perspective of the Atomic Act and its implementing decrees, which were developed in the context of the nuclear technologies in use today, the extent to which innovative technologies are applied to specific designs is crucial for SMRs. In view of the lower capacity and high nuclear safety of the designs, it is advisable to apply a tiered approach. In order to reduce the complexity of the assessment of each applicable legislative requirement by the SÚBJ, it would be appropriate for the operator of a nuclear installation to take into account the characteristics of a particular SMR design using a tiered approach. The modification would oblige the operator of a nuclear installation to demonstrate that the safety of the installation is not compromised when applying the tiered approach. The conclusions of the analysis of the current developments and the Atomic Act suggest the need for changes at the statutory level.

Building Act and Environmental Impact Assessment Act

The competence of the first-instance building authority for public structures (i.e., structures defined in Annex 3 of the NBA) will be exercised by the Transport and Energy Building Authority (DESÚ). Public structures include „nuclear installation structures and related structures located inside and outside the nuclear installation site". In the case of technical infrastructure structures for the energy sector, the MIT is the superior administrative authority of the DESÚ.

In the design, permitting, implementation and use of nuclear installation structures and structures on the premises of a nuclear installation which are nuclear installations, the technical requirements for construction laid down in the NBA or other legal regulations shall be applied appropriately so as not to endanger the safety, health and life of persons or animals and the environment. The interests of environmental protection are safeguarded through the Single Environmental Opinion (SEO), which is issued in lieu of administrative actions provided for by other environmental legislation. For the construction of nuclear installations, the Ministry of the Environment, which is the central administrative authority for the issuance of the SEO, issues the SEO as a basis for the authorisation of the project under the NBA. For a nuclear installation and related structures located inside and outside the nuclear installation, a so-called framework permit can be issued (analogy to the zoning decision under the original Building Act No. 183/2006 Coll.). With the exception of administrative acts under the Environmental Impact Assessment Act, neither the SEO nor the administrative acts in lieu of which the SEO is issued shall be issued prior to the issuance of a framework permit under the NBA. In the case of a project for which a framework permit is issued under the NBA, the competent authority shall always discuss the project under consideration with the registrant in such a way that the environmental interests affected by the project under consideration are preliminarily identified before the framework permit is issued. For projects in the EIA regime, the SEO will also be issued, either as part of the EIA process (in which case the SEO will also be the EIA opinion) or after the EIA opinion has been issued (the choice is up to the registrant). In the case of the SMR, a separate EIA process of an interstate nature can be expected with respect to potential sites, which will have a relatively significant time impact on the permitting procedures.


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In order to enable construction, the SMR must be included in the conceptual documents of the Czech Republic, especially in the SEP, the Czech Spatial Development Policy and the Spatial Development Plan. If the spatial planning documentation does not exclude the production of electricity or heat through SMRs and if the existing production areas in the spatial planning documentation allow for the production of electricity or heat and the transition to the production of electricity or heat through SMRs does not negatively change (i) the delineation of the existing production area in the spatial planning documentation, (ii) the protection, safety and emergency zones of the existing production plant, (iii) the noise, traffic and other emissions load on the territory, the spatial planning documentation does not need to be modified for the production of electricity or heat through SMRs. The SEP will be crucial for follow-up processes and documents (such as the Spatial Development Principles and Regional Energy Policies), as it takes into account not only the use of the reactor, but also the scale and locations for the planned construction.

9.2 Legislative measures needed to eliminate risks in the permitting process

Atomic Act

In the Czech Republic, the use of nuclear energy is governed by the

Atomic Act and the relevant implementing regulations. Currently, the legislation in force applies to all nuclear power installations regardless of size and power, including small and medium-sized reactors.

In 2023-2024, the Atomic Act and its decrees will be amended in relation to the licensing of new nuclear sources, including SMRs. Some decrees are explicitly based on nuclear technologies used in the Czech Republic and established practice. Conceptually, they are very narrow and their application to other technologies or unmodified processes is practically excluded. This approach poses a problem for SMRs, but also for upcoming new nuclear sources that will use traditional pressurised water technology. This problem is partly addressed by Decree No. 329/2017 Coll., on requirements for the design of nuclear installations, and significantly by Decree No. 409/2016 Coll., on activities especially important in terms of nuclear safety and radiation protection, special professional qualification and training of persons ensuring radiation protection of the registrant.

A full review of the legislation with knowledge of the new technology and possible redrafting will be necessary to resolve this issue.

All regulations in the Czech Republic are based on experience with light-water reactors, especially pressurised water reactors. From the point of view of light water, especially pressurised water SMRs, this is an advantage.

Currently, SÚJB is cooperating with foreign supervisors in the field of SMR, mainly with the USA, Canada, Great Britain, France and Finland. The Atomic Act sets out the requirements for the licensing of activities with nuclear installations in general and does not preclude the SÚJB from proceeding more quickly and efficiently in specific cases by using information and documents from previous official activities or from other sources, e.g., from other authorities, including foreign ones. On the contrary, the procurement of documents from own sources and older activities and the least possible burden on the persons concerned are among the basic principles already laid down for all authorities in the Administrative Procedure Code.

The problematic elements of the implementing regulations identified by the analysis in the Applicability Study can be divided into several basic areas that will need to be addressed:

1. Inappropriate concept of legislation based on the current state of technology in the Czech Republic - To solve this problem, a complete review of the legislation with knowledge of the new technology and its redesign will be necessary.

2. The legislation works casuistically with specific institutes and concepts that will be inadequate or insufficient in the case of SMRs - The problem can be solved by modifying or supplementing the necessary institutes and concepts.

3. Legislation sets out requirements in a specific way that may not suit new technologies - The shortfall needs to be addressed more generally so that the same problem of dealing with changes in the law does not arise when any new technology arrives. Technology specific features need to be addressed at the sub-legislative level to make the process of appropriate response more flexible, including for the introduction of new knowledge on technologies already in use.

4. In many cases, legislation is explicitly limited to „energy“ (or directly electricity-generating) applications of nuclear installations - The solution is to generalise or find another qualitative criterion.

Other measures

From the point of view of the Czech energy sector, there is a need to further address the current problems arising from the impact of the conflict in Ukraine on the structural changes in energy resources and the need to reduce dependence on imports of energy raw materials and the need for long-term conceptual change linked to decarbonisation and the gradual phasing out of the use of coal in the electricity sector. The permitting processes will continue to be time-consuming despite the above-mentioned adjustments and do not allow for the flexible implementation of the necessary plans for new energy sources supporting decarbonisation. Therefore, new legislation is needed to create adequate conditions for the siting, permitting and operation of RES and other low-carbon energy generation plants as well as other projects.

The legal regulation should, inter alia, define the intentions promoting energy independence that will be affected by the modified rules. This will include nuclear reactor power plants (new nuclear power sources including small modular reactors and modifications and extensions to existing nuclear power sources). Furthermore, the construction of power lines, their extension and strengthening to ensure the security of the power system in connection with the connection and to ensure the quality of energy supply to end customers.

In particular, these are tools to speed up permitting procedures. The following examples of possible measures can be given - consider the implementation of these projects as being in the public interest, give priority to addressing the projects under consideration in permitting procedures, including the procedures leading to the issuance of supporting acts, introduce a single-instance procedure for certain types of projects, assess the existing administrative deadlines in spatial planning or permitting procedures and the possibility of shortening them. These objectives will not be achieved at the expense of public safety and security.

The main difference between the construction of SMRs and traditional nuclear power plants is the assumption of the continuous factory production of standardised units in the case of SMRs, as opposed to one-off projects with a need for around six thousand workers at a given site at peak times. Based on the information available from SMR manufacturers, the typical human resource involvement is around 1,000 employees during unit construction peak times and approximately 100-300 permanent employees for operating the facility, depending on the specific design. A concurrent construction of an SMR and a new large reactor might cause a bottleneck in terms of human capital. Depending on the availability of human resources, the solution should be primarily to optimally time projects to avoid overlapping during peaks in the need for staff. On the other hand, the stable occupational load of the professions concerned may be an advantage beyond the horizon of the construction of large nuclear sources in the case of factory production.

The MIT, in cooperation with the MEYS, launched the Working Group on Human Resources for Nuclear Energy Development (WG HR) in 2022. WG HR was formally launched at the Czech Nuclear Committee meeting on 20 September 2022. According to a preliminary analysis, an additional nine thousand professionals of various professions will be needed to ensure the construction of new nuclear power plants. The construction of traditional nuclear power plants will require mainly graduates of engineering, electrical engineering and construction at all levels of education, i.e., university, secondary school and apprenticeship.

The objectives of the WG HR are to propose measures to ensure a sufficient number of personnel for the future nuclear programme by quantifying the required graduates, analysing the current educational capacity on the part of students and teachers, and providing motivational tools to achieve the desired status. The proposed measures will be submitted to the Government for approval. The training of personnel is crucial not only for the construction and operation of the sources, but also for the authorities concerned, such as DESÚ and SÚJB.

The proposed measures of the WG HR are as follows:

Measure 1: Focus on strengthening the common professional base in disciplinary groups that have a direct impact on the construction and operation of energy resources, particularly in the fields of electrical engineering, power engineering, ICT and construction.

Measure 2: Encourage cooperation between schools and professional and employers' associations and increase the share of practical training for pupils at employers' workplaces. Support long-term stabilisation of staffing for energy sources, especially nuclear.

Measure 3: Educate school staff, including involving practitioners in theoretical and practical teaching.

Measure 4: Support a functional career guidance system.

Measure 5: Carry out a communication and marketing campaign in relation to the government's decision to build new nuclear power plants.

These actions are further broken down into sub-key activities with assigned responsibilities and deadlines.

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11 ASSESSMENT OF SCENARIOS AND OPTIONS

The scenarios and options compared below aim to discuss the appropriate solution for ensuring the construction of SMRs in the Czech Republic with maximising the benefits for the Czech industry and energy sector.

Scenarios in the context of economic benefits (Chap. 3)

- **Scenario 1 (S1):** Purchase of a foreign SMR without the involvement of Czech industry
- **Scenario 2 (S2):** Production of part or the whole of the SMR in the Czech Republic
- **Scenario 3 (S3):** The development and deployment of a Czech design

The MIT's mission is also to support Czech industry. Due to the significant interest of foreign and Czech SMR manufacturers in the involvement of Czech companies in supply chains for the serial production of their SMRs or the localisation of production in the Czech Republic, Scenarios 2 and 3 are preferred. Scenario 1 can be considered as an escape or zero scenario and implemented additionally in case of the failure of other scenarios. Currently, there is an opportunity to take advantage of the interest of foreign manufacturers in engaging Czech industry to supply components not only for SMRs for the Czech Republic but also for the region, potentially on a global level. We recommend starting negotiations on the conditions of the localisation of the production of foreign manufacturers in the Czech Republic and evaluating the potential of Czech SMR projects, including the possibilities of support, in parallel. The advantage of foreign projects is the relative advanced stage of their development and the preliminary interest in their designs in the region and globally. Czech designs promise a higher involvement of the Czech industry in their projects; however, they are still in the conceptual design phase, and besides the risk of not completing the development, there is a market risk of commercialisation of the designs in the Czech Republic and abroad. The competitive advantage of Czech designs is in their declared purpose for the heating industry and a lower capacity compared to foreign designs, meaning a wider applicability. In Scenario 3, there is a risk of a waste of development-related funds if state aid is granted. However, by supporting Scenario 3, even if the implementation of the national design fails, the competence of national research institutions and industry will be increased.

SCENARIO	S1	S2	S3
Status of available projects	advanced	advanced	initial phase
Involvement of the Czech industry	low	medium/high	medium/high
Positive impact on employment	low	medium/high	medium/high
Positive impact on GDP	low	high	high
Impact on R&D support in the Czech Republic	no	no	yes
Difficulty of implementation in the Czech Republic	low	medium	high
Existing demand	yes	yes	n/a

Tab. 5: Evaluation matrix for each scenario in relevant aspects

In conclusion, given the interest of advanced foreign projects in the production of components in the Czech Republic, it is desirable to analyse the possibilities of Scenario 2 and to start negotiations with the companies or countries of origin.

Investor model options (Chap. 6)

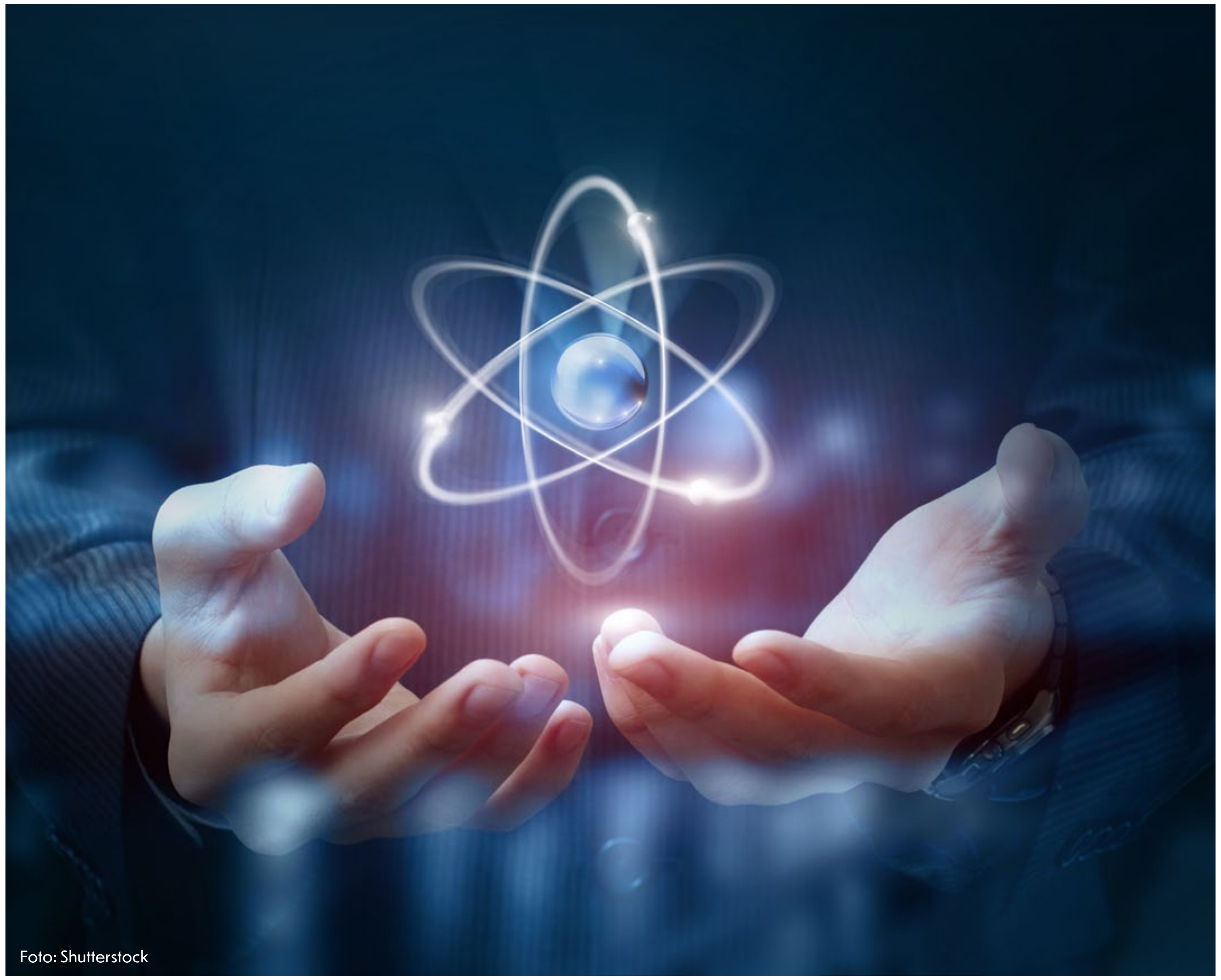
- **Option 1 (O1):** Private company or consortium
- **Option 2 (O2):** Private company or consortium with state aid
- **Option 3 (O3):** State-owned company
- **Option 4 (O4):** Alternative investment and cooperation models

A suitable investor model will provide a level playing field for all those interested in SMRs in the Czech Republic and, with regard to ensuring energy security, appropriate tools to mitigate market failures that are characteristic of nuclear power sources. We therefore recommend evaluating the possibilities of state aid for the construction of SMRs in order to mitigate the effects of financing costs, to allow all competent candidates to implement projects, and at the same time to allow the state to influence energy policy towards energy security with these instruments. This approach is also in line with international recommendations. The aforementioned is best summarised by Option 2.

OPTION	V1	V2	V3	V4
State involvement (guarantees, financing, ...)	none	medium	high	none
Project financing costs	high	medium	low/medium	medium/high
Opportunities for state influence on the project	none	medium	high	none
Openness for investors	high	high	low	medium
Probability of implementation of the SMR	low	high	high	low

Tab. 6: Evaluation matrix for each option in relevant aspects

Conclusion: SMRs are an opportunity to ensure the energy security of the Czech Republic. Option 2 is a way to facilitate the construction of SMR projects by the private sector in collaboration with the state, in line with its objectives.



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12 FINAL RECOMMENDATIONS

a. Utilise the potential of SMRs for the co-generation of electricity and heat with supply to district heating systems, and for hydrogen production.

b. Include SMRs in the State Energy Policy of the Czech Republic, the Hydrogen Strategy of the Czech Republic, the National Energy and Climate Plan of the Czech Republic, the Climate Protection Policy, and other relevant strategies. Take SMRs into account within the framework of the update of the Radioactive Waste and Spent Nuclear Fuel Management Policy in the Czech Republic. Take SMRs into account in the transformation of the heating industry in terms of losses of individual technologies and the efficiency of direct heat production from SMRs; determine the extent of SMR involvement in central heat supply systems.

c. When deploying SMRs and including them in the State Energy Policy of the Czech Republic, the Hydrogen Strategy of the Czech Republic, the National Energy and Climate Plan of the Czech Republic, the Climate Protection Policy, and other relevant strategies, always take into account the priority of ensuring safety, security and non-proliferation requirements, as required by the international and EU commitments of the Czech Republic.

d. In the event that a co-generation SMR source is built primarily to perform the function of providing heat during the heating season, a new category of fee derived from the heat produced needs to be defined in the provisions of Section 121 of the Atomic Act.

e. Communicate transparently and in advance to the public the intentions for the construction of new nuclear sources, including their benefits, with an emphasis on the provision of energy needs, employment, and economic benefits.

f. Set fair and motivating investment conditions for those interested in investing in SMRs, taking into account the need to build the first SMRs in the 2030s, thus facilitating nuclear projects and contributing to overcoming the expected power output deficit which is forecast by CEPS's studies and will be confirmed in the SEP update.

g. For commercial deployment, use the most advanced SMR projects based on light-water reactors available with regard to the earliest possible construction, eligibility of the technology to obtain permits in the Czech Republic and minimisation of implementation risks.

h. With regard to the interest of the state in the timely procurement of the necessary capacity, in the case of direct state involvement in the construction (e.g., by nationalising ČEZ or by creating a joint venture, see Option 2 and Option 3 in Chapter 6), it is strategically advisable to narrow interest to the most advanced designs, from countries that do not pose a security risk to the Czech Republic, and at the same time to evaluate the speed of development of other projects. Due to the currently declared interest in these designs abroad, some of them may be unavailable for the Czech Republic at the time of the need for upgrading.

i. With regard to the complexity, long-term nature, novelty of technologies and procedures, choose investor Option 2 at least for the first few projects. Financing will obviously have to come from many sources. The basic premise will be: Who bears the risk of implementation in terms of time, parameters, budget; who bears the risk of the price (margin) of the end product, the certainty of selling its volume; who bears the risk of life cycle costs.

j. Analyse all potential models of public support from the state, including an assessment of the likelihood of successful notification of all proposals to the European Commission, and select the most appropriate one or a combination of them. (i) Evaluate options for sources of financing (international, European and national funds, European Investment Bank, intergovernmental loans, export financing, repayable financial assistance, supplier equity participation, government guarantees, etc.), (ii) evaluate SMR revenue assurance (PPA, CfD, RAB, etc.), and (iii) assess other parameters key to model selection. Assess options for the state ownership of SMRs, including the benefits and drawbacks and non-discriminatory use of selected instruments by private companies to enable the construction of SMRs.

k. Pursue the possibility of using funds from EU or European Investment Bank instruments for the preparatory phases and construction of the SMR.

l. Discuss the possibility of providing a guarantee to export and credit institutions for possible financing of SMR construction by private companies.

m. Analyse the possibility of investment incentives for the expansion of existing and new suppliers in the nuclear industry to motivate foreign investment in the Czech Republic.

n. Initiate legislative and regulatory changes to enable an effective licensing framework for SMRs. In particular, update the nuclear law in relation to foreign experience and cooperation with foreign regulators from the countries of origin of SMRs (e.g., by allowing more efficient licensing procedures), and streamline other permitting processes, especially under the Building Act.

o. Provide the necessary resources to State administration in order to cover the SMR agenda, in particular resources for SÚJB to effectively cooperate with partner regulators and to amend the atomic law in timely fashion.

p. Accelerate the site selection and preparation process so that sites are ready for SMR construction in the first half of the 2030s.

q. In accordance with the Building Act, make this Plan available to the spatial planning authorities, i.e., the municipalities concerned and the regional authorities, with a request to take it into account in their spatial analysis documents.

r. Conduct negotiations with the Ministry of Regional Development on the change of technology at specific current locations of energy sources with regard to the parameters of the technology and their demands on the territory (e.g., protection and safety zones), for a possible necessary update of the Spatial Development Policy of the Czech Republic.

s. Coordinate the preparation and implementation of large nuclear power source projects and SMRs to ensure sufficient capacity and procedural compliance.

t. Develop an analysis of the economic benefits of involvement in foreign SMR supply chains.

u. Actively grasp the opportunity for the development of industry, employment and the national economy, i.e., examine offers for the production of components for SMRs in the Czech Republic or the involvement of Czech companies in the supply chains of foreign manufacturers. The opportunity to take a leading role in SMR production in the EU may be limited in scope and time.

v. Prepare an analysis of the cooperation of interested countries and concerns on a cross-border fleet approach.

w. Coordinate EU action with Member States declaring plans for the construction of SMR projects. Support the streamlining of licensing processes for SMRs at EU level.

x. Evaluate possible business models for supplier selection and, in particular, according to the preferences of investors and potential investors, support these on the part of the state.

y. Analyse the possibilities, processes and opportunities for concluding an intergovernmental agreement and the interest of the governments of the manufacturers' countries of origin. In case of confirmation of the investor's interest, possibly also prepare special rules of the international agreement that may be concluded between the Czech Republic and an EU Non-Member State for the inclusion of supplies, services and works intended for joint implementation or use of the project by the contracting parties.

z. In relation to the nuclear fuel supplier, the security interest of the Czech Republic is to ensure diversified, reliable and affordable supplies.

aa. In relation to the expected scope of the construction of SMRs, ensure the capacity of SÚRAO for new nuclear sources (including SMRs) or examine the options of building a new facility in a new location or storage on the site of the deep repository for RW and SNF under preparation.

bb. Ensure adequate capacity for spent fuel storage in the deep repository project.

cc. Update estimates of operational radioactive waste produced and the inventory of SNF.

dd. Prepare estimates of the expected inventory and economics of RW and SNF and storage capacity of radioactive waste from SMR reactors and incorporate them into the update of the RW and SNF Management Policy in accordance with Government Resolution No 24 of 11 January 2023.

ee. Update the levies of regular fees on the nuclear account after 2030 in the context of the development of SMRs in the Czech Republic within the framework of the amendments to the Atomic Act.

ff. Consider SNF as a possible source of fissile material for fuel for Generation IV reactors and take this into account in plans for its disposal in a deep repository.

gg. Include SMR technologies in the support of science, research and innovation under the current instruments: i.e. continue support under the Programme for the Support of Applied Research, Experimental Development and Innovation of the National Centre of Competence (now the Centre for Advanced Nuclear Technologies II) and set priority research objectives for the THÉTA II calls; continue to support activities related to the development of Czech SMR design at the level of scientific research grants; and continue to monitor the possibility of further support for the commercialisation of Czech SMR designs according to demand, which may be an alternative in the case of unavailability of foreign technologies.

hh. Promote training and retraining programmes for the future construction and operation of SMRs in coordination with regions, especially those that will be affected by the department from coal mining and combustion. Explore the possibility of scholarships or incentives for foreign students and workers, taking into account the demographics and structure of education in the Czech Republic

13 TASKS AND RESPONSIBILITIES

i. Use the Roadmap as an input for the State Energy Policy;

ii. prepare an analysis of financing and state aid methods for the construction and analysis of ownership and operation models for small and medium-sized reactor projects and submit information to the Government with recommendations for further action;

iii. actively negotiate and support the involvement of Czech companies in the supply chains of foreign designs of small and medium-sized modular reactors;

iv. submit information to the Government on the possibilities of using the previously concluded intergovernmental agreements for cooperation in the field of small and medium-sized modular reactors and, if necessary, start preparing the extension of the existing agreements or initiate activities aimed at concluding new agreements; accelerate the development of selected small and medium modular reactor technologies;

v. propose the streamlining of licensing and permitting processes for small and medium modular reactor technologies in the forthcoming amendments to the legislation on the preparation of nuclear new build;

vi. in the Spatial Development Policy of the Czech Republic, examine the possibility of establishing a task for ministries and central administrative authorities and for spatial planning to assess the need to define the sites listed in the Roadmap for small and medium modular reactor technology in the spatial planning documentation of regions and municipalities;

vii. identify preferred sites for small and medium-sized reactors in the Czech Republic and negotiate with investors on the preparation of related and induced investments and associated infrastructure at the sites of the planned build of small and medium-sized modular reactors;

viii. recommend to the Governors and the Mayor of the Capital City of Prague to cooperate in the implementation of the Plan's tasks.

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14 LIST OF ABBREVIATIONS

CapEX - Capital Expenditure

CEPS - Transmission system operator of the Czech Republic

CfD - Contract for Difference

CR - Czech Republic

DESÚ - Transport and Energy Building Authority

EDU - Dukovany Power Plant

EIA - Environmental Impact Assessment

EIB - European Investment Bank

EMA - Engineering, Manufacturing, Assembly delivery model

EPC - Engineering, Procurement, Construction delivery model

EPZ - Emergency Planning Zone

ERO - Energy Regulatory Office

ETE - Temelín Power Plant

EU - European Union

FOAK - First of a Kind

GDP - Gross domestic product

HAW - Highly Active Waste

IAEA - International Atomic Energy Agency

JV - Joint Venture

LCOE - Levelized Cost of Energy

MAF - Assessment of resource adequacy of the Czech electricity system (MAF CZ 2022)

MIT - Ministry of Industry and Trade

MoE - Ministry of the Environment

MoF - Ministry of Finance

NAP NE - National Action Plan for the Development of Nuclear Energy in the Czech Republic

NBA - New Building Act

NDF - National Development Fund

NHSI - Nuclear Harmonization and Standardization Initiative

NI - Nuclear island

NIMBY – 'Not in My Backyard' phenomenon; meaning one's opposition to the locating of something considered undesirable in one's neighbourhood

NOAK - Nth of a Kind

NPP - Nuclear power plant

OECD NEA - Nuclear Energy Agency of the Organisation for Economic and Trade Co-operation

PPA - Power Purchase Agreement

RAB - Regulated Asset Base

R&D - Research and Development

RES - Renewable Energy Sources

RFA - Repayable financial assistance

RW – Radioactive waste

SEP - State Energy Policy

SEO - Single Environmental Opinion

SMR - Small and medium reactors / small modular reactors

SNF - Spent nuclear fuel

SPV - Special Purpose Vehicle

SÚJB - State Office for Nuclear Safety

SÚRAO - Radioactive Waste Repository Authority

SWOT - Method of analysis of strengths, weaknesses, opportunities and threats

TACR - Technology Agency of the Czech Republic

TI - Turbine Island

ÚJV - Nuclear Research Institute

WACC - Weighted average cost of capital

WENRA - Western European Nuclear Regulators Association

WG HR - Working Group on Human Resources for Nuclear Energy Development

WG SMR - Working Group on the applicability of small and medium reactors in the Czech Republic

15 ANNEXES

15.1 Annex A: Overview of the meetings and conclusions of the Working Group

Overview of WG SMR meetings

1. 28 February 2022: Ongoing activities in the EU, the Czech Republic and the MIT, the project Applicability of Small and Medium-Sized Reactors in the Czech Republic,
2. 28 March 2022: Resource adequacy of the electricity system of the Czech Republic, the concept of a tiered approach in nuclear legislation,
3. 10 May 2022: Presentation of the needs of members of the Heating Association of the Czech Republic, the Association of the Chemical Industry of the Czech Republic, the Steel Union,
4. 20 June 2022: Presentation of the project of the Moravian-Silesian Region, Ústí nad Labem Region, South Bohemia Region, and the possibilities of support from the MoE/SEF, MIT,
5. 23 September 2022: Presentation of the strategy of Sev.en, EPH, SUAS, Innogy, PRE,
6. 17 October 2022: Presentation of Czech designs by ZČÚ/CIIRC Teplator, Witkowitz SMR David, CVR CR-100, Section for Science, Research and Innovation at the Office of the Government of the Czech Republic,
7. 30 November 2022: Financing options, European Investment Bank, UK Export Finance, CSOB, Česká spořitelna, National Development Fund,
8. 20 December 2022: Supply chain, MIT negotiations with SMR suppliers, prospects of Škoda JS and SAFICH PROJEKTY GROUP for SMR supplies, CzechTrade activities and economic diplomacy projects (PROPED), possibilities of coordination and presentation of supply chain readiness.
9. 09 January 2023: Financing options, EXIM bank

Main conclusions of the WG SMR meetings

a. A stable and transparent business and legislative environment is a prerequisite for investment in SMRs

b. Industry expects the simplification of permitting processes and the setting of non-discriminatory conditions for SMR construction

c. The Czech Republic should actively support and initiate a „pre-licensing" exchange of design information with regulators in the countries of origin of SMR manufacturers and not wait for the emergence of an international regulatory environment for SMRs

d. The safety requirements to ensure nuclear safety will not be different for SMRs compared to large units; it is only possible to simplify the processes to take into account the potential safety advantages of SMRs and focus on a tiered approach.

e. Industry expects the state to secure permitting and recommends that the state itself provide a preliminary site survey to ensure compliance with the requirements of Decree No. 378/2016 Coll. and thus attract investors

f. The interest of the state in SMR technology, as declared in the SEP, and the support of the regions are crucial for the identification of sites and the construction of SMRs

g. Regions are ready to cooperate in the preparation of sites and infrastructure with the state and investors

h. The WG expects opinions from the state regarding guarantees, risk assurance and setting up financing options for SMR projects

i. Financing needs to be set up on the basis of the most efficient allocation of risks between the parties involved

j. Commercial entities are unable to effectively bear some of the risks of SMR projects

k. Given the seasonality of heat supply, the economics of SMRs should be based primarily on electricity supply

l. There are mainly two investor models in the Czech Republic: (i) the investor will be the state or a state-owned company, or (ii) an energy or industrial company

m. Potential SMR investment candidates from industry and the energy sector are waiting for affordable, commercial SMR technology and are currently in the role of observer,

n. Light-water SMRs are a priority for application in the Czech Republic from the point of view of legislation

o. SMR technology should be certified to facilitate permitting processes

p. The Czech supply chain is able to produce components for SMRs directly on demand and Czech companies are able to act as an integrator or sub-integrators of SMR projects

q. The state should provide public education on SMRs

r. It is necessary to provide human resources for the construction and operation of the SMR, including support for study programmes

s. Financial institutions expect a specific project proposal to determine the parameters and financing options

15.2 Annex B: Overview of light-water SMR technologies with parameters according to the Applicability Study

Parameters of light-water SMRs according to the Applicability Study

TECHNOLOGY DEVELOPMENT, COUNTRY OF ORIGIN	NUSCALE POWER CORPORATION, USA	HOLTEC INTERNATIONAL, USA	GE-HITACHI NUCLEAR ENERGY, USA AND HITACHI-GE NUCLEAR ENERGY, JAPAN	EDF, FRANCE + CEA, NAVAL GROUP, FRAMATOME, TECHNICATOME AND TRACTEBEL-ENGIE	ROLLS-ROYCE SMR LTD., UK	KAERI, REPUBLIC OF KOREA, K. A. CARE, SAUDI ARABIA
Reactor type	integrated pressurised water reactor	pressurised water reactor	boiling water reactor	integrated pressurised water reactor	Three-loop pressurised water reactor	integrated pressurised water reactor
Refrigerant/moderator	light water / light water	light water / light water	light water / light water	light water / light water	light water / light water	light water / light water
Thermal/electrical output	250 MWt / 77 MWe (1 module)	525 MWt / 160 MWe	870 MWt / 270 - 290 MWe	2x540 MWt / 2x170 MWe	1,357 MWt / 470 MWe	4 x 365 MWt / 4 x 107 MWe
Primary circulation	natural circulation	natural circulation	natural circulation	forced circulation	forced circulation	forced circulation
Operating pressure (primary/secondary) [MPa]	13.8/4.3	15.5/3.4	7.2/direct cycle	15/4.5	15.5/7.8	15/5.8
Refrigerant inlet/outlet temperature of active zone [°C]	249/316	243/321	270/288	280/307	295/325	296/322
Gross electrical efficiency [%]	30.8	30.5	32.2	31.5	34.6	29.3
Own electricity consumption [%]	4.87	4.87 (expert estimate)	4.7 (expert estimate)	4.87 (expert estimate)	5 (expert estimate)	4.87 (expert estimate)
Fuel type/distribution	UO2, square layout 17x17	UO2, pellets, square distribution	UO2, 10x10 array	UO2, square layout 17x17	UO2, square layout 17 x 17	UO2, pellets, square layout 17x17
Number of fuel assemblies in the active zone	37	57	240	76	121	57
Fuel enrichment [%]	< 4.95	4 (average)	3.81 (average) / 4.95 (maximum)	< 5	< 4.95 (average)	< 5
Fuel burn-up [GWd/t]	>= 45	45	49.6	-	50 - 60	< 54
Fuel change cycle [months]	18	24	12 - 24	24 (half of the active zone)	18 months	
Service life [years]	60	80	60	60	60	60
Fuel cycle	standard three-phase fuel exchange scheme	about 1/3 of the fuel is changed at each fuel exchange	open fuel cycle with standard BWR fuel	open fuel cycle with standard LWR fuel	open cycle	open fuel cycle with standard LWR fuel
Distinguishing features	unlimited reactor after-cooling during power failure and without the need to add water	passive safety cooling systems and active non-safety systems; critical components below quality level. Integrated dry spent fuel storage and transport system	natural circulation in BWR, integrated isolation valves, isolation condenser	integrated NSSS with a pool connected to containment, boron-free in normal operation and all design conditions (DBC), semi-closed nuclear island	modular approach to facilitate fast and cost-effective construction	Use for water desalination and process heat supply, integrated primary system

Economic parameters of SMR according to US EIA in comparison with other technologies

TECHNOLOGY (2021 PRICES)	SMR	POWER PLANT WITH ULTRA SUPERCRITICAL (USC) COAL BOILER	USC WITH 30% CO_2 CAPTURE AND STORAGE RATE (CCS)	USC WITH A 90% CAPTURE AND CO_2 STORAGE RATE (CCS)	SINGLE-SHAFT COMBINED CYCLE	COMBINED CYCLE WITH A 90% CCS	INDUSTRIAL COMBUSTI ON TURBINE	BATTERY STORAGE	BIOMASS	PHOTOVOLTAIC POWER PLANT WITH ROTATING PANELS	PHOTOVOLTAIC POWER PLANT WITH STORAGE
First year of availability	2028	2025	2025	2025	2024	2024	2023	2022	2025	2023	2023
Installed power [MW]	600	650	650	650	418	377	237	50	50	150	150
Delivery time [y]	6	4	4	4	3	3	2	1	4	2	2
Specific investment costs - overnight [CZK/kW]	148,760	88,332	109,386	140,825	26,040	59,322	17,020	28,534	98,089	28,772	37,900
Technological optimism coefficient	1.1	1	1.01	1.02	1	1.04	1	1	1	1	1
Total overnight costs [CZK/kW]	163,634	88,332	110,491	143,643	26,040	61,685	17,020	28,534	98,111	28,772	37,900
Variable operating costs [CZK/MWh]	68.1	102.1	160.7	249.1	57.9	132.5	102.1	0	109.7	0	0
Fixed operating costs [CZK/kW.y]	2,156	921	1,232	1,352	320	626	159	563	2,854	346	730
Specific heat consumption for electricity production [kWh/kWh]	3.061	2.532	2.858	3.665	1.885	2.088	2.903		3.956		

Annual Energy Outlook 2022 (https://www.eia.gov/outlooks/aeo/)

15.3 Annex C: Criteria for the level of technological readiness of SMR projects

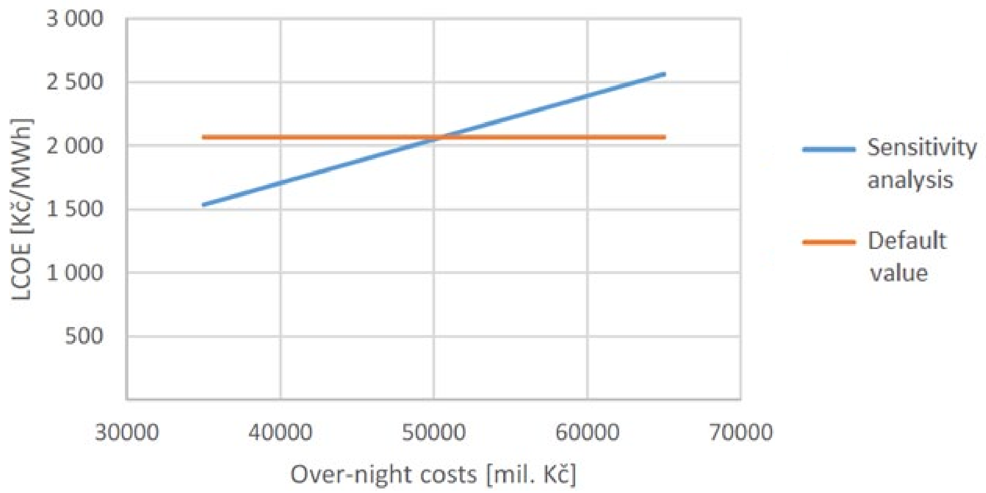
TRL 9	The project is implemented and the reactor system is operational	TRL 9: The actual/real SMR system is operated/operates over the full range of expected conditions.	The project has been implemented in its final form and is operating at full scale under expected operating conditions.
TRL 7-8	The reactor system is commissioned/being commissioned	TRL 8: The actual system is completed and qualified through tests and demonstrations	This SMR project technology has been shown to be operationally proven in its final form and under the expected conditions. In almost all cases, this TRL represents the end of the actual development of the project. Examples include developmental testing and evaluation of SMR project systems. Supporting information includes operating procedures that are virtually/nearly complete. The Operational Readiness Review (ORR) was successfully completed prior to the start of hot functional testing.
		TRL 7: Full-scale or prototype key equipment/systems/technologies of the project have been successfully tested in a relevant/appropriate environment.	This represents a major advance from TRL 6. TRL 7 requires the demonstration of an actual prototype system in a relevant environment. Examples include full-scale prototype testing during cold commissioning/start-up. Supporting information includes full-scale test results and analysis of differences between test environments and an analysis of what the experimental results mean for the relevant operating system/environment. The final design is virtually complete.
TRL 4-6	Demonstrator of the technology used in the reactor project	TRL 6: Engineering/pilot scale, validation of a similar (prototype) key device/system/technology of the project in a relevant environment	Engineering scale models or prototypes are tested in the appropriate environment. This represents a major step in the demonstrated technology readiness of the SMR project. Examples include testing a prototype system on an engineering scale. Supporting information includes engineering scale test results and analysis of differences between the engineering scale, prototype system/medium, and analysis of what the experimental results mean for the relevant operating system/environment. TRL 6 initiates a real technical evolution of the technology as an operating system. The main difference between TRL 5 and 6 is the transition from laboratory scale to engineering scale and the establishment of scaling factors to enable the design of the operating system. The prototype should be able to perform all the functions that the operating system will require. The operational environment for testing should closely match the actual operational environment.
		TRL 5: Laboratory scale, validation of a similar system in a relevant environment	The basic technological components of the SMR project are integrated in such a way that the system configuration corresponds in almost all respects to the final version of the project (basic design). Examples include testing a high-fidelity system at laboratory scale in a simulated environment with a range of simulants and real waste. Supporting information includes the results of lab-scale testing, an analysis of the differences between the lab and the relevant operating system/environment, and an analysis of what the experimental results mean for the relevant operating system/environment. The main difference between TRL 4 and 5 is the increased fidelity of the system and environment to the actual application. The tested system is almost a prototype.
		TRL 4: Validation of components and/or the system in a laboratory environment	The core technology components are integrated to ensure that the individual components work together properly in the system. Examples include ad hoc hardware integration in the lab. Supporting information includes results of integrated experiments and estimates of how experimental components and experimental test results differ from expected system performance goals. TRL 4-6 represent a bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system is likely to be a combination of hand-held equipment and a few special components that may require special handling, calibration or securing to work.
TRL 2-3	Research and development for verification pre-conceptual and conceptual design of the reactor	TRL 3: SMR conceptual design developed.	Active research and development of the SMR project has been initiated following the pre-conceptual project. This includes analytical and laboratory scale studies to physically validate the analytical predictions of individual elements of the technology. Examples include components that are not yet integrated or are being tested in representative experimental facilities. Supporting information includes the results of laboratory tests performed to measure the parameters of interest and comparisons with analytical predictions for critical subsystems. At TRL 3, the work has moved from the paper phase to experimental work, verifying that the project concept works as expected on experimental devices. However, the technology components used in the SMR project are not yet integrated into the overall system. Modelling and simulation can be used to complement physical experiments.
		TRL 2: Pre-conceptual project created	Once the basic principles have been verified, a pre-conceptual design of the SMR can be developed. Applications of the technologies are speculative and there may not be experimental validation or a detailed analysis to support these assumptions at this stage. Examples are still limited to analytical studies. Supporting information includes publications or other references that outline the application under consideration and provide analysis supporting the concept. The step from TRL 1 to TRL 2 moves ideas from pure to applied research. Most of the work involves analytical or paper-based studies with an emphasis on better understanding the science. The experimental work is designed to confirm the basic scientific observations made during TRL 1.
TRL 1	Basic research on the technology considered for the reactor project	TRL 1: Basic principles identified and published	This is the lowest level of technology readiness used in the SMR project. Basic research is beginning to translate into applied research and development. Examples include theoretical studies of the basic properties of a technology or experimental work that consists mainly of observations of physical phenomena. Supporting information includes published research or other references that identify the principles underlying the technologies used in the pre-conceptual design of the project.

15.4 Annex D:Sensitivity analysis of input parameters to LCOE SMR according to the Applicability Study

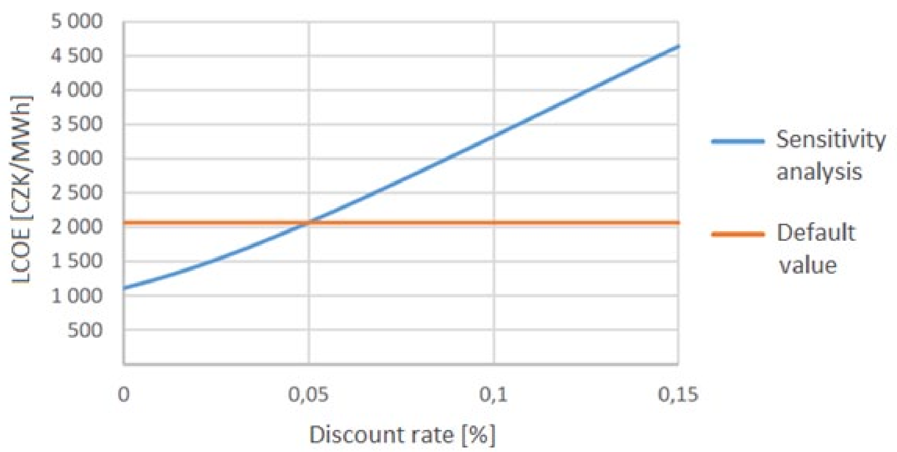
Common assumptions:

- Lightwater reactor
- Initial annual use with an electricity supply of 7 500 h/year
- WACC at 5%
- Power supply lifetime 60 years
- Installed electrical capacity 300 MWe
- Specific investment overnight costs 165 mil. CZK/MWe

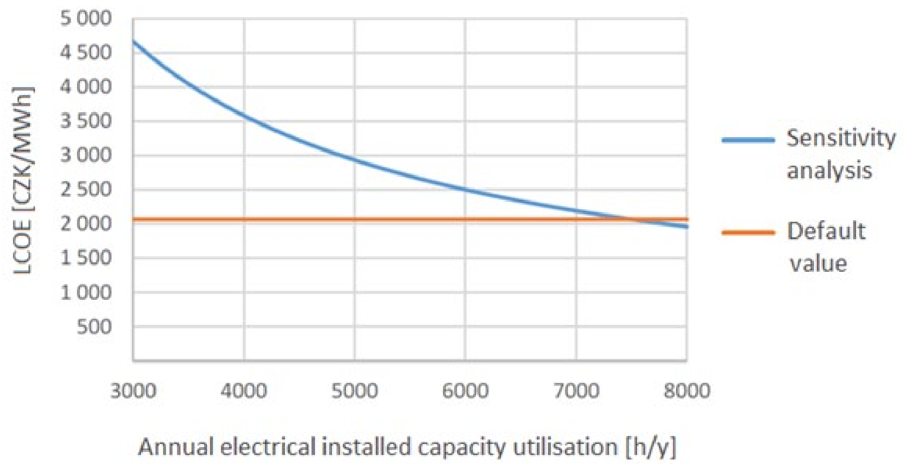
Sensitivity analysis of LCOE to investment costs (overnight costs):



Sensitivity analysis of the SMR LCOE to the discount rate:



Sensitivity analysis of the LCOE SMR to the use of electrical installed capacity:



15.5 Annex E: Overview of sites according to the Applicability Study

Sources/locations of significant non-nuclear sources suitable for SMR siting according to exclusion criteria: 1 - minimum supply of 1 000 TJ of heat and 1.5 TWh of electricity (including sources with such supply potential); 2 - sources with more than 50% of primary fuel in the form of coal. These sites are connected to the heating and electricity networks (400 kV or 110 kV).

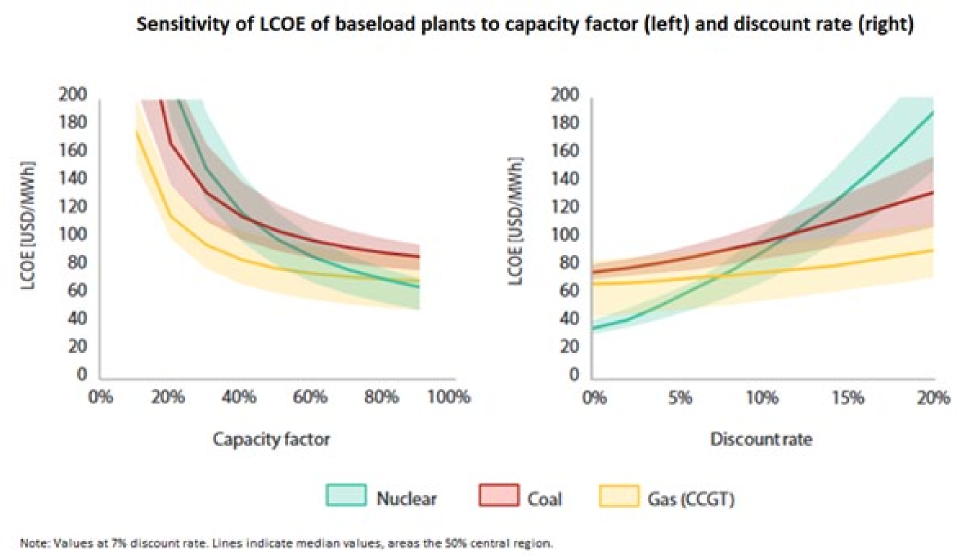
SERIAL NO.	SOURCE NAME [ACCORDING TO ERO]	INSTALLED T-CAPACITY [MWT]	TOTAL E-CAPACITY [MW]	ANNUAL GROSS ELECTRICITY PRODUCTION [GWH]	ANNUAL GROSS HEAT PRODUCTION [TJ]	ANNUAL SUPPLY HEAT [TJ]	SUPPLIED DISTRICT HEATING AREAS	DATA PER YEAR	REGION	SOURCE TYPE
1	Mělník I Power Plant	1,098	240	0	16,230	8,954	Prague, Mělník and the surroundings of Neratovice	2016	CB	T
2	Mělník II Power Plant	613	220	0	11,754	1,547	Prague, Mělník and the surroundings of Neratovice	2016	CB	T
3	Třebovice Power Plant	765	174	773	9,570	3,713	Ostrava	2017	MS	T
4	Opatovice Power Plant	1,068	363	960	12,113	3,259	Hradec Králové Pardubice, Chrudim	2015	P	T
5	CHP Plant Trmice	469	89	139	0	2,911	Ústí nad Labem	2016	Ú	T
6	Plzeňská teplárenská, a. s. - CHP Plant	499	151	0	8,747	2,650	Pilsen	2015	PL	T
7	CHP Plant Přívoz	176	14	82	2,358	1,894	Ostrava	2017	MS	T
8	CHP Plant Komořany	1,076	239	707	0	1,724	Most Litvínov	2016	Ú	T
9	PP Vřesová	1,100	240	1,700	23,096	1,619	Karlovy Vary Chodov, Nejdek	2014	K	T
10	CHP Plant Olomouc	213	50	0	3,394	1,592	Olomouc	2014	O	T
11	Kladno Power Plant	966	473	0	19,410	1,484	Kladno	2016	CB	T
12	CHP Plant České Budějovice	412	52	105	2,796	1,477	České Budějovice	2014	SB	T
13	CHP Plant Karviná	248	55	162	2,476	1,412	Karviná Havířov	2017	MS	T
14	Poříčí Power Plant	485	165	420	6,384	1,292	Trutnov and its surroundings	2014	HK	T
15	Ledvice III Power Plant	277	110	1,593	0	1,254	Teplice, Bílina Ledvice, Krupka, Dubí	2016	Ú	T
16	CHP Plant Přerov	347	48	0	3,555	1,161	Přerov	2014	O	T
17	CHP Plant ČSA	171	24	48	1,258	1,034	Karviná Havířov	2017	MS	T
18	CHP Plant Zlín	268	69	120	0	1,000	Zlín	2020	Z	T
19	Prunéřov II Power Plant	1,581	750	4,050	0	939	Chomutov, Jirkov Klášterec nad Ohří	2016	Ú	C+
20	CHP Plant Na Moráni	177	26	73	1,285	868	Chomutov	2016	Ú	C+
21	ENERGY Ústí nad Labem, a. s.	248	16	0	1,272	841	Ústí nad Labem	2016	Ú	C+
22	Tisova I+II Power Plant	520	289	1,000	1,090	763	Sokolov	2014	K	C+
23	Dětmarovice Power Plant	2,074	800	1,763	14,583	557	Bohumín, Orlová	2017	MS	C+
24	Tušimice Power Plant	1,774	800	5,632	0	530	Kadaň	2016	Ú	C+
25	CHP Plant Malešice	492	122	0	0	0	Prague	2020	Prague	C+
26	Počerady I Power Plant	2,435	1,000	6,099	0	63	-	2016	Ú	C
27	Chvaletice Power Plant	2,024	820	2,159	0	140	-	2020	P	C

POŘ. Č.	NÁZEV ZDROJE [DLE ERÚ]	INSTALOVANÝ T-VÝKON [MWT]	CELKOVÝ E-VÝKON [MW]	ROČNÍ VÝROBA ELEKTŘINY BRUTTO [GWH]	ROČNÍ VÝROBA TEPLA BRUTTO [TJ]	ROČNÍ DODÁVKA TEPLA [TJ]	ZÁSOBOVANÉ SCZT	ÚDAJE ZA ROK	KRAJ	TYP ZDROJE
28	Energetika Třinec, a. s.	612	102	675	11,186	1,750	Třinec	2017	MS	I
29	Lovochemie - Thermal Power Plant	268	44	118	2,557	1,694	Lovosice	2016	Ú	I
30	Thermal Power Plant ŠKO-ENERGO	414	88	0	5,419	1,602	Mladá Boleslav	2016	CB	I
31	Thermal Power Plant Otrokovice	247	50	0	0	1,416	Otrokovice	2020	Z	I
32	Thermal Power Plant Zelená louka 1+2	381	76	0	1,633	1,135	Pardubice	2018	P	I
33	SPOLANA, a. s. - Thermal Power Plant	280	77	0	1,760	0	Neratovice	2016	CB	I
34	Plzeňská teplárenská, a. s. - Energy	364	113	0	0	813	Pilsen	2017	PL	I
35	Thermal Power Plant - Kralupy n. Vltavou	361	67	0	5,267	4,510	Refinery - Kralupy nad Vltavou	2016	CB	O
36	Thermal Power Plant Brno	1,072	181	260	4,207	3,559	Brno	2015	SM	O
37	Deza, a. s. - Thermal Power Plant	206	18	139	0	2,042	Val. Meziříčí	2018	Z	O
38	Mondi Štětí a. s.	540	112	569	10,719	1,113	Štětí	2017	Ú	O
39	Incinerator - Heat production section	92	23	60	2,174	1,018	Brno	2020	SM	O
40	Incinerator - plant 1400000	116	17	35	0	849	Prague	2017		O
41	Počerady II Power Plant	1,220	845	1,813	0	0	-	2016	Ú	O
42	Steam PP Vřesová	821	400	2,008	0	0	-	2014	K	O
43	Spalovna – závod 1400000	116	17	35	0	849	Prague	2017		O
44	Elektrárna Počerady II	1 220	845	1813	0	0	-	2016	ÚK	O
45	PPE Vřesová	821	400	2 008	0	0	-	2014	KK	O

Beyond these locations, there is also the potential to locate SMRs at the existing sites of the **Temelín** and **Dukovany** nuclear power plants. There is a possibility of preparing the **Blahutovice** nuclear site for SMR, which is currently designated for energy purposes in the land use plan.

- T Heating plants
- C Coal-fired power plants
- C+ Coal-fired power plants with potential to increase heat supply
- I Coal-fired power plants servicing industrial facilities
- O Other significant non-nuclear and non-coal sources of heat or electricity in the Czech Republic

15.6 Annex F: LCOE sensitivity of individual resources to the capacity factor and discount factor



Source: International Energy Agency - Projected cost of electricity generation 2020[28]

15.7 Annex G: UKEF and EXIM export financing options

- UKEF (Great Britain) - Follows OECD rules, i.e., up to 85% of the project value and a maximum repayment period of 18 years. According to the requirements, at least 20% of the supplies must come from the UK. This value includes goods, services, intangible assets and subcontracts. It has a budget of £5 billion for projects in the Czech Republic. In case of interest, it also allows support for individual regions if a guarantee from the state is provided. They support over 60 currencies for financing, including the Czech crown. For financing parameters, they take into account the institution's credit rating. Specifics are contingent on the overall method of financing and the number of projects. UKEF is ready to provide individual consultations to both companies and regions.

- EXIM (USA) - EXIM is active in financing the nuclear sector, both in Europe and worldwide. They finance new power plants, but also support the renovation of existing plants. EXIM considers three areas in nuclear sector projects- (1) credit aspects, (2) the legal and regulatory framework of the country, and (3) an external nuclear consultant for specific technical, legal, economic, or other expertise. EXIM assesses a country's previous experience, looking at the country's qualified supply chain and nuclear regulatory authority. They have environmental and social practices and guidelines to follow and they respect IAEA safety standards. The conditions of financing for the nuclear sector are e.g., for new structures a repayment period of up to 18 years, the share of US supplies up to 85% of the contract value, a local share at the level of 30% etc., in line with OECD rules. There is currently no maximum amount of financing identified to support an SMR project. The decision on the amount of these funds depends on the specific project - the technology considered, the permit granted, the number of units considered, etc. EXIM is ready to provide companies with individual consultations.

[28] https://iea.blob.core.windows.net/assets/ae17da3d-e8a5-4163-a3ec-2e6fb0b5677d/Projected-Costs-of-Generating-Electricity-2020.pdf

MINISTRY OF INDUSTRY AND TRADE
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