# PREPARATION OF PRELIMINARY TECHNICAL STUDY FOR THE CONSIDERATION OF THE PEACETIME APPLICATION OF NUCLEAR ENERGY IN THE REPUBLIC OF SERBIA JN-14/24

EDF, International Nuclear Development

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# 1• Supporting the Republic of Serbia in meeting its objectives to deploy new nuclear capacities

At EDF, with an existing fleet of 66 nuclear reactors and plans for at least 10 new units in France and the United Kingdom, we recognize the pivotal role of nuclear power in carbon-free electricity generation.

**EDF is fully committed to support new ambitions for the development of new nuclear capacities across the world, and notably in Europe, more particularly helping Serbia to achieve its own challenges in an evolving energy landscape.**

The Government of the Republic of Serbia is in the process of analyzing **the perspective of adding Nuclear Power Plants (NPPs) to the country's energy mix on its path to decarbonization.**

In that perspective, the Government of the Republic of Serbia is actively setting a structured framework to evaluate the prerequisites for implementing a civil nuclear programme in the country. The evaluation process will be fully aligned with the International Atomic Energy Agency (IAEA) milestones approach.

On the 8$^{th}$ of April 2024, a Memorandum of Understanding (MoU) was signed between The Government of the Republic of Serbia and EDF. This emphasizes EDF's willingness to support Serbia in its decarbonization roadmap, in particular by means of implementation of nuclear power plants.

A Letter of Engagement was signed in August 2024 between the Government of Serbia and EDF. This Letter of Engagement aims notably at supporting the Serbian Government in developing a comprehensive nuclear roadmap.

In addition, EDF, in partnership with Egis, has been awarded a contract by Serbia's Ministry of Mining & Energy to conduct a preliminary study on the potential role of nuclear power in Serbia's energy future following a public procurement process ref JN-14/24.

Egis Nuclear introduction, nuclear capabilities.

This preliminary study, launched in November 2024, covered the following scope of work:

- Work Package #1: Development of a Nuclear Roadmap
- Work Package #2: Technology assessment and nuclear market survey
- Work Package #3: Supply-demand analysis to define potential power future (2045) dispatches in Serbia

For each of the 3 Work Package a full and dedicated report has been issued to the Ministry of Mining and Energy. This document presents the Executive Summary of the work completed across the 3 Work Packages, offering stakeholders a clear view of the project's outcomes. It provides a concise overview of each Work Package, highlighting the main activities carried out and the key results achieved.

# EXECUTIVE SUMMARY

# 2• Executive Summary

## 2•1• Work Package #1: Roadmap for Nuclear Energy Development in Serbia

The Republic of Serbia stands at a crucial juncture in its energy transition. Currently, coal represents approximately 70% of Serbia's electricity production, creating significant environmental challenges. The Government of Serbia, committed to energy diversification, sustainability, and decarbonization, has set ambitious targets, including phasing out coal by 2050 and enhancing renewable energy sources such as solar and wind. In alignment with these objectives, the potential introduction of nuclear power emerges as a significant strategic option, capable of providing reliable, low-carbon baseload energy, and fostering technological and economic growth.

To facilitate informed decision-making, EDF, leveraging its global nuclear expertise and the IAEA Milestone Approach, has collaborated with the Serbian Ministry of Mining and Energy to develop a comprehensive nuclear energy roadmap. This roadmap provides a structured pathway to guide Serbia through the crucial preparatory phases of developing a nuclear energy infrastructure.

The detailed report identifies priority actions, critical milestones, and the necessary legal, regulatory, technical, financial, and human resources frameworks. The key priorities and recommendations made by EDF are listed below.

### Key Priorities and Recommendations

1. **National Strategy and Policy Alignment:**
   - Establish clear political and public consensus around nuclear energy as part of Serbia's future energy mix.
   - Integrate nuclear power objectives within Serbia's broader decarbonization and energy security strategies.
2. **Regulatory and Legal Framework Development:**
   - Enhance the existing legal framework and establish an independent, competent nuclear regulatory body aligned with international standards and IAEA guidelines.
   - Join international conventions and treaties essential for nuclear safety, security, and liability, ensuring international credibility and cooperation.
3. **Technical Feasibility and Infrastructure:**
   - Conduct comprehensive site-selection studies, prioritizing geological stability, environmental safety, cooling capabilities, and grid integration.
   - Undertake detailed grid capacity assessments to ensure efficient nuclear integration and resilience.
4. **Human Capacity Building:**
   - Develop robust educational and vocational training programs, leveraging partnerships with international institutions and established nuclear operators.
   - Initiate capacity-building measures, including targeted scholarships, international exchanges, and diaspora engagement.

5. **Public Engagement and Communication:**
   - Launch comprehensive public awareness campaigns emphasizing transparency, safety, environmental protection, and socio-economic benefits.
   - Engage stakeholders through consultations, fostering public acceptance and support for nuclear energy.

6. **Industrial Development and Economic Integration:**
   - Map and bolster Serbian industrial capacities, progressively integrating local enterprises into the nuclear supply chain through phased development.
   - Establish partnerships with international nuclear supply chains to foster economic growth, technological transfer, and job creation.

7. **Robust Financing Strategy:**
   - Formulate a transparent, diversified financial strategy involving public funds, international financial institutions, export credit agencies, and private sector participation.
   - Develop a comprehensive risk management framework to ensure project bankability, economic viability, and investor confidence.

## Implementation Timeline

- **Phase 1 (Years 1–2):** Pre-feasibility assessments, establishing a national nuclear position, and initial regulatory frameworks.
- **Phase 2 (Years 3–7):** Detailed feasibility studies, site characterization, regulatory and human resources capacity building, procurement process (including vendor selection) and financing structures.
- **Phase 3 (Starting year 8):** Construction, commissioning, and operational readiness, culminating in integration of nuclear power into Serbia's energy grid.

## Conclusion

In conclusion by following the structured approach outlined by EDF in this roadmap, Serbia can establish the foundational infrastructure necessary for a successful nuclear energy program, enhancing energy security, environmental sustainability, and economic development. This strategic initiative positions Serbia as a regional leader in energy transition and technological innovation.

## 2•2• Work Package #2: Technology assessment and nuclear market survey

This Section outlines the main findings of the Preliminary Technology Assessment and Screening Study conducted to support the Government of Serbia in considering nuclear energy as part of its long-term energy strategy. This Work Package has been delivered by Egis.

As Serbia charts a course toward decarbonization and long-term energy security, nuclear power emerges as a credible candidate to replace fossil baseload capacity while complementing variable renewables. The study was carried out under Work Package 2. Its aim is to provide a first-level, structured comparison of currently available nuclear technologies, both conventional large-scale reactors and emerging Small Modular Reactors (SMRs) and assess how they could support Serbia's decarbonisation, energy security, and infrastructure goals.

This preliminary study does not aim to recommend a preferred technology, the assessment offers a comparative overview of selected Generation III/III+ reactor designs, with a focus on their technological maturity, deployment readiness, licensing status, and suitability within the specific Serbian context, including grid compatibility, siting considerations, and future regulatory requirements. The technologies reviewed included large-scale options such as the AP1000 (Westinghouse), EPR1200 (EDF), VVER-1200 (Gidropress), and APR1400 (KHNP), as well as SMRs like the AP300, BWRX-300, Rolls-Royce SMR, Holtec, and NUWARD. Special attention has been paid to how these technologies align with international safety standards, European Union regulations, and IAEA guidance.

While the availability of commercial and vendor-specific data remains limited at this stage, the study provides indicative insights into key aspects such as cost structures, delivery models, financing approaches, and vendor experience. These findings will serve as a foundation for more detailed techno-economic feasibility studies and can inform Serbia's future vendor engagement and strategic planning.

The study confirms that nuclear energy can play a strategic role in Serbia's energy transition. It offers a reliable, low-carbon source of electricity capable of replacing coal while ensuring grid stability. Both large-scale and SMR technologies have potential benefits: large reactors may offer economies of scale and deployment readiness, while SMRs provide more flexible deployment and lower initial investment needs. However, technology maturity and deployment timelines differ widely across suppliers, underlining the importance of maintaining deeper engagement with vendors in the next phases.

Beyond the technical review, the assessment also touches on key enablers for successful deployment: strengthening the national regulatory body (SRBATOM), developing a competent Owner/Operator structure, and ensuring that technology selection is integrated into broader infrastructure and planning decisions. Initial reflections were also made on societal and environmental considerations, including radioactive waste pathways, water usage, land footprint, and stakeholder/public acceptance. These areas will require dedicated treatment in future licensing and feasibility phases.

In conclusion, this Work Package has provided the Government of Serbia with an initial screening and comparison of reactor technologies suited for future deployment. It provides a transparent, structured view of the main technology options, and highlights the areas where further analysis, engagement, and capacity-building efforts will be needed. It reinforces the need to build institutional, regulatory, and technical capacity in parallel with technology selection efforts. While it does not answer all questions, it gives the Government of Serbia the necessary tools to move forward with confidence and clarity in the next steps of its decision-making process.

## 2•3• Work Package #3: Supply-demand analysis to define potential power future (2045) dispatches in Serbia

To meet future electric load growth in Serbia, a potential supply avenue is nuclear energy.

The considered study year is 2045, consistent with the timeframe of a nuclear program and with the milestones already set by the Serbian authorities.

In order to obtain generation profiles, a preliminary supply-demand balance analysis is carried out. The simulations were run with the ANTARES Simulator© software, on a model provided by experts from Elektromreža Srbije (EMS) and otherwise used for the National Development Plan. Supply-demand assessment. To carry out this analysis, it is necessary to make assumptions about the overall generation capacity in Serbia, as well as electricity demand. Assumptions are based on INECP and on information available to Serbia TSO at the time of data collection

Five different options for new nuclear generation were considered: 2x400 MW, 1x1000 MW, 1x1200 MW, 4x400 MW and 2x1200 MW.

Main findings of the study are:

- Nuclear power affects the generation of lignite and gas units in Serbia, respectively decreasing of 66% and 8% for the 2*1200MW scenario
- Serbia becomes a net exporter of electricity in the 2*1200 MW scenario

# WORK PACKAGE #1

# BUILDING A ROADMAP SUPPORTING THE DEVELOPMENT OF NUCLEAR ENERGY IN THE SERBIAN ENERGY MIX

# 3• Work Package #1 Building a roadmap supporting the development of nuclear energy in the Serbian energy mix

## 3•1• Context

The **development of a nuclear program is a complex**, long-term endeavor that requires a structured and phased approach, from assessing national readiness to implementing governance, safety, and technical frameworks. Serbia's ambition to diversify its energy mix while meeting its climate commitments emphasizes increasing energy efficiency, expanding renewable energy capacity, and exploring nuclear energy as a secure, low-carbon baseload option.

In this context, EDF has been entrusted with delivering a preliminary **nuclear roadmap** for Serbia. This deliverable is elaborated in the framework of the **Work Package #1 "Building a roadmap supporting the development of nuclear energy in the Serbian energy mix"** of the service contract signed with the Ministry of Mining and Energy in 2024. This roadmap aims to assist Serbian authorities in identifying the key milestones, infrastructure requirements, and governance processes essential for launching a successful nuclear program.

This document is also prepared within the framework of the **Letter of Engagement signed in August 2024 between the Government of Serbia and EDF**. It aims to provide strategic considerations and practical recommendations for Serbia's initial steps in developing a national nuclear program. These recommendations draw upon EDF's extensive experience as the world's leading nuclear operator, and internationally recognized guidelines, notably the **IAEA Milestone Approach** for establishing a nuclear infrastructure.

The roadmap integrates:

- lessons learned from EDF's new nuclear development: EDF has an extensive experience in the **operation and construction of nuclear reactors**, combined with its expertise in decarbonizing energy systems. With **66 reactors in operation globally**, including EPR units in France, China, and Finland, EDF has a proven track record of delivering safe, reliable, and low-carbon nuclear energy.
- **December 2024 workshop in Belgrade**, where EDF and key Serbian stakeholders explored the 19 infrastructure issues identified in the IAEA Milestone Approach. These discussions helped shape the roadmap, with a particular focus on **priority areas**.

This note outlines the critical components of Serbia's nuclear roadmap, focusing on the necessary early actions and priority infrastructures issues to build a solid foundation for future success. It also reflects the shared insights from the December 2024 workshop and provides a practical pathway for Serbia to progress toward its goal of developing a safe and sustainable nuclear energy program. This roadmap will serve as a living document, evolving as Serbia progresses on its path to becoming a regional leader in energy transition.

### 3•1•1• Consideration on Serbia's Future Energy Mix

Serbia is at a pivotal stage in its energy transition, aiming to modernize its energy sector, enhance energy security, and align with international commitments to reduce greenhouse gas emissions.

Today, Serbia's electricity generation is dominated by coal, accounting for **70% of the country's power generation**, complemented by hydropower. However, **ageing coal-fired power plants** and increasing environmental pressures will force a reduction in the role of coal in the national energy mix.

Serbia's **Integrated National Energy and Climate Plan (INECP) for 2021 – 2030,** with projections to 2050, stresses that achieving deep decarbonisation depends on the progressive reduction of fossil fuel based electricity generation—above all coal, which is currently the country's largest source of $CO_2$ emissions. Consistent with this trajectory, the Energy Sector Development Strategy of the Republic of Serbia up to 2040 (with projections to 2050) sets a target for the complete phase out of coal fired power generation by 2050. Furthermore, climate change is expected to impact the reliability and capacity of hydroelectric plants, which are a vital part of Serbia's energy infrastructure.

In response to these challenges, Serbia's energy strategy emphasizes diversification and decarbonization. The INECP defines three main pillars for the country's future energy mix:

1. **Renewable Energy (solar and wind)** – Rapidly deployable and essential for short-term goals.
2. **Hydropower** – Modernization and expansion of hydropower plants to ensure continued reliability and competitiveness.
3. **Nuclear Energy** – A potential long term option for secure baseload supply—specifically in the alternative Scenario S N, which envisages introducing up to about 1 GW of nuclear capacity after 2040 (although not included in the plan's reference base case scenario).

The introduction of nuclear energy would also contribute to Serbia's economic and technological development. A nuclear program does not merely provide clean electricity but also stimulates innovation, enhances industrial capacity, and creates high-skilled jobs across various sectors. This aligns with Serbia's broader goal of becoming a regional leader in energy transition and technological advancement.

Serbia underscored its alignment with the EU regulatory framework by first having its Government formally adopt the Integrated National Energy and Climate Plan (INECP) on 25 July 2024, and then, on 29 November 2024, seeing the National Assembly adopt the complementary Energy Sector Development Strategy up to 2040, with projections to 2050. Together, the two documents provide the near and long term framework for the country's energy transition.

### 3•1•2• IAEA Milestone Approach and December 2024 Workshop

A key milestone in this collaborative effort was the **December 2024 workshop in Belgrade**, organized as part of Work Package #1 of the EDF/MoME contract. This two-day workshop brought together key Serbian stakeholders from institutional, scientific, and academic spheres to explore the **IAEA Milestone Approach** and its **19 infrastructure** issues crucial for the development of a national nuclear program.

During the workshop, EDF shared its expertise on these critical areas and facilitated in-depth discussions on their practical implementation in Serbia. The event provided a platform for key stakeholders to exchange ideas and collaborate on defining Serbia's nuclear priorities. The key takeaways and recommendations from this workshop have been integrated into the roadmap and will serve as a foundation for future actions.

A particular focus was placed on **priority infrastructure issues** that are essential at this early stage of Serbia's nuclear journey. These include:

- Defining a clear national position and ensuring political alignment across institutions.
- Strengthening the legal and regulatory framework to align with international standards.
- Conducting preliminary technical studies, including (i) site selection, identifying suitable locations based on technical, environmental, and safety criteria and (ii) grid capacity assessment to ensure its readiness for integrating nuclear power.
- Workforce Development and Capacity Building: Establishing educational and training programs in collaboration with universities and international organizations.
- Public Engagement and Communication: Building public trust through transparent communication about the benefits and safety of nuclear energy.
- Industrial involvement: securing a successful nuclear programme and creating opportunities for economic growth, job creation, and competence development.
- Securing robust and transparent funding and financing strategies.

### 3•1•3• Development of the Nuclear Roadmap

Developing a nuclear energy program is a strategic decision that requires thorough preparation and leadership at every stage. The Amendment of the Law on Energy (Official Gazette RS No. 94/2024) add an entirely new Chapter XIIa (Arts. 365a–365v) titled "Nuclear Energy", which structures Serbia's Nuclear Energy Development Programme into three sequential phases:

#### 1. Phase 1 – Feasibility (Art. 365a para. 3)

Preparation of technical economic, legal, financial and environmental analyses; review of institutional and human resource gaps; and early public information activities.

#### 2. Phase 2 – Programme drafting (Art. 365a paras. 4 6)

Detailed pre site study, assessment of bilateral or regional cooperation models, and compilation of an Integrated Report that will underpin a "Strategy for the Peaceful Use of Nuclear Energy", to be adopted by the National Assembly.

#### 3. Phase 3 – Implementation (Art. 365a para. 7)

Triggered only if the Strategy so provides; covers licensing, construction and operation of a nuclear power plant, with the detailed rules to be set out in a dedicated act.

**Article 365b** appoints the Ministry of Mining and Energy as lead coordinator for Phases 1–2, in partnership with other relevant State bodies and stakeholders, and lists fifteen concrete tasks to be executed (drafting the road map, analysing potential sites, creating a nuclear information centre, drawing up a skills development plan, etc.).

**Article 365v** permits Phases 1–2 to be financed from the state budget and other lawful sources.

## 3•2• Aims and Objectives of the Nuclear Roadmap

Following the guidance of the **IAEA Milestone Approach**, a nuclear program is defined and built through three major successive phases, from pre-feasibility studies to the beginning of commercial operations. Each phase represents a crucial step in ensuring that all technical, legal, economic, and organizational aspects are adequately prepared.

The nuclear roadmap provides a structured pathway for Serbia to anticipate and secure long-term, critical tasks necessary for the successful development of a nuclear program, such as supply chain development, public acceptance, human capacity building, financing, and regulatory compliance. It is based on a **provisional schedule**, highlighting key milestones and identifying the critical path for the program's progression.


## 3•3• Activities to Be Carried Out in Priority by the Government

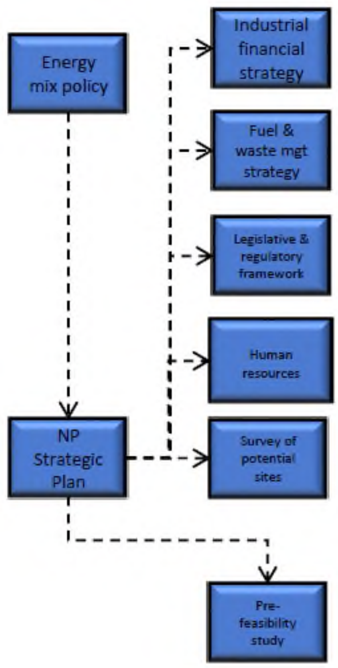
The IAEA identifies **19 infrastructure issues** required for the successful development of a nuclear program. These areas encompass facilities, equipment, human and financial resources, as well as the legal and regulatory framework. Ensuring comprehensive development of these infrastructures is vital for Serbia to achieve its nuclear ambitions.


The **December 2024 workshop in Belgrade**, provided a deep dive into these 19 infrastructure issues. The workshop allowed key Serbian stakeholders from institutional, scientific, and academic sectors to identify the most important areas to prioritize in the coming years. The discussions at this workshop form the basis of the recommendations outlined below.

## 3•3•1• Key Infrastructure Development by Phase

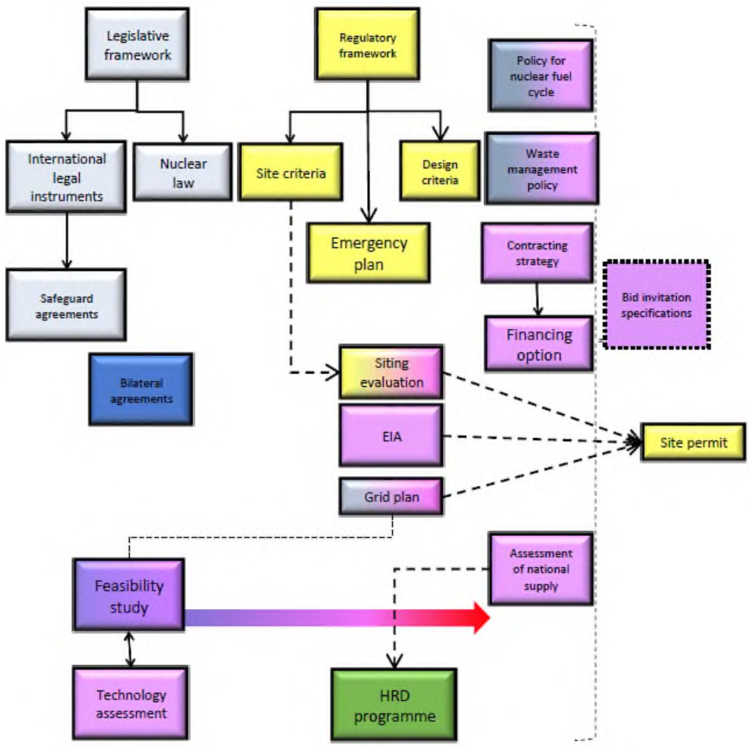
### 3•3•1•1• Phase 1: 1 to 3 Years

During Phase 1, Serbia must focus on conducting preliminary assessments, establishing a national position, and preparing the legal and regulatory framework. By the end of Phase 1, the government should be ready to make an informed decision on whether to proceed with the nuclear program.




**Priority Activities:**

- Building a national position on nuclear energy, including long-term strategy and public policy development.
- Initiating stakeholder engagement and public consultation programs.
- Legal and regulatory framework
- Conducting preliminary technical studies, including siting and grid capacity assessments.
- Developing the human capacity-building framework
- Assessing the potential for the local industry to be involved
- Raising awareness on funding and financing strategies.



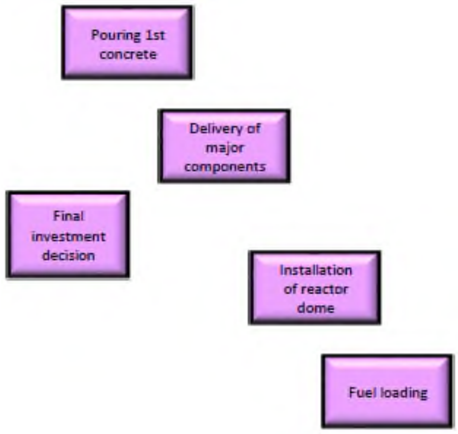

### 3•3•1•2• Phase 2: 2 to 7 Years

In Phase 2, the focus shifts to detailed site evaluation, feasibility studies, and developing governance structures. This phase will prepare Serbia to invite bids or negotiate bilateral agreements with the nuclear technology provider.

**Priority Activities:**

- Preparing and issuing site permits and construction licenses.
- Finalizing the legal and regulatory framework, including national policies (fuel cycle, waste management).
- Establishing governance structures and roles for key organizations.
- Expanding human capacity and partnerships with international institutions.
- Conducting technology assessment and vendor selection process.

### 3•3•1•3• Phase 3: 7 to 10 Years




Phase 3 involves construction and commissioning activities, with a focus on ensuring compliance with safety and operational standards.

- **Priority Activities:**
  - Concluding the main contracts for the construction of the nuclear power plants (in particular with the technology vendor preferred bidder).
  - Completing the project management organisation of the future owner operator.
  - Launching preparatory works on site.
  - Closing the financing and proceeding to the FID.
  - Finalizing construction and licencing permits.
  - Completing the training of operators and regulatory staff.
  - Commissioning the nuclear power plant.

At the end of **Phase 3**, the nuclear power plant is ready for commissioning and subsequent integration into the national energy grid. This milestone marks the culmination of extensive planning, construction, and commissioning activities carried out under a robust governance and regulatory framework.

Given Serbia's current circumstances, several key tasks within the nuclear roadmap should be considered priorities for immediate action. To date, no formal decision has been made regarding the deployment of nuclear energy in Serbia. While an amendment to the nuclear law has removed the legal ban on nuclear development, Serbia still lacks a comprehensive legal framework, competent regulatory authorities, and the necessary technical expertise to undertake a nuclear power plant project.

According to the **IAEA Milestone Approach**, commissioning a nuclear power plant—regardless of the chosen technology—requires a preparatory period of at least **10 to 15 years**. This period involves a series of critical activities, including the establishment of a legal and regulatory framework, extensive planning and construction activities, and securing the appropriate licenses and permits.

In this context, it is crucial for the Serbian government to prioritize specific activities that lay the groundwork for the successful development of a nuclear program. These recommendations are outlined in the following sections. Additionally, international cooperation agreements with experienced nuclear countries or with multilateral bodies could accelerate the programme by providing regulatory know-how, technical expertise, and capacity-building support.

## 3•4• Priority Recommendations for Serbia

### 3•4•1• Building a National Position: Program Development Strategy and Associated Public Policies

A well-defined national position is the cornerstone of any successful nuclear program. It establishes the government's long-term vision for nuclear energy, provides political alignment, and ensures consistency in planning and decision-making. Before launching formal studies on the technical and financial implications of nuclear power, it is essential for the Serbian government to articulate a clear strategy and set of policies that will guide the development of the program. This national position must address the role of nuclear energy in Serbia's electricity mix, key planning considerations, and specific objectives regarding nuclear capacity.

The national position serves two primary purposes:

1. **Defining the country's long-term strategy for** the development of nuclear energy.
2. **Establishing public policies** to oversee the deployment of the nuclear program and align it with Serbia's economic, social, environmental, and development goals.

To build this national position, several key components must be developed:

- **National Energy Policy**: Define the role of nuclear power in Serbia's future energy mix, set clear planning considerations, and identify specific capacity targets for nuclear energy.
- **Strategic Objectives:** Outline the political, economic, social, and environmental goals associated with nuclear power, ensuring alignment with Serbia's broader national development objectives.
- **Governance and Organizational Structure**: Create a detailed framework for the governance of the nuclear sector. This includes clarifying responsibilities among stakeholders, establishing an organization to monitor program development on behalf of the government, and appointing the future owner/operator of the nuclear facility.

The national position will serve as the foundation for the political decision to proceed with nuclear energy development. Therefore, it should be the first area of focus within the nuclear roadmap.

#### 3•4•1•1• National Energy Policy as the First Building Block

The national energy policy should clarify nuclear energy's role in Serbia's long-term energy strategy. It must integrate nuclear energy into the country's broader decarbonization and energy security goals, detailing how it will contribute to both environmental sustainability and economic development. This policy can be framed through a series of policy papers, as illustrated by the experience of countries like France or UK:

- **The Energy Pathways to 2050**, a reference study by the French National Grid Operator (RTE) has defined and analysed 6 detailed Scenarios, concluding on how the scenario with nuclear energy is more advantageous.
  - Under the tripartite Partnership Agreement signed in March 2025 between the Ministry of Mining and Energy of the Republic of Serbia (MRE), the French Development Agency (AFD), and RTE International (RTEi), and supported by the FEXTE Fund mechanism, RTEi will conduct a national 'Energy Pathways to 2050' study for Serbia. Building on RTE's original reference work, which analysed six detailed energy scenarios, the Serbian version of the study will further refine

and expand the projections for introducing nuclear energy, complementing the insights of the INECP's Scenario S-N.

- **The 10-Point Plan for a Green Industrial Revolution**: This initiative set clear decarbonization objectives, mobilized UK government investment, and aimed to create green jobs while promoting innovation in energy technologies.
- **The Energy White Paper:** This document provided a comprehensive strategy for the UK's energy transition, addressing long-term objectives, consumer interests, sectoral investments, and workforce development by 2050.

### 3•4•1•2• Phased Approach to Strategy and Governance

The development of a comprehensive national position must follow a phased approach. In the UK, this was achieved through the establishment of a dedicated body responsible for overseeing the national nuclear strategy and managing the nuclear program's execution.

Developing a robust national position will provide a strong foundation for Serbia's nuclear program and ensure that decisions are grounded in a coherent, long-term strategy. This step is essential not only for securing political support but also for building public confidence and attracting potential investors and international partners.

In Phases 1 and 2 of the nuclear programme, the Ministry of Mining and Energy (MoME), in cooperation with other relevant state bodies and stakeholders, is tasked with acting as Serbia's Nuclear Energy Programme Implementing Organization (NEPIO). To effectively fulfil this role, it is recommended that MoME:

#### Recommendations 1

i. **Ensure that the NEPIO** is provided with clear mandates, resources, and reporting lines.
ii. **Establish strong interministerial coordination** to integrate energy, environmental, financial, and safety aspects.
iii. **Conduct and coordinate pre-feasibility studies**.
iv. **Prepare a strategy and plan for stakeholder involvement, engaging early and transparently with the public** to build awareness and acceptance.
v. **Coordinate a comprehensive self-evaluation of Serbia's national nuclear power infrastructure development,** as a preparatory step toward requesting an Integrated Nuclear Infrastructure Review (INIR) Mission supported by the IAEA. This process should systematically assess Serbia's progress across the 19 infrastructure issues defined in the IAEA's Milestones Approach. Early self-assessment will help identify gaps, prioritize actions, and demonstrate Serbia's commitment to international best practices for embarking countries.
vi. **Seek technical assistance and peer reviews** from international bodies such as the IAEA, and experienced partner countries.

## 3•4•2• Public Acceptance and Stakeholder Involvement

Public acceptance is a critical factor for the successful development of a nuclear power program. Building trust, ensuring transparency, and engaging stakeholders at all levels are key to fostering long-term public support. This requires a **strategic communication plan and a well-designed stakeholder engagement program** that addresses concerns, promotes socio-economic benefits, and ensures open dialogue with the community. The goal is not only to secure initial public acceptance but also to maintain it throughout the entire lifecycle of the nuclear power plant (NPP)—from planning and construction to operation and decommissioning.

A robust **public acceptance and stakeholder involvement program** should be built around the following key drivers:

- **Understanding community concerns and expectations**: Ensuring that the needs and fears of local communities are taken into consideration.
- **Developing a comprehensive communication strategy**: Tailoring messages to national, regional, and local audiences, and ensuring consistency and transparency.
- **Building long-term relationships through consultation**: Engaging with communities and stakeholders regularly to create trust and shared understanding.
- **Promoting socio-economic development**: Demonstrating the added value of nuclear projects beyond electricity production, such as job creation, improved quality of life, and infrastructure development.
- **Ensuring oversight by independent third parties**: Strengthening public confidence by involving external organizations to monitor and report on project activities.

### 3•4•2•1• Core Elements of Public Acceptance and Communication Strategy

An effective public acceptance strategy should be developed in two main areas:

1. **Public Communication and Awareness Campaigns**
2. **Promotion of Local and National Socio-Economic Development**

#### 1. Public Communication and Awareness Campaigns

The communication strategy must be transparent, well-structured, and adaptable to different audience needs. It should emphasize safety, environmental protection, and the benefits of nuclear energy while addressing common concerns such as health risks, waste management, and emergency preparedness.

**⌘ Key Actions:**

- **Analyse public perception and concerns**: Conduct surveys and studies to understand the public's attitude toward nuclear energy and identify primary concerns.
- **Prepare clear, evidence-based messages**: Tailor messages for different stakeholder groups, highlighting the benefits of nuclear power in addressing Serbia's energy needs and decarbonization goals.
- **Develop targeted relationships**: Build connections with scientific societies, elected officials, media, farmers, doctors, and other opinion leaders. These relationships help amplify accurate information and foster local support.

- **Coordinate with institutional stakeholders**: Collaborate with government agencies, provinces, regulatory bodies, and waste management organizations to ensure coherent messaging and policies.
- **Organize public consultations:** Engage communities in open dialogues about nuclear energy through public hearings, informational sessions, and site visits, ensuring compliance with the nuclear law and regulatory framework.

**2. Promotion of Local and National Socio-Economic Development**

A nuclear project can offer significant socio-economic opportunities for local and national communities. Proactively promoting these benefits is crucial to gaining and maintaining public support.

**⌘ Key Actions:**

- **Identify and design local infrastructure projects:** Align new infrastructure with both the project's requirements and local population needs.
- **Foster partnerships with local businesses:** Prioritize local suppliers and service providers, ensuring that the project contributes to regional economic growth.
- **Develop comprehensive training programs:** Collaborate with educational institutions and technical schools to provide targeted training for local residents, preparing them for employment opportunities within the project.
- **Promote long-term job creation:** Highlight the employment opportunities not only during construction but also during the operational phase. This should include direct jobs at the plant and indirect jobs in related industries.

### 3•4•2•2• Ensuring Transparency and Good Governance

Transparency is a cornerstone of public trust. Providing reliable, accessible, and timely information on nuclear safety, project status, and potential impacts is essential to maintaining public confidence. **France's Transparency Law** serves as a model example, guaranteeing public access to information and presenting transparency as a fundamental aspect of nuclear safety and governance.

By following these principles, Serbia can establish a high level of trust and credibility with its citizens. Transparency and good governance will not only enhance public confidence but also help attract potential investors who see public support as a key indicator of project stability.

### 3•4•2•3• Public Acceptance: A Proven Methodology for Long-Term Success

Public acceptance is not a one-time activity but a continuous process. It evolves over time and must be nurtured through regular engagement and responsive communication. Developing public support will significantly facilitate the implementation of Serbia's nuclear program and help secure financing and partnerships from the international community.

**Recommendations 2:**

During Phase 1, the NEPIO shall:

i. **Develop a stakeholder engagement plan**, as part of the Comprehensive Report, that clearly defines each organization's role, prioritizes stakeholder groups – including neighbouring countries, addresses their key issues with tailored engagement methods, and determines the specific tools and approaches required.

ii. **Conduct surveys** to determine the public's knowledge and receptiveness to nuclear power.

iii. **Develop public information tools** that respond to the results of the surveys and to explain the **government's interest in, and the potential benefits from, nuclear power.**

iv. **Provide targeted communication training** for Serbian officials involved in the nuclear program.

### 3•4•3• Legal and Regulatory Framework

The establishment of a comprehensive and transparent legal and regulatory framework is essential for the successful deployment of a nuclear power program. It provides the foundation for ensuring the **safety, security, and environmental protection** required for nuclear energy, while also playing a crucial role in gaining public trust and securing investment. Without a robust framework, project implementation risks delays, increased costs, and reduced public support.

A well-structured legal and regulatory framework should be developed in line with **IAEA safety standards and international best practices,** ensuring that Serbia's nuclear program is credible and aligned with global norms. This involves several critical components:

#### 1. Updating and Strengthening Domestic Standards

Serbia has already achieved a certain level of alignment between its domestic regulations and international nuclear safety standards. However, further work is needed to fully integrate evolving international best practices, particularly in areas such as emergency preparedness and response, radiation protection, radioactive waste management, and cybersecurity.

#### 2. Strengthening the Capacity and Competence of the Regulatory Authority

Serbia already has an independent regulatory authority responsible for nuclear and radiation safety. In the context of launching a nuclear power programme, advancing the Authority's technical expertise, resources, and operational capacity will be critical. In the forthcoming period, efforts will focus on strengthening the Authority's institutional framework, technical skills, and inspection capabilities, supported by IAEA Technical Assistance (TA) programmes and cooperation with other international partners. A competent and well-resourced regulator remains essential to maintaining public trust and ensuring the highest safety standards throughout the nuclear lifecycle.

#### 3. Identifying Specific National Requirements

Serbia must carefully define specific national requirements for nuclear power plant design, site selection, and operational standards. These requirements should be identified early to avoid costly design modifications and delays during the licensing process. The regulatory framework must also include provisions for environmental impact assessments and public consultations as part of the approval process.

## 4. Designing an Adapted Licensing Process

An efficient licensing process is crucial to ensure timely project implementation while maintaining the highest safety standards. Serbia should design a licensing system that facilitates the transfer of technical information on plant design and safety demonstration while allowing for flexibility in the case of new technological advancements. This will reduce administrative bottlenecks and provide clear pathways for project developers.

### 3•4•3•1• Current Status and Next Steps

**Serbia will be conducting a comprehensive assessment of its legal and regulatory framework to identify gaps relative to international safety standards and best practices**, in preparation for the development of a civil nuclear power programme. This review should include an analysis of Serbia's adherence to key international conventions and treaties.

Accession to key international conventions is essential for Serbia to build a safe, credible, and internationally recognized nuclear power programme. Safety conventions ensure protection of people and the environment, safeguard agreements and security instruments uphold non-proliferation commitments, and liability frameworks provide legal certainty for investors and the public. Environmental conventions strengthen transparency and regional trust, while alignment with EU nuclear instruments facilitates Serbia's integration into the European energy framework. Early compliance will help strengthen Serbia's regulatory environment, accelerate project development, and enhance engagement with international partners.

Here follows a comprehensive list of key international conventions and treaties that Serbia should be (or verify if it already is) a party to, in order to fully support the development of its civil nuclear power programme:

1. IAEA Safety-Related Conventions
   a. **Convention on Nuclear Safety (CNS)** (1994)
   b. **Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management** (1997)
   c. **Convention on Early Notification of a Nuclear Accident** (1986)
   d. **Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency** (1986)

2. Nuclear Security and Safeguards Instruments
   a. **Treaty on the Non-Proliferation of Nuclear Weapons (NPT)** (1968)
   b. **Comprehensive Safeguards Agreement (CSA)** with the IAEA
   c. **Additional Protocol (AP) to the Safeguards Agreement**
   d. **Convention on the Physical Protection of Nuclear Material (CPPNM)** (1980)
   e. **Amendment to the Convention on the Physical Protection of Nuclear Material (CPPNM Amendment)** (2005)

3. Civil Liability for Nuclear Damage
    a. **Vienna Convention on Civil Liability for Nuclear Damage (1963)** (and preferably its 1997 Protocol)
    b. **Convention on Supplementary Compensation for Nuclear Damage (CSC)** (1997) — or at least consideration of joining *(Note: Alternatively, some countries opt for the Paris Convention and Brussels Supplementary Convention, but those are under the OECD framework and more European focused.)*

4. Other Relevant Treaties and Agreements
    a. **Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention)** (1991)
    b. **Aarhus Convention on Access to Information, Public Participation and Access to Justice in Environmental Matters** (1998)
    c. **International Labour Organization (ILO) Conventions** related to radiation protection of workers

5. Regional / EU-Related Instruments (as Serbia advances toward EU alignment)
    a. **EURATOM Treaty** compliance&
    b. Participation in Euratom's safeguards and cooperation programmes

## ⌘ Recommendations 3

During Phase 1, the NEPIO shall:

i. Conduct a thorough review of existing laws and regulations to identify gaps and areas for improvement, and describe the **schedule for adherence to relevant international standards and best practices.**

ii. **Starting in late Phase 1 and continuing in Phase 2: Strengthening the Capacity and Competence of the Independent Nuclear Safety Authority**
    a. **Coordinate the development of a high-level regulatory framework roadmap that aligns with the envisaged nuclear power programme.** This plan should take into account existing international experience, Serbia's current regulatory framework for radiation safety and nuclear security, and identify areas requiring enhancement. The independent Safety Authority should be actively consulted during this process and will ultimately be responsible for drafting, adopting, and implementing the necessary detailed regulations.
    b. Ensure **adequate resources and staffing** for effective oversight and enforcement, identifying prospective senior managers for the regulatory body.
    c. **Foster International Cooperation, p**artnering with experienced countries and organizations, such as the IAEA and the European Commission, to access technical assistance and regulatory expertise.

### 3•4•4• Launching Preliminary Technical Studies

Serbia is at a critical crossroads in defining its future energy mix. The country's strategy must carefully balance **energy security, economic growth, decarbonization, and system resilience**. Several scenarios have been developed to evaluate Serbia's energy future, each incorporating different combinations of **renewable energy, hydropower, natural gas, and nuclear power**. However, these scenarios must be analysed holistically, avoiding comparisons based solely on **Levelized Cost of Energy (LCOE).** While LCOE is an important metric, it does not account for broader system benefits such as resilience, carbon reduction potential, and energy sovereignty.

The optimal energy mix for Serbia will depend on multiple factors, including:

- **Renewable Energy Potential**: Assessing the country's capacity for solar, wind, and hydropower development.
- **Nuclear Power Potential**: Evaluating the feasibility and impact of deploying nuclear power as a source of baseload, low-carbon electricity.
- **Grid Capacity and System Integration**: Ensuring the electrical grid can accommodate new energy sources and large-scale nuclear plants.
- **Technology Costs and Investment Availability**: Balancing short-term affordability with long-term benefits.
- **Import and Export Opportunities**: Leveraging regional energy markets to optimize supply and demand.

Regional cooperation is crucial for Serbia's energy strategy, both to ensure security of supply and to enhance the country's competitiveness in electricity generation. The **Ministry of Mining and Energy** initiated a regional crisis plan in partnership with **North Macedonia and Albania** to develop contingency measures for energy disruptions during the 2022–23 winter. As part of this effort, a joint working group was established to address supply risks and explore opportunities for cooperation on large strategic energy projects.

Moreover, the **Integrated National Energy and Climate Plan (INECP)** highlights the importance of regional cooperation in achieving Serbia's clean energy transition. Building new interconnections and diversifying supply routes are essential for improving resilience and stability.

The **feasibility and competitiveness** of a nuclear power plant project depend heavily on the **availability of suitable sites**. Identifying and securing these sites is a critical step in Phase 1 of the nuclear roadmap. The selection process must consider a wide range of technical, environmental, and logistical factors to ensure that the chosen locations meet all safety and operational requirements.

#### Key criteria for site selection include:

- **Geological Characteristics**: Stability and suitability of the site to withstand seismic and environmental risks.
- **Cooling Capacity**: Proximity to reliable water sources for cooling purposes, which is essential for nuclear plant operations.
- **Induced Hazards**: Assessment of nearby industrial activities, population density, and potential external hazards.
- **Grid Integration and Transport Accessibility**: Availability of transmission infrastructure and access for construction and maintenance.

**Recommendations 4:**

i. **Energy Mix Scenario Analysis Enhancement:** Under the tripartite Partnership Agreement with AFD and RTEi, Serbia's "Energy Pathways to 2050" study will deliver a comprehensive, multi-criteria analysis of the country's future energy mix. This study will build on the INECP Scenario S-N and apply RTE's proven methodology, incorporating resilience, decarbonization, and energy sovereignty considerations beyond basic cost comparisons, while clarifying the potential role of nuclear energy in Serbia's transition.

ii. **Conduct a Comparative Site Analysis**, identifying potential nuclear plant sites based on geological suitability, cooling capacity, induced hazards, and logistical factors. Evaluate and rank these sites using transparent, standardized criteria to support a well-informed decision on the preferred location.

iii. **Assess Nuclear Integration into the Grid**: for each shortlisted site, analyse the technical and financial requirements for connecting nuclear capacity to the power system and prepare grid reinforcement plans, including new transmission lines or interconnections, to ensure stable and resilient integration of nuclear power.

iv. **Ensure that relevant technical competent organizations are represented in the NEPIO**

## 3•4•5• Human Capacity Building

**Human Capacity Building (HCB)** is a cornerstone of the sustainable development of Serbia's nuclear program. It is a long-term process that requires continuous investment and adaptation. A successful nuclear program requires not only technical expertise but also a well-rounded workforce capable of supporting every phase of the nuclear lifecycle—from planning and construction to operation, maintenance, and decommissioning. Establishing a comprehensive educational and training framework is crucial to achieving this goal.

Serbia must prioritize the development of **human resources** at both institutional and technical levels to ensure the safe, efficient, and sustainable deployment of nuclear energy. This will involve building a **multi-disciplinary workforce** composed of engineers, technicians, regulatory experts, safety inspectors, project managers, and communication specialists.

Based on international reference models for nuclear newcomer countries, a typical distribution of workforce needs across different phases of a nuclear power programme could be:

- Phase 1&2 (Preparatory and Pre-Project Phases):
  - About 60–70% focused on institutional and regulatory capacity-building (legal experts, licensing specialists, public communication teams, policy analysts).
  - About 30–40% in technical pre-feasibility fields (grid studies, siting analysis, environmental impact specialists).
- Phase 3 (Contracting and Construction):
  - Workforce shifts to 70–75% technical and engineering specialists (civil, mechanical, nuclear, and electrical engineers; quality assurance inspectors; project managers).
  - 25–30% continues in regulatory oversight and stakeholder engagement to supervise safety and transparency.
- Operation Phase (Commissioning and Operation of NPP):

- Approximately 65–70% plant operational staff (reactor operators, maintenance engineers, safety officers).
- 15–20% dedicated to regulatory inspection and oversight.
- 10–15% in public communication, emergency preparedness, and long-term policy development.

Overall, developing a sustainable nuclear workforce will require a combination of higher education programs, specialized vocational training, international secondments, and partnerships with established nuclear organizations. Early investment in human capacity building is critical to maintaining project timelines, ensuring safety, and meeting international standards.

**Collaboration with international organizations such as the IAEA, European Nuclear Education Network (ENEN) and I2EN (International Institute for Nuclear Energy); Development of Domestic Expertise, introducing scholarships for specialized degrees** in nuclear-related fields and funding **international study opportunities for national talent;** partnering with established nuclear countries to **gain on-the-job training and mentorship** from seasoned experts: those are key considerations to be taken to develop a sound workforce.

**Recommendations 5:**

i. **Engage with Experienced Partners:** Collaborate with IAEA, European institutions, and experienced industrial partners to design training programs and share best practices.

ii. **Assess Current Capabilities and Identify Future Needs:** Conduct a comprehensive evaluation of existing skills, knowledge, and competencies within Serbia’s energy sector to establish a baseline for human resource planning.

iii. **Perform a Gap Analysis:** Identify specific skill gaps and develop a targeted strategy to address them, ensuring the workforce is prepared to meet the demands of each phase of the nuclear program.

iv. **Implement a Clear Action Plan:** Develop a national human capacity-building strategy, which should include education programs, technical training, mentorship, and international collaboration.

v. **Develop a platform to engage the Serbian diaspora:** Collaborate with the Ministry of Foreign Affairs and Serbian Embassies worldwide to identify the expertise of Serbian citizens living abroad and propose attractive re-entry plans that encourage their return and contribution to Serbia’s development.

A well-trained workforce is essential for ensuring the safety, efficiency, and sustainability of Serbia’s nuclear program. By investing in human capacity building now, Serbia will not only meet the demands of its nuclear ambitions but also lay the foundation for **long-term economic growth, innovation, and self-reliance.**

## 3•4•6• Industrial Involvement

Industrial involvement is a critical pillar for ensuring the successful implementation and long-term sustainability of Serbia’s nuclear program. A well-developed local industrial base will not only reduce dependence on external suppliers but also create opportunities for economic growth, job creation, and technology transfer. By integrating Serbian industries into the global nuclear supply chain, the country can position itself as an active participant in the international nuclear sector while strengthening its domestic capabilities.

A comprehensive strategy for industrial involvement should focus on two main objectives:

1. **Mapping and Assessing Existing Industrial Capabilities**: Identify industries and companies that have the potential to contribute to the nuclear supply chain, assess their readiness, and provide targeted support to help them meet nuclear industry requirements.
2. **Fostering Partnerships and Knowledge Transfer**: Build partnerships between Serbian companies and experienced international nuclear suppliers to facilitate technology transfer, improve quality standards, and enhance local expertise.

### 3•4•6•1• Key Components of Industrial Development

#### Mapping and Assessing Industrial Capabilities

The first step in developing industrial involvement is to map Serbia's current industrial landscape and assess which sectors could potentially contribute to the nuclear program. This mapping exercise should identify local companies in fields such as construction, engineering, manufacturing, logistics, and information technology. Each company's capabilities should be evaluated against the specific requirements of nuclear projects, such as precision manufacturing, adherence to safety standards, and quality assurance.

#### Phased Localization Strategy

Given the complexity of nuclear projects, a **phased localization strategy** should be adopted. This strategy starts with involving local companies in auxiliary services (e.g., civil works, logistics, and construction materials) and gradually expands to more advanced components and systems as local industry gains experience and capacity. This approach minimizes risks while maximizing local involvement over time.

- **Phase 1:** Focus on basic services such as construction, site preparation, logistics, and auxiliary support.
- **Phase 2:** Expand into component manufacturing, electrical systems, and mechanical equipment.
- **Phase 3:** Develop advanced manufacturing capabilities for nuclear-specific components, instrumentation, and control systems.

#### Compliance with Nuclear Standards and Safety Culture

The nuclear industry operates under **strict quality and safety standards**, including ISO 19443, which specifically applies to suppliers in the nuclear sector. Local companies must be trained to adopt these standards and incorporate a strong **safety culture** in their operations. Compliance is not only a technical requirement but also a fundamental aspect of building trust with international partners and ensuring long-term project success.

#### Building Long-Term International Partnerships

Establishing partnerships with experienced international suppliers and nuclear operators is essential for accelerating local capacity building. These partnerships can help Serbian companies meet nuclear industry standards, reduce learning curves, and integrate into the global nuclear supply chain. EDF's extensive experience in managing complex supply chain ecosystems can serve as a model for this process.

**Participating in Global Nuclear Supply Chains**

Beyond contributing to the national nuclear programme, local companies could seek opportunities to participate in global nuclear supply chains, providing products and services for projects in Europe and other regions. Building capabilities to meet international nuclear quality and safety standards would enhance the competitiveness of local industries and open opportunities for long-term growth, diversification, and integration into the global nuclear sector.

**Recommendations 6:**

i. **Mapping National and Regional Industrial Capabilities**
   a. **Conduct a detailed assessment of existing industrial capabilities** and evaluate their readiness to participate in nuclear projects.
   b. **Identify sectors with high potential for involvement** and assess the level of investment required for them to meet nuclear standards.

ii. **Suppliers' Academy Programme**
   a. **Initiate preliminary training sessions regarding nuclear technology and suppliers' excellence fundamentals**, dedicated to key industrial players and NEPIO members.
   b. **Define a dedicate supplier development plan**, getting support from experienced partners.

A well-executed industrial development strategy will not only support the success of Serbia's nuclear program but also create lasting economic benefits by fostering local innovation, job creation, and international competitiveness. By building a strong network of capable local suppliers, Serbia can establish itself as a key player in the regional and global nuclear industry.

## 3•4•7• Funding and Financing

Securing a comprehensive and sustainable financing strategy is essential for realizing Serbia's nuclear ambitions. The development of a nuclear power program is a **long-term, capital-intensive undertaking** that requires significant financial resources. Therefore, an effective strategy must combine **public and private sector participation**, leverage **international funding opportunities**, and ensure that the financing structure is robust, transparent, and aligned with international standards.

### 3•4•7•1• Key Sources of Funding

1. **Public Financing**: Government-led financing plays a crucial role in the early stages of the program to cover feasibility studies, regulatory framework development, and capacity building. Direct public investment demonstrates national commitment and helps attract external investors.
2. **Export Credit Agencies (ECAs):** ECAs provide important financial support, particularly during **Phase 2 and Phase 3** of the nuclear roadmap. Their involvement can take the form of **technical assistance, guarantees, and long-term loans** for project preparation and construction activities.
3. **Development Banks and International Financial Institutions:** Institutions such as the **European Investment Bank (EIB) and World Bank** can offer concessional loans for infrastructure development and capacity-building activities related to the nuclear program.

4. **Private Sector Participation and Public-Private Partnerships (PPPs):** The private sector can play a significant role in financing and managing certain aspects of the project, particularly through PPP models. This approach can reduce the financial burden on the government and promote greater efficiency.

### 3•4•7•2• Developing a Robust Financial Strategy

For Serbia to attract and secure international funding, it is critical to establish a **comprehensive business case** and a **regulatory and contractual framework** that aligns with best practices in project finance. Key elements of a successful financing strategy include:

#### 1. Solid Business Case and Bankability

A strong business case is essential for securing financing and ensuring long-term project viability. It must address:

- **Revenue Projections**: Clearly define the expected returns, including electricity sales and export opportunities.
- **Cost Structure**: Provide a transparent and realistic estimation of total project costs, including construction, operation, and decommissioning expenses.
- **Risk Mitigation Measures**: Identify potential risks and outline strategies for managing and mitigating them.

#### 2. Comprehensive Risk Analysis

The identification, assessment, and allocation of risks are fundamental to raising financing for a nuclear power plant. Key risks to be addressed include:

- **Construction Risks:** Delays and cost overruns.
- **Regulatory Risks:** Uncertainty related to licensing and compliance.
- **Procurement Risks:** Challenges in sourcing nuclear-specific components; potential need for a **lex specialis** framework.
- **Market Risks:** Fluctuations in electricity prices and demand.
- **Operational Risks:** Technical failures and maintenance issues.

#### 3. Regulatory and Contractual Framework

Developing a stable and transparent regulatory environment is critical for attracting investors. This includes:

- **Licensing and Permitting Frameworks:** Clear and predictable procedures for site selection, construction, and operation.
- **Contracts and Power Purchase Agreements (PPAs):** Secure long-term electricity sales contracts to reduce market risk and improve project bankability.

#### 4. Competitive and Blended Financing

A financing strategy should explore **blended financing mechanisms** that combine public funds with concessional loans, export credits, and private sector investment. Examples include:

- **Public Financing at Preferential Rates**: Low-interest government loans to cover early-stage project costs.
- **Export Credits with Refinancing Solutions:** Access to competitive interest rates through ECAs, with refinancing options as the project matures.

### Recommendations 7:

i. **Assess Existing Mechanisms:**
   a. Conduct a thorough review of available financing options (e.g. Regulated Asset Base, Power Purchase Agreements, sovereign guarantees).
   b. Use this assessment to design a regulatory framework with clearly shared responsibilities, ensuring revenue stability for investors and affordability for consumers.

ii. **Establish National Financing Modalities**:
   a. Define how Serbia will finance the development of its nuclear program through dedicated legislation or specialized funding instruments.
   b. Determine conditions under which public and private sources contribute, providing a clear path for both early-stage costs and long-term project expansion.

iii. **Address the government's role in reducing financial risks:**
   a. Role of the government in ensuring a secure revenue stream, as well as
   b. Role in securing the required debt and equity for the project.

A well-designed financing strategy will not only enable Serbia to launch its nuclear program but also ensure its financial sustainability over the long term. By leveraging international expertise and funding opportunities, Serbia can reduce risks, attract investment, and secure the necessary resources to achieve its energy ambitions.

# 3•5• Resource Requirements, and Cost Estimates for Phases 1 and 2

*(Assuming Phase 1: 2 years, Phase 2: 5 years)*

## 3•5•1• Introduction

This section provides an indicative overview of the human resource needs, macro-level activities, and approximate cost estimates for an embarking country (here, Serbia as an example) preparing for a nuclear power programme under the IAEA Milestones Approach. Specifically:

- **Phase 1 (2 years)** focuses on the pre-feasibility stage, national decision-making, early legal and regulatory groundwork, and establishment of an initial coordinating body (NEPIO).
- **Phase 2 (5 years)** covers in-depth project development activities such as site selection, technology/vendor evaluations, detailed regulatory framework development, and the progressive ramp-up of the regulatory authority and the future owner/operator.

All figures here are for illustration and must be adapted to real national conditions (e.g. existing institutional capacity, local labour market). The activities assume a streamlined scenario without major political or financing delays.

## 3•5•2• Key Organizations and Their Roles

- **NEPIO (Nuclear Energy Programme Implementing Organization)**
  - Composed of representatives from government ministries, academia, and external advisers.
  - Coordinates national efforts, conducts strategic studies, and liaises with stakeholders.
  - Plays a leading role in Phase 1 and continues as a coordination body in Phase 2, albeit with gradually reduced scope as the Owner/Operator and Regulatory Authority take on more responsibilities.
- **Regulatory Authority**
  - The legally mandated body responsible for nuclear safety, radiation protection, security, and safeguards.
  - In Phase 1, it begins capacity building, reviews legislative gaps, and drafts the overarching regulatory framework.
  - In Phase 2, it expands significantly to develop regulations in detail, define licensing processes, and oversee initial vendor or site licensing activities.
- **Owner/Operator**
  - The eventual entity (utility or special-purpose vehicle) that will own and operate the nuclear power plant.
  - In Phase 1, it often exists in nascent form or as a project office.
  - In Phase 2, it grows substantially, undertakes project feasibility studies, site surveys, technology selection, and prepares for eventual construction and operation.

### 3•5•3• Phase 1 (2 Years) — Activities and Resource Needs

**Phase 1 must be driven primarily by NEPIO**, which will direct and coordinate all nuclear power programme activities, from legal and regulatory gap analyses to stakeholder engagement. Given Phase 1's overarching objective—namely, confirming a national commitment and establishing initial frameworks—**most responsibilities should rest with NEPIO.**

**Preliminary activities** for the future **Regulatory Authority** and **Owner/Operator** will begin late in Phase 1 to accelerate Phase 2, but both organizations remain in **initial planning mode** rather than ramping up fully. This allows the major resource commitments for the Regulatory Authority and Owner/Operator to shift into Phase 2, after the government's decision to proceed is confirmed.

#### Key Objectives

- **Establish NEPIO and Confirm National Position:** Formally set up NEPIO, perform pre-feasibility studies, and secure political consensus on whether to proceed with nuclear power.
- **Initial Legislative & Regulatory Gap Analysis**: Identify gaps in existing laws, propose new legislation or amendments for nuclear regulation.
- **High-Level Planning:** Outline financing options, human resource development strategies, stakeholder engagement campaigns, and next steps for site selection screening.
- **Stakeholder Engagement**: Begin structured communications with the public, policymakers, media, and civil society.

#### Typical Staffing — Phase 1

- **NEPIO**
  - ~15–20 FTE total (a mix of senior policy, legal, technical, and communications experts).
  - 2–4 senior executives (often seconded from ministries/utilities); 10–15 mid-level/junior staff.
  - Additional part-time consultants or external experts (IAEA or international).
- **Regulatory Authority & Owner / Operator**
  - In the latter part of Phase 1, small 'setup' teams (e.g. a handful of staff each) will start laying the groundwork for the Regulatory Authority and Owner/Operator. These setup teams, working under NEPIO's overall coordination, would:
    - Draft initial organizational mandates and operating procedures.
    - Begin scoping budget and staffing strategies.
    - Identify early training or fellowship opportunities.
    - Engage in preliminary stakeholder consultations (especially with ministries, local communities, and industry).
  - The purpose of these limited-scope teams is to **accelerate Phase 2 readiness**; by the time the official decision to proceed is issued, these entities can scale more rapidly.

### 3•5•4• Phase 2 (5 Years) — Activities and Resource Needs

Once a formal decision to proceed is made, the Regulatory Authority and Owner/Operator undergo a major **scale-up**. This includes:

- Expanding Regulator staff to support licensing, site evaluation, and drafting of further regulations.
- Expanding Owner/Operator staff to oversee site investigations, vendor selection, feasibility studies, contract negotiations, and financing.

#### Key Objectives

- **Feasibility Studies & Site Selection**: Conduct detailed site surveys, environmental assessments, and stakeholder consultations leading to site licensing.
- **Technology/Vendor Evaluation**: Solicit bids or undertake direct negotiations, assess technical and commercial offers, finalize technology choice.
- **Regulatory Framework in Practice:** Draft detailed regulations and guidance for licensing, inspection, and enforcement. Conduct readiness reviews for licensing steps.
- **Financing & Contracting:** Secure financing terms (sovereign guarantees, export credits, PPP, etc.), prepare vendor or EPC (Engineering, Procurement, Construction) contracts.
- **Human Resource Development Ramp-Up**: Expand the regulatory authority and Owner/Operator workforce with specialized training, scholarships, and international partnerships.
- **Stakeholder Engagement:** Intensify public information campaigns, especially around final site selection, technology, and environmental or safety impacts.

#### Typical Staffing — Phase 2

- **NEPIO**
  - NEPIO's role typically **shrinks** or shifts in focus during Phase 2, as the Owner/Operator and Regulator become the primary implementers.
  - The organization might reduce to ~10 FTE for senior coordination/policy tasks, plus part-time consultants as needed.
- **Regulatory Authority**
  - Must ramp up significantly to handle licensing, siting, safety assessment, inspection.
  - Growth from ~5 FTE at the end of Phase 1 to ~40–50 FTE by late Phase 2, including specialists in reactor technology, safety analysis, environmental assessment, security, and legal.
  - Intensive training programs, technical cooperation, and peer reviews are critical (e.g. IAEA missions, cooperation with established regulators).
- **Owner/Operator**
  - Grows from a small project team (~4 people in Phase 1) to ~40–60 staff by the end of Phase 2.
  - Includes project managers, contract/legal specialists, nuclear engineers, safety analysts, planning teams, corporate support, etc.

– Begins structuring procurement for the future nuclear power plant (long lead items, supply chain development).

### 3•5•5• In summary

Shifting Phase 1 to **2 years** and Phase 2 to **5 years** generally compresses the initial national decision-making period and extends the detailed project development work. The overall effect is:

- **Phase 1:** More intense, focused timeframe for completing the pre-feasibility study, forming NEPIO, initiating stakeholder outreach, and drafting core legislation.
- **Phase 2:** A longer window to conduct rigorous site investigations, mature the regulatory authority, finalize financing, and engage in detailed engineering and licensing preparations.

By the end of Phase 2 (Year 7 overall), the country would ideally be prepared to invite bids for a nuclear power plant, finalize contracts, or even begin preliminary construction activities—pending a firm go-ahead from the government, the regulator, and key stakeholders.

## 3•6• Proposed Timeline – focus on Phase 1 and Phase 2

Below is a condensed timeline of macro-activities:

### 3•6•1• Phase 1: Preparatory Phase (Approx. 2 Years)

1. **Establish NEPIO (Months 1–3)**
   - Government decree establishing NEPIO and its mandate.
   - Appointment of leadership and allocation of initial resources.
   - Launch of preliminary project planning.
2. **Pre-Feasibility Studies & National Position Development (Months 3–12)**
   - Conduct high-level technical, economic, and energy system analyses.
   - Gather stakeholder input and engage advisory bodies.
   - Develop a preliminary National Position on nuclear energy.
   - **Major Output**: *Interim Comprehensive Report* (at approx. Month 12).
3. **Legislative & Regulatory Gap Analysis (Months 3–18)**
   - Assess existing legal and regulatory frameworks against IAEA standards.
   - Identify required new laws, amendments, or secondary legislation.
   - Prepare draft proposals for legislative updates.
4. **Human Resource Development Planning (Months 6–18)**
   - Identify workforce needs across government, regulatory, and technical sectors.
   - Launch partnerships with universities and technical institutions.
   - Establish initial training pathways and international collaborations.
5. **Stakeholder Engagement and Communication Strategy (Ongoing)**
   - Launch nationwide awareness campaigns.
   - Engage civil society, academia, private sector, and media proactively.
6. **Final National Position and Strategy Development (Months 15–24)**
   - Integrate findings of pre-feasibility studies, stakeholder feedback, and gap analysis.
   - Prepare a **Comprehensive Report** summarizing all Phase 1 outputs.
   - Formulate a **draft Strategy for the Development of the Peaceful Use of Nuclear Energy.**
   - **Major Outputs:**
     1. *Comprehensive Report* (around Month 20–22).
     2. *Draft National Strategy* for Parliamentary or Governmental adoption.
7. **Decision to Proceed to Phase 2 (End of Year 2)**
   - Formal governmental review and decision based on Comprehensive Report and Strategy.

### 3•6•2• Phase 2: Preparatory Infrastructure Development Phase (Approx. 5 Years)

1. **Strengthening the Regulatory Authority (Year 1-3)**
   - Months 1–12:
     1. Recruit and train additional regulatory staff.
     2. Begin drafting detailed regulations.
   - Year 2–3:
     3. Develop and adopt detailed licensing regulations and procedures.
     4. Begin site-specific licensing activities and expand inspection capacity.

2. **Expansion of Owner/Operator Organization (Year 1-5)**
   - Months 1–24: Grow project management and technical teams, start site investigations, technology evaluation, vendor discussions.
   - Year 3–5: Finalize site choice, confirm technology/vendor, progress on financing arrangements.

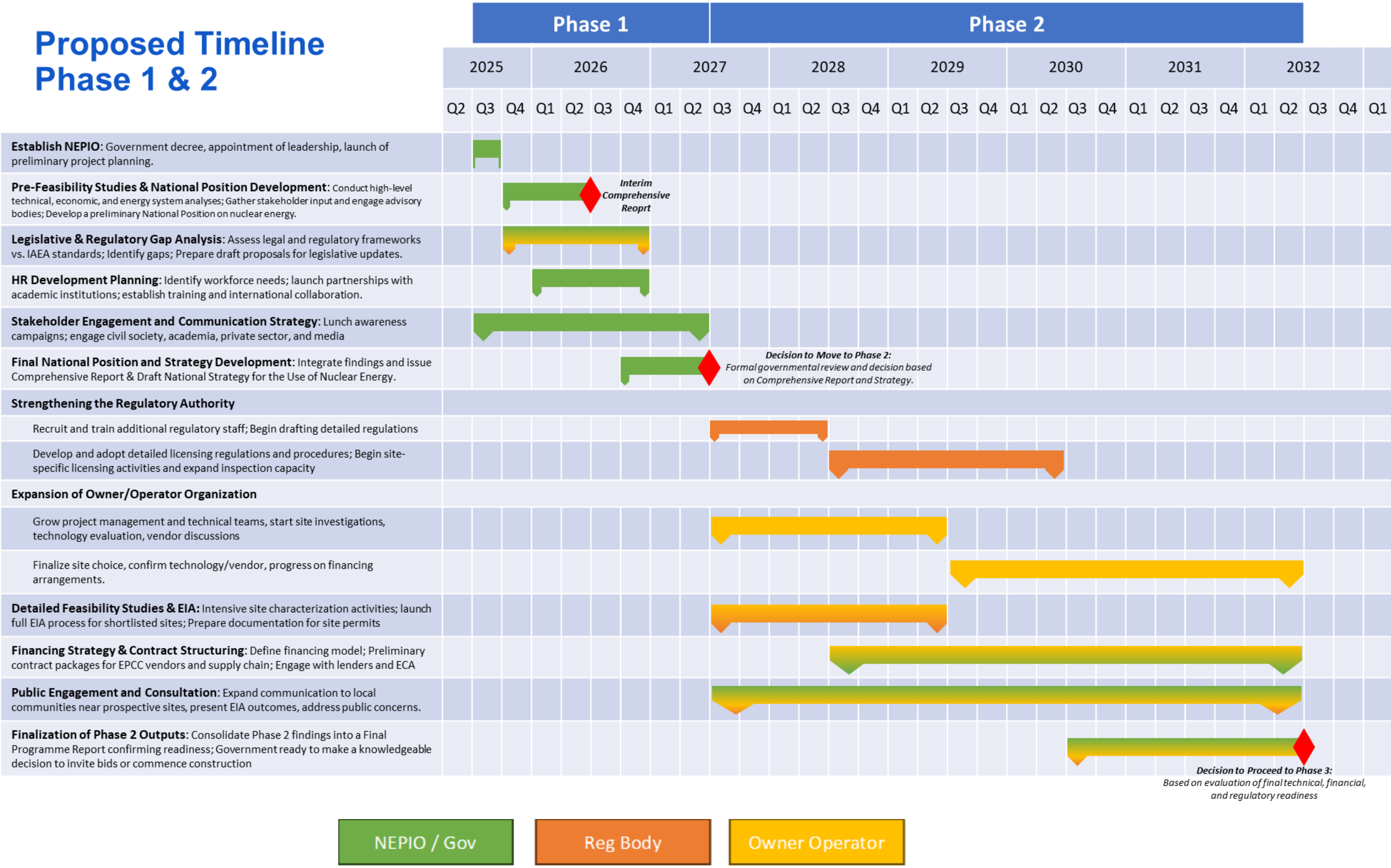
3. **Detailed Feasibility Studies and Environmental Impact Assessment (Year 1–2)**
   - Intensive site characterization activities (geological, hydrological, environmental).
   - Launch full EIA processes for shortlisted sites.
   - Prepare necessary documentation for site permits.

4. **Financing Strategy and Contract Structuring (Starting Year 2)**
   - Define financing model (public, private, PPP, or export credit support).
   - Prepare preliminary contract packages for EPC vendors and supply chain partners.
   - Engage with lenders and export credit agencies to align project structuring.

5. **Public Engagement and Consultation (Ongoing)**
   - Expand communication to local communities near prospective sites, present EIA outcomes, address public concerns.

6. **Finalization of Phase 2 Outputs (Years 4–5)**
   - Consolidate Phase 2 findings into a *Final Programme Report* confirming readiness.
   - Meet IAEA **Milestone 2**: Government ready to make a knowledgeable decision to invite bids or commence construction.

7. **Decision to Proceed to Phase 3**
   - Based on evaluation of final technical, financial, and regulatory readiness.


Proposed Timeline
Phase 1 & 2
Phase 1
Phase 2
2025
2026
2027
2028
2029
2030
2031
2032
Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1
Establish NEPIO: Government decree, appointment of leadership, launch of preliminary project planning.
Pre-Feasibility Studies & National Position Development: Conduct high-level technical, economic, and energy system analyses; Gather stakeholder input and engage advisory bodies; Develop a preliminary National Position on nuclear energy.
Interim Comprehensive Reoprt
Legislative & Regulatory Gap Analysis: Assess legal and regulatory frameworks vs. IAEA standards; Identify gaps; Prepare draft proposals for legislative updates.
HR Development Planning: Identify workforce needs; launch partnerships with academic institutions; establish training and international collaboration.
Stakeholder Engagement and Communication Strategy: Lunch awareness campaigns; engage civil society, academia, private sector, and media
Final National Position and Strategy Development: Integrate findings and issue Comprehensive Report & Draft National Strategy for the Use of Nuclear Energy.
Decision to Move to Phase 2: Formal governmental review and decision based on Comprehensive Report and Strategy.
Strengthening the Regulatory Authority
Recruit and train additional regulatory staff; Begin drafting detailed regulations
Develop and adopt detailed licensing regulations and procedures; Begin site-specific licensing activities and expand inspection capacity
Expansion of Owner/Operator Organization
Grow project management and technical teams, start site investigations, technology evaluation, vendor discussions
Finalize site choice, confirm technology/vendor, progress on financing arrangements.
Detailed Feasibility Studies & EIA: Intensive site characterization activities; launch full EIA process for shortlisted sites; Prepare documentation for site permits
Financing Strategy & Contract Structuring: Define financing model; Preliminary contract packages for EPCC vendors and supply chain; Engage with lenders and ECA
Public Engagement and Consultation: Expand communication to local communities near prospective sites, present EIA outcomes, address public concerns.
Finalization of Phase 2 Outputs: Consolidate Phase 2 findings into a Final Programme Report confirming readiness; Government ready to make a knowledgeable decision to invite bids or commence construction
Decision to Proceed to Phase 3: Based on evaluation of final technical, financial, and regulatory readiness
NEPIO / Gov
Reg Body
Owner Operator

# WORK PACKAGE #2

# TECHNOLOGY ASSESSMENT AND NUCLEAR MARKET SURVEY

# 4• Work Package #2: Technology Assessment And Nuclear Market Survey

This Preliminary Technical Assessment to Evaluate the Case for Implementing a Nuclear Power Program in Serbia has been undertaken; by Egis, acting as technical advisor, to support the Government of Serbia in making informed, strategic decisions regarding the possible adoption of nuclear energy as part of its long-term energy policy. The assessment provides an early-stage, high-level evaluation of nuclear reactor technologies that could help Serbia achieve its energy transition objectives, including decarbonization, diversification, and energy independence.

At its core, the study aims to offer a **structured, comparative review of available nuclear reactor options**, spanning both conventional large-scale designs and emerging Small Modular Reactors (SMRs). The assessment focuses on understanding the technological maturity, deployment readiness, and overall suitability of these technologies in relation to Serbia's national goals, energy system needs, and future regulatory environment.

To ensure a robust foundation for future decision-making, the study evaluates how each technology aligns with internationally recognized safety standards, EU regulatory frameworks, and IAEA guidance. This includes a review of the licensing landscape and the potential challenges and pathways that may emerge should Serbia pursue a nuclear program.

In parallel, the study provides **indicative insights into financial and delivery-related considerations** such as capital expenditure (CAPEX), operational costs (OPEX), financing models, and deployment structures. These insights are based solely on information that is publicly available or shared by vendors on a non-confidential basis. While detailed commercial data remains limited at this stage, the study offers a transparent and consistent comparative perspective suitable for pre-feasibility level planning.

Another key objective is to explore the **environmental and societal dimensions** associated with nuclear deployment. This includes waste management strategies, radiological safety concerns, land and water use implications, and public perception issues each of which plays a critical role in the long-term sustainability and acceptability of nuclear projects.

Recognizing that successful nuclear deployment is not solely a technological question, the study also examines **strategic partnership potential and supply chain considerations**. It considers the geopolitical context of technology vendors, localization opportunities within Serbia, and the availability of experienced international partners, EPC contractors, operators, and fuel cycle suppliers that could contribute to project delivery.

The assessment was developed **using a structured analytical approach combining technical expertise with publicly available data sources.** The objective was to ensure a balanced review of the technologies considered, while maintaining transparency and consistency in the comparison of potential options.

Importantly, the study also seeks to **support the alignment of Serbia's nuclear ambitions with its broader national objectives.** By providing structured insights and transparent screening logic, the assessment serves as an enabler for more detailed feasibility work and engagement with vendors, regulators, and financing institutions in the next phases.

Finally, the study contributes to **capacity building and knowledge transfer** by equipping key stakeholders with a foundational understanding of nuclear technology options and the multi-dimensional considerations that influence their deployment. It sets clear expectations and criteria for future phases of work, while highlighting areas where further data, engagement, or clarification will be needed.

In summary, this Phase 1 Pre-Feasibility Study delivers a strategic, early-stage evaluation of nuclear technology options tailored to Serbia's context. It does not provide a definitive recommendation, but rather establishes a well-informed, methodologically sound foundation for guiding future decisions on nuclear energy development.

# 4•1• Introduction

## 4•1•1• Background and Scope of the High-Level Assessment

This chapter provides an overview of the broader context and objectives that inform this high-level nuclear technology assessment. As Serbia explores nuclear power as a potential solution for meeting future energy demands, it is crucial to conduct a preliminary, high-level evaluation of various nuclear technologies. This pre-feasibility assessment aims to inform government stakeholders by offering a broad, strategic understanding of available nuclear options, from conventional reactors to emerging Small Modular Reactors (SMRs), and their potential alignment with Serbia's national energy goals.

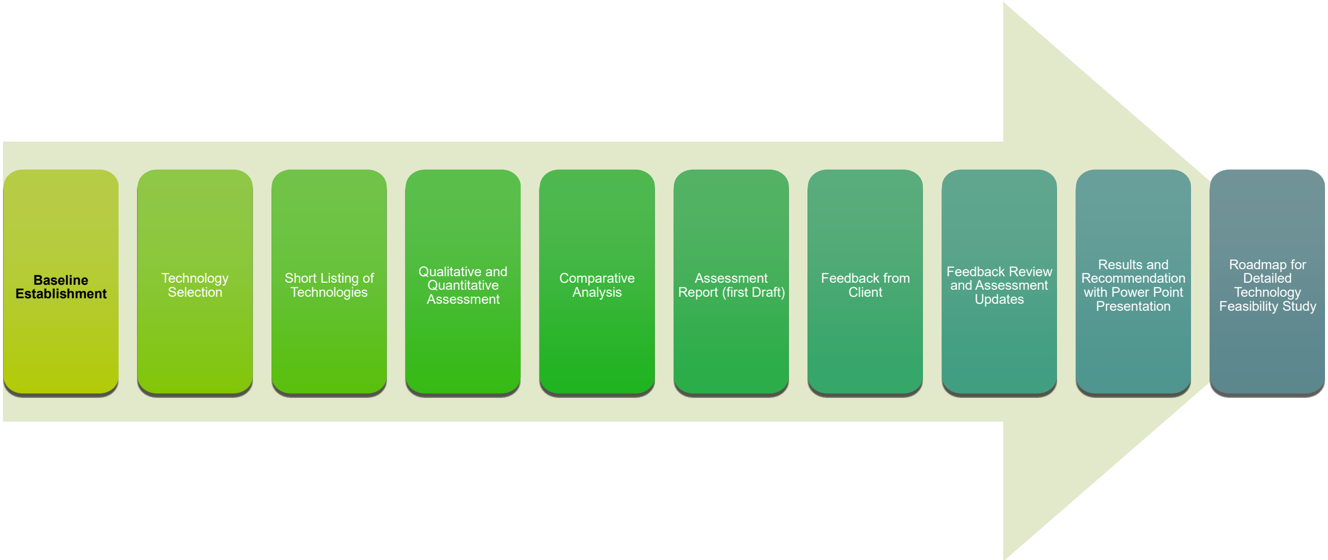
In accordance with the scope of services defined for this assignment, the assessment is limited to Generation III and Generation III+ reactor technologies, including both large-scale reactors and SMRs. Generation IV or experimental technologies are explicitly excluded from this evaluation.

The assessment's scope is designed to give stakeholders a preliminary insight into:

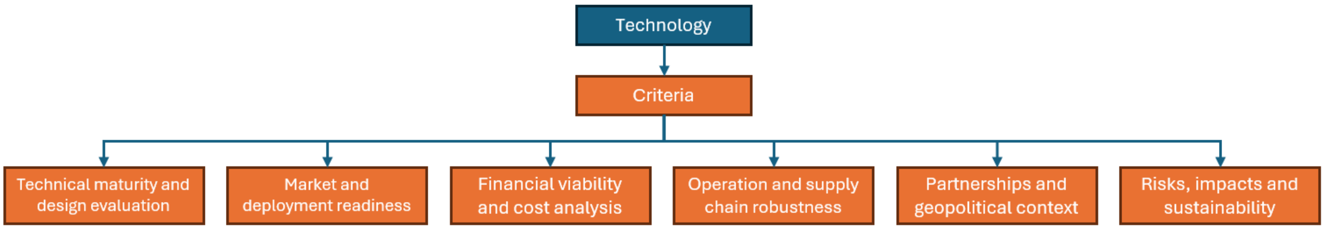
- **Technological Maturity:** Reviewing the current status of nuclear technologies, both conventional and SMRs, including their design evolution, operational history, and readiness for deployment.
- **Licensing and Regulatory Considerations:** Examining each technology's compliance with international safety standards and the potential regulatory challenges for Serbia (EU Criteria).
- **Economic and Financial Viability**: Analyzing costs, financing options, and economic feasibility in the context of Serbia's budgetary constraints and financial resources.
- **Environmental and Social Impact:** Evaluating the environmental footprint, waste management practices, and societal acceptance of nuclear technologies, which are crucial for ensuring sustainability.
- **Geopolitical and Partnership Factors**: Considering potential international partnerships, supply chain robustness, and geopolitical risks associated with technology providers, which will be essential for establishing secure, long-term collaboration.

**This high-level assessment is not intended to make definitive recommendations but** rather to provide a foundation for further, more detailed feasibility studies. It identifies promising technologies and potential challenges, creating a roadmap for Serbia's future nuclear decision-making process. Ultimately, the insights gathered in this preliminary study will help align Serbia's nuclear ambitions with its strategic energy goals, regulatory requirements and economic capabilities, setting the stage for a more detailed and informed technology selection process.

## 4•1•2• Qualitative vs. Quantitative Assessment Approach




The assessment approach for nuclear technology options uses a balanced combination of qualitative and quantitative criteria to ensure a comprehensive evaluation. This dual approach provides a holistic view of each technology’s strengths, challenges, and suitability for Serbia's energy goals.




The qualitative dimension focuses on aspects that require expert judgment and contextual understanding. It provides a strategic perspective on the potential strengths, challenges, and overall positioning of the technologies considered within the broader context of nuclear program development.

The quantitative dimension complements this perspective by incorporating available data and measurable indicators where publicly available information exists. These elements provide a factual basis to support the comparative review of technologies at a high level.

Together, these qualitative and quantitative assessments offer a multi-dimensional perspective, ensuring Serbia’s decision-makers receive a thorough and balanced understanding of each technology’s potential. This approach leverages both hard data and expert interpretation to guide the upcoming detailed technology selection process.

### 4•1•3• Methodology and Criteria for Technology Selection

The methodology used to identify the nuclear technologies included in this pre-feasibility assessment follows a structured review process designed to provide a representative overview of reactor technologies currently considered in international nuclear programs.

An initial landscape review of available nuclear reactor technologies was conducted, covering both large-scale Generation III/III+ reactors and emerging Small Modular Reactors (SMRs). This initial review considered technologies that are currently under development, undergoing licensing processes, or being deployed in international nuclear programs.

From this broader technology landscape, a subset of reactor designs was selected for further high-level assessment. The objective of this selection was to retain a representative range of technologies reflecting different reactor concepts, deployment approaches, and industrial ecosystems currently shaping the global nuclear market.

The technologies retained for the high-level assessment therefore represent a balanced sample of reactor designs that are considered relevant to the international nuclear sector and potentially applicable within the context of Serbia's long-term energy strategy.

By following this structured, top-down approach, the assessment methodically narrows down the list of potential technologies, ensuring alignment with Serbia's strategic goals while considering technical, financial, environmental, and social aspects. The outcome is a well-founded selection of technologies for a more detailed feasibility assessment in Serbia.

#### 4•1•3•1• List of Technology

This section outlines the initial list of 15 nuclear technologies considered for evaluation. These technologies, categorized into conventional reactors and Small Modular Reactors (SMRs), represent the starting point of a systematic selection process. Through a detailed assessment based on strategic, technical, economic, and environmental criteria, this list will be narrowed down to **9**[1] technologies **4** conventional reactors and **5** SMRs that will advance to the pre-feasibility study stage. The following tables provide an overview of these technologies

- **Pressurized Water Reactors (PWR)**

| Technology Name | Country of Origin | Description |
|---|---|---|
| EPR 1600 | France | Large PWR with advanced safety features, with 4 Loops developed by EDF/Framatome. |
| EPR 1200 | France | Smaller version with 3 loops of the EPR with enhanced economic feasibility, developed by EDF/Framatome. |
| APR 1400 | South Korea | Advanced PWR with enhanced safety and operability, designed by Korea Hydro & Nuclear Power. |

[1] Initial Scope only 8 Technologies

| Technology Name | Country of Origin | Description |
| --- | --- | --- |
| VVER-1200 | Russia | Russian-designed PWR with modern safety features and high efficiency developed by ROSATOM. |
| VVER-TOI | Russia | Improved version of VVER-1200 with enhanced digital controls and more passive systems and constructability developed by ROSATOM. |
| AP1000 | USA | Westinghouse-designed PWR with passive safety systems and modular construction. |
| HPR1000 (Hualong One) | China | Generation III+ pressurized water reactor (PWR) developed by China General Nuclear (CGN) and China National Nuclear Corporation (CNNC). It integrates features from CPR1000 and ACP1000 designs, offering enhanced safety systems, passive safety features, modular construction, and standardized twin-unit deployment. Deployed in China and internationally (e.g., Pakistan), with growing global interest. |
| APR1000 | South Korea | Advanced PWR with enhanced safety and operability, designed by Korea Hydro & Nuclear Power. |

#### 1.1.1.1 Pressurized Heavy Water Reactors (PHWR)

| Technology Name | Country of Origin | Description |
| --- | --- | --- |
| CANDU | Canada | Heavy water reactor known for using natural uranium fuel and high efficiency, developed by SNC-Lavalin. |

#### 1.1.1.2 Boiling Water Reactors (BWR)

| Technology Name | Country of Origin | Description |
| --- | --- | --- |
| ABWR | Japan/USA | Advanced BWR jointly developed by GE Hitachi and Toshiba, known for modular construction. |

- **Pressurized Water Reactor (PWR) - Small Modular Reactors**

| Technology Name | Country of Origin | Description |
|---|---|---|
| NUWARD | France | EDF's SMR concept focusing on scalability and low carbon solutions for local grids. |
| NuScale | USA | Modular SMR with a focus on passive safety and flexible deployment. |
| Rolls Royce SMR | UK | UK-based SMR with modular manufacturing and reduced construction times. |
| SMR-300 | USA | Holtec International's SMR designed for affordability and reliability. |
| AP300 | USA | Westinghouse’s SMR variant of its AP1000, focusing on safety and modularity. |
| I-SMR | South Korea | KHNP's SMR, tailored for diverse applications including district heating and desalination. |
| ACP100 | China | Chinese-designed SMR developed by China National Nuclear Corporation (CNNC), focusing on remote and small-scale energy needs. |
| RITM 200N | Russia | Russian SMR developed by Afrikantov OKBM JSC, for use in icebreakers and remote locations, highly compact and robust. |

- **Boiling Water Reactor (BWR) - Small Modular Reactors**

| Technology Name | Country of Origin | Description |
|---|---|---|
| BWRX-300 | USA | GE Hitachi’s small modular boiling water reactor with simplified design and lower costs. |

### 4•1•3•2• Assessment Results

- **Large Nuclear Power Plant – LNPP[2]**

[2] **Justification: EPR1200 Operational Readiness and Cost-Efficiency**
The EPR1200 is an evolution of the EPR1600, developed specifically to address the challenges faced in first-of-a-kind projects such as Flamanville 3 and Olkiluoto 3. Although the EPR1200 has not yet been commissioned, its design incorporates key simplifications such as reduced plant output, increased standardization, and improved constructability intended to lower CAPEX and shorten construction timelines.
These improvements are directly informed by operational feedback from successfully deployed EPR1600 units, particularly the Taishan reactors in China. As such, the assessment of the EPR1200’s operational and deployment readiness, as well as its relative cost-efficiency, is grounded in the lessons learned and refined practices derived from the EPR1600 fleet.

| Technology | Overview | Strengths | Key Challenges |
|---|---|---|---|
| **EPR-1600** | Large European Gen III+ PWR reactor with advanced safety and high capacity. | Proven technology; multiple redundancies; strong EU regulatory alignment; high power output. | High capital cost; long construction timelines; complex deployment for smaller grids. |
| **EPR-1200** | Smaller version of EPR-1600 with streamlined design for European markets. | Strong alignment with EU standards; advanced safety features; cost-efficiency over EPR-1600. | Early-stage commercial development; fewer operational references compared to EPR-1600. |
| **AP1000** | US Gen III+ PWR with passive safety systems and modular construction. | NRC-certified; strong operational experience; modular design shortens construction time. | Requires EU licensing; larger grid dependency; fewer European operational references. |
| **APR1400** | Korean-designed Gen III+ reactor with advanced safety and reliability. | Proven track record; EUR-certified; competitive LCOE; high capacity (1400 MWe). | Limited European deployment; public acceptance barriers outside Korea. Complex deployment for smaller grids |
| **VVER-1200 (AES 2006)** | Russian Gen III+ reactor with modern design and advanced safety systems. | Proven operational success; double containment design; strong efficiency (1200 MWe). | Geopolitical challenges in EU markets; public perception barriers. |
| **VVER-TOI** | Upgraded version of VVER-1200 with enhanced digital controls and efficiency. | Improved constructability; advanced digital systems; reduced construction time and costs. | Limited deployment outside Russia; requires EU licensing and adaptation to WENRA standards. |
| **HPR1000 (Hualong One)** | Advanced Chinese PWR developed from CPR1000 and ACP1000 designs, featuring enhanced safety systems and modular construction. Deployed in China and Pakistan, with international expansion plans. | Modern design with triple safety redundancy; improved passive safety; international deployment experience (e.g., Karachi K2/K3); standardized twin-unit design; higher licensing maturity. | Limited licensing outside China; not yet certified by EU regulators; financing typically state-driven; geopolitical and perception concerns remain in some regions. |
| **CANDU** | Canadian-designed heavy water reactor using natural uranium. | Flexible fuel options (natural uranium, MOX); proven design; good load-following capabilities. | Water usage concerns; fewer recent commercial deployments in EU. |
| **ABWR** | Advanced boiling water reactor from Japan/USA with modular design. | NRC and international approvals; short construction time; proven operational success. | Limited deployment in Europe; public perception concerns regarding BWR technology. |
| **APR1000** | Korean Gen III reactor developed for European market with cost optimization. | EUR-certified; modular design; improved safety and constructability based on APR1400. | Limited operational deployment; requires European acceptance and public trust-building. |

## Small Modular Reactor

| Summary Table | | | |
|---|---|---|---|
| **Technology** | **Overview** | **Strengths** | **Key Challenges** |
| **NUWARD** | EDF's French SMR concept targeting scalability and grid stability. | Strong EU alignment; modular design; ideal for decentralized grids; EUR compliance underway. | Limited deployment; early-stage design; requires pilot projects or detailed regulatory review to validate the safety and commercial use. |
| **NuScale** | US-based modular SMR with proven NRC certification and passive safety. | NRC-approved; highly scalable; load-following capabilities; rapid deployment timelines. | Requires EU-specific licensing; no operational units; high upfront financing costs. |
| **BWRX-300** | GE-Hitachi's advanced boiling water SMR with cost-efficient modular design. | Modular and cost-effective; short construction time; GDA progressing; strong global backing. | Limited operational experience; requires EU regulatory compliance and public trust. |
| **Rolls-Royce SMR** | UK-designed SMR with modular manufacturing and rapid deployment. | UK government support; short deployment timeline (~5 years); cost-effective and scalable. | Supply chain localization needed; limited global references. |
| **Holtec SMR-300** | US-based SMR with advanced passive safety and short construction timelines. | Walk-Away Safe™ passive safety; 2.5-year deployment time; modular and scalable design. | EU certification pending; localization challenges; public acceptance for non-EU design. |
| **AP300** | Westinghouse's SMR variant of AP1000, offering proven technology. | Based on licensed AP1000; passive safety; modular deployment; competitive cost and timelines. | Lacks EUR certification; limited EU experience; supply chain challenges for localization. |
| **I-SMR (KHNP)** | Korean SMR optimized for multi-purpose use, including district heating. | Boron-free operation; strong modularity; scalable for phased investments; short deployment time. | Requires EU licensing; early-stage deployment; public perception barriers for non-EU tech. |
| **ACP-100** | Chinese SMR with compact design ideal for distributed power and heating. | Modular and flexible design; short construction time (~3 years); multi-purpose applications. | No EU certification; public trust challenges; geopolitical concerns in European markets. |
| **RITM-200** | Russian SMR with proven operational success in icebreakers and remote grids. | Proven reliability; rapid deployment; strong for isolated or multi-purpose applications. | Lacks EU regulatory approval; geopolitical challenges; public perception barriers in EU. |

## ⌘ Selected Technologies for High-Level Assessment – LNPP

| Technology | Country | Overview | Deployment Status | Why its fit for Serbia |
|---|---|---|---|---|
| EPR-1200 | France | Compact version of EPR-1600, designed for cost-efficiency and deployment in global markets. | No operational units yet; Under development;. Potential deployment in Saudi Arabia, Poland, Kazakhstan, Netherlands, and Slovenia. | Backed by EDF, a global nuclear leader, the EPR-1200 offers a proven regulatory pathway within the EU, ensuring compliance with Serbia's nuclear framework. Its cost-optimized design and advanced safety features provide a long-term, high-performance energy solution for Serbia's grid and industrial needs. |
| AP1000 | USA | U.S.-designed Gen III+ reactor with passive safety systems and modular construction. | Operational units in the U.S., China, and planned construction in other countries (e.g., India, Poland). | Developed by Westinghouse, the AP1000's passive safety, modular construction, and regulatory approvals in multiple markets demonstrate its deployment reliability. Its flexibility in grid integration and proven performance make it an attractive solution for Serbia's evolving energy mix and regulatory ambitions. |
| VVER-1200 (AES 2006) | Russia | Russian-designed Gen III+ reactor with modern design and advanced safety features. | Operational units in Russia, Belarus, and select non-EU countries (e.g., Turkey, Bangladesh). | With a strong track record of successful deployments, the VVER-1200 is backed by Rosatom, a global nuclear leader with experience in delivering turnkey nuclear projects. Its high capacity factor, robust safety systems, and scalability provide Serbia with a reliable and cost-effective baseload power solution. |
| APR1000 | South Korea | Smaller version of APR1400 tailored for European markets with cost-optimized construction. | EUR-certified; no operational units yet. The Czech Republic has selected the APR1000 for upcoming projects. | Developed by KHNP, the APR1000 is designed for cost efficiency, high safety standards, and regulatory adaptability for EU markets. Serbia can benefit from KHNP's experience in nuclear project execution, strong localization potential, and flexible financing models to support long-term energy security. |

Table 112: List of LNPPTechnologies for High Level Assessment

## ✦ Selected Technologies for High-Level Assessment - SMR

| Technology | Country | Overview | Deployment Status | Why its fit for Serbia |
|---|---|---|---|---|
| **NUWARD** | France | EDF's French SMR concept targeting scalability, grid stability, and low-carbon energy solutions. | Early-stage design; no operational units; regulatory compliance under EUR certification underway. | NUWARD's modular design and EU compliance make it ideal for decentralized grids, aligning with Serbia's EU regulatory framework and goals for flexible, clean energy solutions. |
| **BWRX-300** | USA | GE Hitachi's advanced boiling water SMR, emphasizing cost-effective modular construction and operational efficiency. | Limited operational experience; progressing through Generic Design Assessment (GDA) in the UK. | The BWRX-300's modular and cost-effective design suits Serbia's phased investment needs, while its advanced safety features align with Serbia's long-term decarbonization and energy independence objectives. |
| **Rolls-Royce SMR** | UK | UK-developed modular SMR designed for rapid deployment and cost efficiency, supported by advanced manufacturing techniques. | Early deployment planned in the UK with strong government backing; no operational units yet. | Rolls-Royce SMR's short deployment timeline and scalability align with Serbia's need for phased investments and flexible energy deployment, offering a cost-effective and future-ready solution. |
| **AP300** | USA | Westinghouse's SMR variant of the AP1000, focusing on passive safety, modular construction, and adaptability to smaller grid capacities. | Based on proven AP1000 technology; no operational units yet; undergoing regulatory assessments. | The AP300 combines proven AP1000 features with scalability for smaller grids, making it well-suited to Serbia's grid size and regulatory requirements, while ensuring safety and operational reliability. |
| **Holtec SMR-300** | USA | Holtec International's modular SMR featuring advanced passive safety systems and short deployment timelines. | No operational units; undergoing regulatory review in various regions; strong focus on deployment readiness. | Holtec SMR-300's Walk-Away Safe™ passive safety features and 2.5-year construction timeline make it an attractive option for Serbia, ensuring safety, cost-efficiency, and adaptability to smaller grids and phased investments. |

Table 223: List of SMRTechnologies for High Level Assessment

# 4•2• Nuclear Technology

## 4•2•1• Overview of Conventional Nuclear Technologies

### 4•2•1•1• Basics of Nuclear Technology

#### Basics of Nuclear Technology

Nuclear energy production hinges on two fundamental processes: nuclear fission and nuclear fusion. Both methods alter atomic structures to liberate energy fission splits a heavy atom into two lighter atoms, while fusion combines two lighter atoms into one heavier atom. Currently, nuclear fission is the primary method for energy production worldwide due to its established technology and efficiency, whereas nuclear fusion, despite its potential for clean and abundant energy, remains in developmental stages.

In nuclear fission, heavy elements like uranium or plutonium are bombarded with neutrons, causing the atoms to split and release energy along with more neutrons that perpetuate the chain reaction. This reaction generates significant heat used to produce steam and drive turbines to generate electricity. In contrast, nuclear fusion a process mimicking the energy production in stars requires immense pressure and temperature to achieve and sustain, making it less practical with today's technology.

Reactor designs have evolved significantly since the 1940s, focusing on enhancing safety, reliability, and sustainability. Lessons from incidents such as Three Mile Island, Chernobyl, and Fukushima have spurred advancements in safety features and emergency protocols.

Uranium remains the primary fuel for nuclear reactors, with natural uranium consisting mostly of isotopes uranium-238 (U-238) and uranium-235 (U-235). U-235, though less abundant, is critical for sustaining nuclear reactions due to its fissionable properties. Reactor designs often require fuel enrichment to increase the proportion of U-235, typically to levels below 5%.

Additionally, some reactors employ plutonium or thorium as alternative or supplementary fuels. Plutonium is produced in reactors from U-238 and also possesses isotopes critical for nuclear reactions. Thorium, another naturally occurring element, can be converted in reactors to uranium-233 (U-233), which is also fissionable, sustaining the chain reaction.

#### Pressurized Water Reactors (PWR)

PWRs utilize a dual-circuit water system. The primary cooling circuit flows through the reactor core at high pressure, preventing the water from boiling even at temperatures around 325°C. This heated water transfers its energy to a secondary circuit where water is converted to steam at a lower pressure in a steam generator. The pressurizer in the primary circuit maintains the necessary pressure to keep the water in a liquid state.

#### Boiling Water Reactors (BWR)

In contrast to PWRs, BWRs operate with a single water circuit at a lower pressure, allowing the water to boil directly in the reactor core at approximately 285°C. About 12%–15% of the water in the upper part of the core exists as steam. This steam passes directly to the turbines, which are part of the reactor circuit and thus require substantial shielding.

#### Heavy Water Reactors

Heavy water reactors use deuterium oxide (D2O) as the moderator, which allows them to utilize natural uranium as fuel. This type of reactor does not require enriched fuel, offering certain economic and strategic advantages.

## 4•2•2• Generation III+ and Large Light-Water Reactors

The global nuclear power industry has continuously evolved since its inception, with **Light-Water Reactors (LWRs)** emerging as the dominant technology for commercial nuclear energy generation. Originating from pioneering efforts in the **United States, France, Germany, Russia, Japan, and Korea**, LWR designs have undergone significant advancements, incorporating **enhanced safety features, improved performance, and greater adaptability to modern energy needs**. As Serbia embarks on its **nuclear energy journey**, it stands to benefit from the vast global expertise and technological innovation that have shaped today's reactor offerings.

### 4•2•2•1• Global Expertise, Local Adaptation

Early in the development of nuclear energy, U.S. companies such as Westinghouse, General Electric, Combustion Engineering, and Babcock & Wilcox laid the foundation for PWR and BWR technologies. Over time, European and Asian countries refined these designs, aligning them with their national manufacturing capabilities and regulatory frameworks. Today, nations like **France, Germany, South Korea, and Japan** have successfully localized and enhanced their LWR technologies, ensuring their competitiveness on the international stage. Meanwhile, **Russia and China have developed their own unique pressurized water reactor (PWR) designs,** exporting them to emerging nuclear markets.

For Serbia, this global landscape presents a unique opportunity to select a proven, advanced, and regionally compatible reactor technology that aligns with its energy independence, decarbonization goals, and long-term economic sustainability. By leveraging the best practices and technological expertise from established nuclear nations (like France, Uniter States, Russia), Serbia can adopt a state-of-the-art reactor while integrating local capabilities for supply chain development and regulatory adaptation.

### 4•2•2•2• Advancements in Light-Water Reactor Technologies

With Serbia prioritizing safety, regulatory compatibility, and economic feasibility, selecting a **Generation III+ PWR** ensures access to a **proven and globally deployed technology** that aligns with modern energy demands. Technologies like the **EPR-1200 (France), AP1000 (USA), VVER-1200 (Russia), and APR1000 (South Korea)** represent leading-edge options, each offering unique advantages for Serbia's energy security and grid compatibility.

## 4•2•3• Technology Differentiation and Strategic Considerations for Serbia

While all selected reactor technologies share the fundamental principles of Light-Water Reactor (LWR) technology, their differentiating features lie in their approach to safety, operational simplicity, and cost efficiency. Each design has been optimized to meet specific market, regulatory, and deployment needs, providing Serbia with a range of options that balance safety, economic feasibility, and long-term sustainability.

#### 4•2•3•1• Key Differentiating Features

- European, Korean, and Japanese PWRs – These designs focus on larger plant capacities to capture economies of scale, ensuring high power output, improved efficiency, and long-term economic viability. Technologies such as the EPR-1200 (France) and APR1000 (Korea) exemplify this approach, delivering high-capacity performance while maintaining stringent safety and regulatory standards.
- AP1000 (USA) – In contrast, the AP1000 prioritizes simplicity and passive safety by minimizing the need for complex safety systems, extensive piping, and active pumps. Instead of relying on mechanical pumps to provide emergency cooling in accident scenarios, the AP1000 leverages gravity-driven cooling systems, ensuring automatic and reliable cooling without external power or operator intervention. This design philosophy reduces construction complexity and enhances safety through inherent design features.
- VVER-1200 (Russia) – This reactor incorporates a double containment structure and advanced core cooling mechanisms to enhance accident tolerance and long-term reliability. Drawing lessons from previous nuclear incidents, the VVER-1200 features multiple passive and active safety systems, aligning with modern regulatory expectations while offering competitive deployment costs in large-scale grid settings.

#### 4•2•3•2• Safety Enhancements and Lessons from Past Events

Modern reactor designs, including the EPR-1200, AP1000, VVER-1200, and APR1000, integrate lessons learned from historical nuclear incidents such as Chernobyl and Fukushima. These technologies incorporate:

- Advanced passive safety features, reducing reliance on external power and human intervention.
- Reinforced containment structures to prevent radioactive releases in extreme conditions.
- Improved emergency cooling and accident management systems that ensure resilience in station blackout scenarios.

#### 4•2•3•3• Operational Longevity and Future-Proofing

All new-generation reactor designs **target a 60-year operational lifespan**, a significant improvement over previous designs with a **40-year lifetime**. This extended lifespan enhances Serbia’s energy security, investment viability, and long-term sustainability by ensuring a stable, low-carbon energy supply for decades to come.

### 4•2•4• Safety Enhancements in Modern Nuclear Technologies

Modern **Generation III+ nuclear reactors** have significantly improved safety margins compared to earlier designs, with a tenfold increase in safety performance based on probabilistic safety assessments. These enhancements are design-specific and incorporate lessons learned from past reactor operations, leveraging advanced risk analyses and engineering innovations to ensure higher resilience and lower operational risks.

Serbia’s selected reactor technologies, including EPR-1200, AP1000, VVER-1200, and APR1000, integrate these next-generation safety features, ensuring compliance with international regulatory expectations and alignment with Serbia’s commitment to safe, sustainable nuclear energy.

#### 4•2•4•1• Key Safety Enhancements in Serbia's Selected Reactors

- Passive Safety Systems – Many Generation III+ reactors reduce reliance on active cooling systems, instead using gravity, natural convection, and heat removal mechanisms to ensure cooling in the event of an emergency.
- Core Catchers – Some advanced designs, such as the EPR-1200 and VVER-1200, include core catchers, which prevent core meltdown scenarios from compromising containment.
- Reinforced Containment Structures – These technologies integrate double containment systems, improving resilience to external shocks and severe accident conditions.
- Severe Accident Management – Advanced accident-tolerant fuel, improved emergency response planning, and automated safety features further enhance the safety profile of selected designs.

By adopting these highly resilient technologies, Serbia will strengthen its nuclear safety framework, ensuring long-term operational security while minimizing risks to public health and the environment.

#### 4•2•4•2• Nonproliferation and Fuel Cycle Security

Serbia's nuclear energy strategy is firmly aligned with international nonproliferation commitments and ensures strict regulatory oversight over uranium enrichment and spent fuel management.

Light-Water Reactors (LWRs), including Serbia's selected technologies, utilize low-enriched uranium (LEU) with enrichment levels below 5%—a standard that minimizes proliferation risks while maintaining efficient energy production.

**✦ Key Nonproliferation Considerations for Serbia**

- Strict IAEA Oversight – All uranium enrichment and spent fuel management will comply with International Atomic Energy Agency (IAEA) safeguards, ensuring no diversion for unauthorized uses.
- Reprocessing Considerations – While reprocessing spent fuel can reduce waste, it also requires robust security protocols to prevent unintended proliferation risks. Serbia will explore best practices from France, the UK, and Russia, where reprocessing has successfully converted spent fuel into mixed oxide (MOX) fuel for continued reactor use.
- Controlled Supply Chain – Serbia's approach will emphasize supplier agreements with trusted nuclear technology providers, ensuring secure uranium sourcing and controlled fuel cycle management.

#### 4•2•4•3• Nuclear Waste Management and Long-Term Sustainability for Serbia

As Serbia advances its nuclear energy strategy, responsible nuclear waste management remains a critical component of ensuring long-term environmental safety and regulatory compliance. All light-water reactor (LWR) technologies, including EPR-1200, AP1000, VVER-1200, and APR1000, share similar waste disposal challenges, primarily concerning the storage and eventual disposal of spent nuclear fuel.

Global best practices demonstrate various successful approaches to nuclear waste management, with leading nations implementing long-term geological repositories and reprocessing techniques to reduce waste volumes and improve disposal efficiency.

## Global Leadership and Lessons for Serbia

- Proven Waste Management Strategies – **France** and other reprocessing nations solidify high-level waste in borosilicate glass, reducing waste volume by over 90% and safely storing it in air-cooled vaults.
- Successful Geological Repositories – **Finland and Sweden** lead the world in establishing the first deep geological repositories for spent nuclear fuel, setting global standards in safe, long-term disposal.
- United States Waste Policy Insights – The U.S. continues to evaluate final repository options for spent nuclear fuel (SNF), with no licensed deep geologic disposal facility currently operational. .

## Serbia's Approach to Sustainable Nuclear Waste Management

As Serbia integrates nuclear power into its long-term energy framework, it will adopt a structured, step-by-step approach to waste management, learning from global best practices while ensuring alignment with Serbia's specific regulatory and environmental priorities:

1. Interim Storage Solutions – Spent fuel will be safely stored on-site in dry cask storage or pools, following the highest international safety standards until a long-term solution is implemented.
2. Regulatory and Policy Development – Serbia should establish a comprehensive legal and regulatory framework that aligns with IAEA guidelines, ensuring safe handling, transport, and disposal of nuclear waste.
3. Long-Term Repository Planning – Serbia should collaborate with international partners to explore geological repository options, evaluating locations that meet both technical and societal acceptance criteria.
4. Cost-Inclusive Approach – Similar to international models, nuclear-generated electricity costs will include provisions for waste management and disposal, ensuring a self-sustaining financial structure for long-term solutions.

### 4•2•4•4• Economic Considerations for Serbia's Nuclear Energy Program

As Serbia moves forward with nuclear energy development, economic feasibility remains a critical factor in ensuring the long-term sustainability and affordability of the selected nuclear technologies. While nuclear power plants require significant upfront investment, they offer long-term economic stability, low operating costs, and energy security benefits that align with Serbia's strategic energy goals.

#### Capital Investment and Cost Considerations

Globally, the cost of nuclear power plant construction has varied significantly depending on factors such as regulatory frameworks, supply chain efficiency, financing models, and **the standardization of reactor designs**. Historically, countries like China and South Korea have achieved relatively stable nuclear construction costs through streamlined regulatory processes and widespread deployment of standardized reactor designs. In contrast, other markets such as the Europe and United States have experienced significant cost escalations due to prolonged licensing timelines, supply chain bottlenecks, and industry restarts following decades of limited nuclear construction.

## International Cost Benchmarks[3]

Recent international benchmarks indicate:

- Small Modular Reactors (SMRs):

  First-of-a-kind (FOAK) overnight costs for SMRs are estimated to range between €2,500–€7,000/kWe. This variation reflects early-stage deployment challenges, smaller unit sizes, technology immaturity, and limited supply chain readiness in many regions. While SMRs offer potential advantages in modular construction and scalability, these benefits are yet to be fully demonstrated at commercial scale.

- Large Nuclear Power Plants (LNPPs):

  FOAK overnight costs for Generation III+ reactors, such as the EPR and AP1000, are typically in the range of €5,000–€8,000/kWe, as observed in recent projects across Europe, North America, and Asia. Large reactors benefit from economies of scale in power generation, which can result in lower costs per installed megawatt compared to SMRs, particularly in standardized, serial deployment programs.

- Note:

  *These cost estimates are indicative and should be interpreted with caution. They are influenced by geographic location, labor costs, regulatory requirements, supply chain maturity, and project execution strategies. Additionally, FOAK deployments often face cost premiums of 20–60% compared to subsequent units (Nth-of-a-Kind, NOAK), underscoring the importance of standardization and serial production for cost reduction.*

### Long-Term Economic Benefits and Cost Stability

Despite the high **initial capital investment,** nuclear power offers low fuel costs and stable electricity pricing, making it one of the most cost-effective long-term energy solutions for Serbia. Compared to fossil fuel-based power generation, nuclear plants benefit from:

- **Stable Fuel Costs** – Unlike gas and coal, which are subject to market fluctuations, nuclear fuel costs remain stable and account for only 10% of total electricity costs.
- **Extended Plant Lifespan** – New-generation reactors are designed for 60+ years of operation, maximizing Serbia's return on investment.
- **Low Operating and Maintenance Costs** – Once operational, nuclear plants have lower maintenance and fuel costs compared to conventional power plants.
- **Energy Security and Independence** – By diversifying its energy mix with nuclear power, Serbia can reduce dependence on imported fuels and enhance grid stability.

[3] https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power
https://www.iea.org/reports/projected-costs-of-generating-electricity-2020
https://www.energy.gov/sites/default/files/2024-10/NZW09%20Nuclear%20Energy%20Cost%20Estimates%20for%20Net%20Zero%20World%20Initiative.pdf

#### Ensuring Cost-Effective Nuclear Deployment in Serbia

To optimize nuclear project economics, Serbia will need to:

- **Leverage International Best Practices** – Learning from France, Russia, US, South Korea, and other successful nuclear markets will help Serbia control costs and improve efficiency.
- **Develop a Streamlined Regulatory Framework** – A well-defined, risk-informed licensing process will reduce uncertainty and financing risks.
- **Foster Local Industry and Workforce Development** – Strengthening local supply chains and nuclear expertise will minimize reliance on foreign vendors and enhance cost-effectiveness.
- **Explore Competitive Financing Models** – Serbia should assess various financing structures, including public-private partnerships (PPPs), government-backed loans, and international funding mechanisms, ensuring affordability and long-term financial sustainability.

### 4•2•5• Nuclear Cybersecurity: Safeguarding Serbia's Future Nuclear Infrastructure

**Cybersecurity in nuclear power plants emerges as a critical priority**. With increasing digitalization and interconnected operational technologies, nuclear facilities must be protected from **cyber threats, cyber-physical attacks, and digital espionage** that could compromise safety, security, and operational reliability.

#### The Role of Cybersecurity in Nuclear Safety and Operations

Modern nuclear power plants rely on **highly sophisticated digital control systems, instrumentation, and automation** for monitoring reactor performance, safety mechanisms, and emergency response protocols. A cyberattack targeting these systems could lead to operational disruptions, misinformation, or, in extreme cases, compromised reactor safety.

To mitigate these risks, Serbia must adopt a **robust cybersecurity framework** that aligns with global nuclear cybersecurity standards and best practices, ensuring that digital assets remain secure, resilient, and impervious to cyber threats.

#### Cybersecurity as a Pillar of Serbia's Nuclear Energy Security

For Serbia's nuclear program to achieve regulatory approval, operational efficiency, and long-term sustainability, cybersecurity must be **embedded into the detail technical technology phase of reactor selection, licensing, construction, and operation**. By adopting a proactive, resilient, and continuously evolving cybersecurity approach, Serbia can protect its nuclear infrastructure from cyber threats, safeguard national energy security, and align with international nuclear security commitments.

# 4•3• Assessment of Large Nuclear Power Plant Technologies

## 4•3•1• Introduction

In the **Technology Selection Assessment Phase** [Chapter 2.3], a broad range of **LNPP designs were evaluated** [Chapter 2.3.1]. Following rigorous screening based on **technical maturity, economic feasibility, regulatory readiness, and deployment adaptability**, the **Technology Assessment Committee** has shortlisted four (4) [Chapter 2.3.2.1] leading PWR large technologies for further evaluation in **Pre-Phase 1 Technology Assessment:**

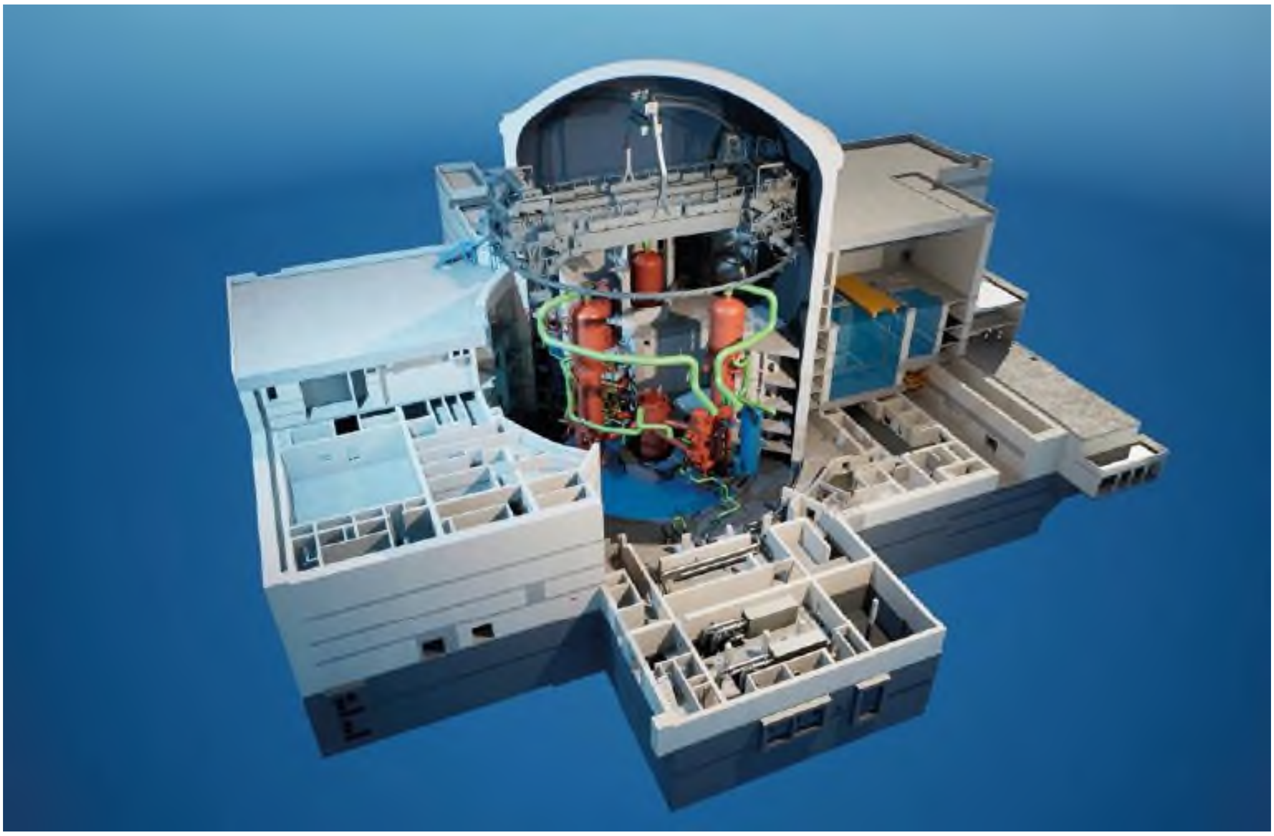
- **Framatome (EDF)** (EPR1200) [See Chapter 5.2]
- **Westinghouse (AP1000)** [ See Chapter 5.3]
- **Rosatom (AES 2006 VVER-1200)** [See Chapter 5.4]
- **Korea Hydro & Nuclear Power (KHNP) (APR100)** [See Chapter 5.5]

### 4•3•1•1• Why PWRs are suitable for Serbia

The Technology Assessment Committee highlights the strong alignment between PWR technology and Serbia's nuclear energy goals due to the following factors:

- Mature Technology – Well-established design with decades of operational experience.
- European Compliance – PWRs designed to meet EU and IAEA regulatory standards, facilitating Serbia's licensing and approval process.
- Proven Safety and Reliability – Advanced passive and active safety systems ensure high resilience to accidents.
- Fuel Supply Security – Multiple global suppliers ensure a stable fuel supply chain.
- Economic Viability – Lower operational risks, high efficiency, and long lifespan make PWRs a cost-effective investment for Serbia's energy sector.

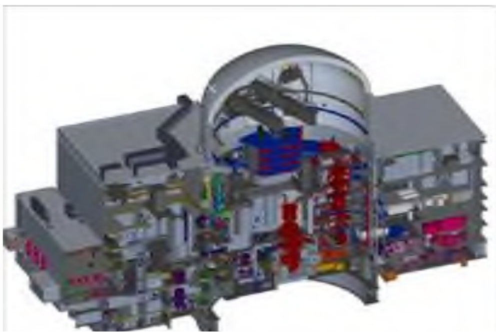
## 4•3•2• EPR 1200 – A Next-Generation European Pressurized Reactor



The **EPR 1200** is a **Generation III+ pressurized water reactor (PWR)** developed by **EDF and Framatome**, based on the proven design principles of the larger **EPR 1600**. The EPR 1200 is specifically tailored to provide high safety margins, enhanced efficiency, and economic viability, making it an ideal option for deployment in European and global markets.

The design builds upon decades of operational experience with large-scale European nuclear reactors (Konvoi), incorporating advanced safety features, optimized construction techniques, and strong regulatory alignment with European standards. Its 1200 MWe capacity makes it well-suited for medium-sized grids, ensuring compatibility with diverse national energy strategies.

EDF’s strategic vision for the EPR reactor technology is built on a European fleet approach, leveraging the experience, supply chain, and operational excellence of EPR projects across Europe. This approach ensures standardization, efficiency, and long-term support for participating countries, making it an ideal model for nations considering nuclear energy expansion, such as Serbia.



| | |
|---|---|
| Core Power | 3300 MWth |
| Electrical Output (net) | 1150 1200 MWe |
| Containment | Single |
| Operation Cycle | 18 to 24 months |
| Primary Coolant System | 3-loop configuration |
| Availability Factor | 0.91 |
| Design Plant Life | 60 years |
| I&C | Fully digital |
| Fuel Assemblies | 177 fuel assemblies 14ft |
| Spent Fuel Storage Capacity | More than 10 years |
| Grid Connection | Compliant with EU Requirements for Generators |
| Load follow flexibility | 25% to 100% nominal power in 30min |

Table 334: Key Plant Design Features

#### 4•3•2•1• Pro and Cons

The EPR 1200 nuclear reactor offers a highly advanced Generation III+ technology with strong safety features, high operational reliability, and proven deployment experience with EPR 1600 in key nuclear markets such as France, Finland, and China. The technology leverages passive safety systems, a robust supply chain, and modular construction methodologies to ensure efficient and secure operations.

However, the implementation of EPR 1200 in Serbia requires a thorough evaluation of technological, economic, regulatory, and logistical considerations. While the high safety standards, localization potential, and long-term operational benefits make it a compelling option, factors such as high capital investment, supply chain logistics, and regulatory adaptation need careful planning and mitigation strategies.

This section provides a structured analysis of the key advantages, challenges, and strategic recommendations to support an informed decision for the deployment of EPR 1200 in Serbia.

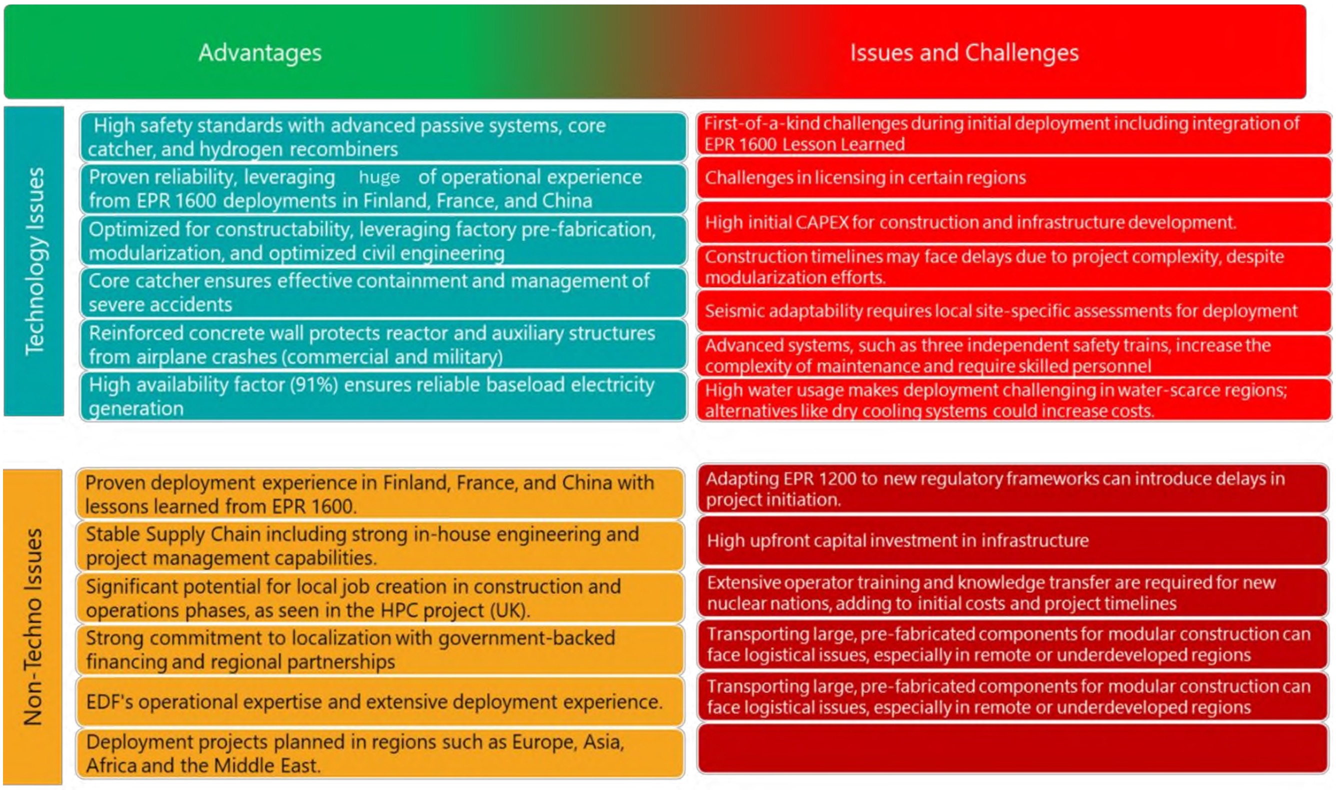



Figure 113: EPR 1200 Advantages and Challenges

### 4•3•2•2• Strategic Recommendations

The deployment of EPR 1200 in Serbia presents a transformative opportunity to enhance energy security, sustainability, and economic growth. While the technology offers state-of-the-art safety features, high efficiency, and compliance with EU and IAEA standards, a detailed technical study must be conducted as part of Nuclear Infrastructure Development Phase 1 to ensure a comprehensive evaluation of its feasibility and integration within Serbia's regulatory and energy landscape.

A key positive aspect of EPR 1200 is its proven safety and reliability, leveraging huge of operational experience in EPR 1600 from deployments in France, Finland, and China. Additionally, its advanced passive safety systems, core catcher, and hydrogen recombiners enhance its resilience against severe accident scenarios. The reactor's high availability factor (91%), load-following capability, and integration potential with hybrid energy systems make it a strong candidate for Serbia's evolving energy needs. Furthermore, the use of modular construction techniques could streamline deployment, optimizing project timelines and reducing on-site construction risks.

However, several critical aspects require further analysis in the next phase. These include regulatory alignment with Serbia's nuclear framework, cost optimization strategies, and the localization of supply chain and workforce development. The high initial CAPEX, complexity of the technology, and the need for specialized training programs must be carefully assessed to ensure a smooth, cost-effective, and sustainable implementation. Additionally, considerations around water resource usage, seismic adaptability, and grid integration must be thoroughly examined to ensure long-term operational stability.

To maximize benefits and mitigate challenges, the next phase should focus on conducting a detailed technology assessment, addressing licensing requirements, financial models, supply chain integration, and project execution strategies. By leveraging international best practices, fostering strong government and industry partnerships, and ensuring regulatory preparedness, Serbia can position itself as a leader in nuclear innovation, securing a reliable, low-carbon, and future-proof energy solution for decades to come.

#### 4•3•2•3• Conclusion

Following a comprehensive evaluation, the Technology Assessment Committee has concluded that **EPR 1200 presents a highly advanced, safe, and future-oriented nuclear technology that aligns with Serbia's long-term energy security and decarbonization objectives**. With its world-class safety features, high operational reliability, and strong integration into the EU nuclear supply chain, EPR 1200 is recognized as a strategic and forward-looking investment capable of supporting Serbia's transition toward stable, low-carbon, and resilient energy production.

However, the committee also acknowledges that several key aspects must be carefully managed to ensure a successful deployment. These include the high initial capital investment, regulatory adaptation to Serbia's framework, and logistical complexities. To address these challenges, the committee emphasizes the need for a structured and phased approach, focusing on regulatory alignment, financing strategies, workforce development, and local supply chain integration.

With proactive government support, strong international collaboration, and a well-defined implementation roadmap, the committee advises that **EPR 1200 can become a cornerstone of Serbia's nuclear energy strategy**. The next phase of the Nuclear Infrastructure Development Plan will be crucial in further analyzing these feasibility aspects, ensuring that Serbia lays a strong foundation for its nuclear energy future, guaranteeing clean, stable, and energy-independent growth for decades to come.

## 4•3•3• AP 1000 – A Modern, Safe, and Efficient Nuclear Power Solution

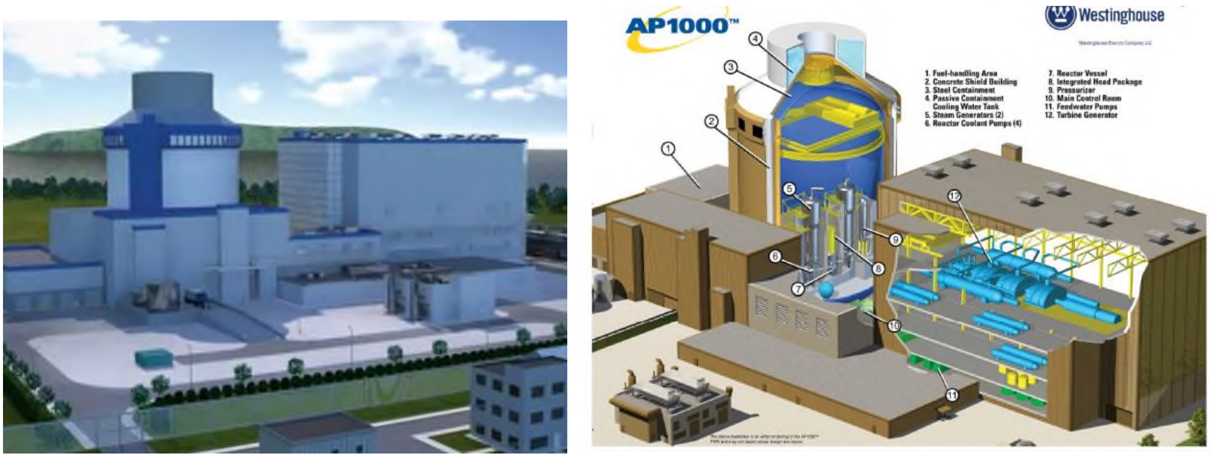
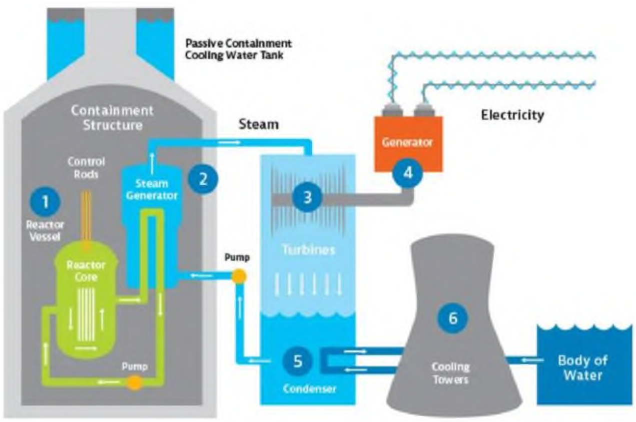
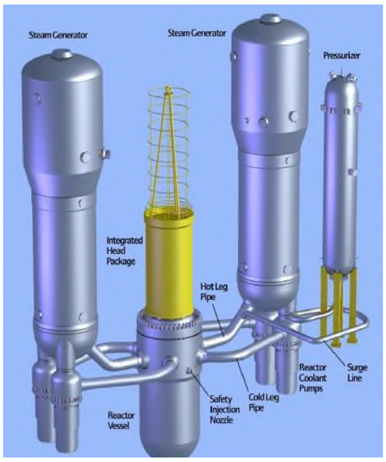



**Figure 224: AP 1000 Layout[4]**

The AP1000 is an advanced Generation III+ pressurized water reactor (PWR) designed by Westinghouse Electric Company. Engineered to enhance safety and economic efficiency, the AP1000 leverages passive safety features, modular construction, and streamlined system components to deliver a simplified yet highly reliable nuclear power solution. It is currently in operation and under construction in multiple countries and/or planned for construction, including China, the United States, Poland, Ukraine, India, and Bulgaria.

### 4•3•3•1• Key Technical Features




[4] Source: Westinghouse

| | |
|---|---|
| Reactor Thermal Power | 3,415 MWth |
| Reactor Electrical Power | 1,115 Mwe |
| Containment | Single |
| Core Inlet/Outlet Temperature | 280.7°C / 321.1°C |
| Number of Fuel Assemblies | 157 |
| Fuel Assembly Length | 14 ft. |
| Core Damage Frequency | $2.4 \times 10{-}7$ |
| Emergency Safeguards | Passive In-Vessel Retention System |
| Number of Steam Generators | 2 |
| Main Coolant Pumps | 4 Canned Rotor |
| Refueling Interval | 18 Months |
| Construction Period | 5 Years |

Table 445: Key Plant Design Features

### 4•3•3•2• Pros and Cons

The AP1000 nuclear reactor presents a highly advanced and economically competitive option for Serbia's energy strategy, offering passive safety, modular construction, and high reliability. Its simplified and standardized design reduces construction complexity, while modular fabrication enables faster deployment, making it a compelling solution for Serbia's long-term energy security and decarbonization goals. With a high availability factor of 93%, the AP1000 ensures stable baseload electricity generation, supporting industrial growth and energy independence.

However, deploying the AP1000 in Serbia requires addressing key challenges. The high capital investment necessitates strong financial structuring, leveraging government-backed funding and international partnerships. Additionally, regulatory adaptation to Serbia's nuclear framework and EU safety standards will be crucial to ensure compliance. Supply chain localization is another key factor, as U.S. export control restrictions (10 CFR Part 810) may limit Serbia's access to certain critical technologies and expertise, requiring strategic partnerships for knowledge transfer.

To fully assess the feasibility of AP1000 deployment, a detailed technical and economic evaluation should be conducted in Phase 1 of Serbia's Nuclear Infrastructure Development Plan. This study should focus on regulatory alignment, financing mechanisms, construction logistics, and workforce development. With proactive planning, strong government support, and international collaboration, the AP1000 could become a cornerstone of Serbia's clean energy future, ensuring a secure, low-carbon, and resilient electricity supply for decades to come.

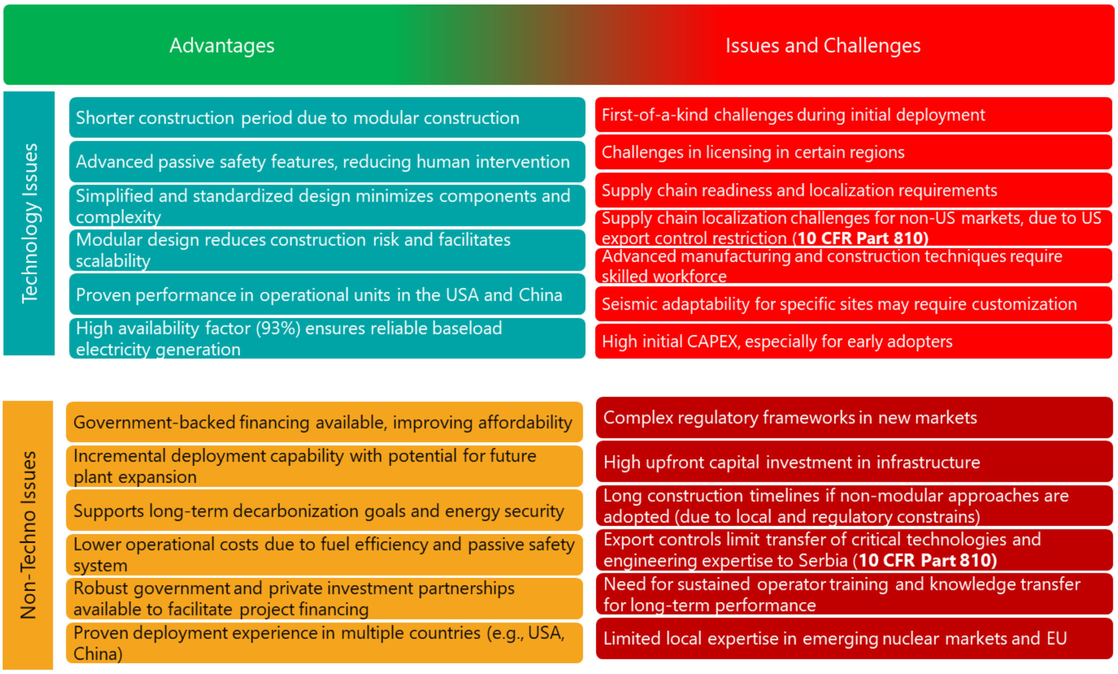



**Figure 335: AP1000 Advantages and Challenges**

## 4•3•3•3• Strategic Recommendations

To successfully implement the AP1000 nuclear reactor in Serbia, a strategic and well-structured approach is essential. Key recommendations include early regulatory engagement to align with Serbian, EU, and IAEA frameworks, ensuring a smooth licensing process. Given the high capital investment, Serbia should explore public-private partnerships, international funding, and phased deployment to optimize costs.

A localized supply chain strategy must be developed to enhance cost efficiency, job creation, and reduce dependency on foreign imports, while also addressing U.S. export control restrictions through alternative knowledge-sharing agreements. Workforce training and knowledge transfer programs in collaboration with Westinghouse and international nuclear institutions will be vital for long-term operational success.

The AP1000's modular construction approach should be leveraged to reduce project risks and construction timelines, requiring strategic partnerships with EPC firms for efficient execution. Additionally, grid integration studies must ensure seamless compatibility with Serbia's energy infrastructure while supporting long-term energy security and decarbonization goals.

A detailed feasibility study during Phase 1 of Serbia's Nuclear Infrastructure Development Program will be essential to evaluate technical, economic, and regulatory aspects. With strong government backing, international collaboration, and structured execution, the AP1000 could play a pivotal role in Serbia's transition to a secure, low-carbon energy future.

#### 4•3•3•4• Conclusion

The AP1000 nuclear reactor represents a proven, advanced, and scalable technology that aligns well with Serbia's long-term energy security and decarbonization objectives. With its passive safety systems, modular construction, and standardized design, the AP1000 offers high operational efficiency, reliability, and cost-effectiveness. Its ability to integrate into Serbia's electricity grid and support future energy expansion makes it a strategic candidate for the country's nuclear development roadmap.

However, as outlined by the Technology Assessment Committee, certain challenges must be carefully addressed. These include high upfront capital costs, regulatory adaptation, localization of the supply chain, and U.S. export control restrictions (10 CFR Part 810), which could impact technology transfer. Additionally, the need for sustained workforce training and knowledge transfer will be crucial for ensuring a competent and skilled nuclear workforce in Serbia.

To ensure a successful implementation, the Committee recommends that a detailed technical and economic feasibility study be conducted during Phase 1 of Serbia's Nuclear Infrastructure Development Program. This study will assess licensing requirements, financing mechanisms, supply chain capabilities, and integration into Serbia's energy strategy. With proactive regulatory engagement, strong government support, and international collaboration, the AP1000 could become a cornerstone of Serbia's clean and secure energy future.

By leveraging global best practices, strategic partnerships, and modular construction efficiencies, Serbia can position itself as a regional leader in nuclear energy deployment, ensuring a resilient, low-carbon, and sustainable energy system for decades to come.

### 4•3•4• VVER 1200 (AES 2006) – ROSATOM's Advanced Nuclear Solution

Rosatom State Corporation is a diversified group of companies responsible for the comprehensive implementation of Russia's nuclear energy policy. The State Corporation owns assets across all segments of the nuclear industry's production chain, including uranium exploration and production, uranium enrichment and conversion, fuel fabrication, design and construction of nuclear power plants (NPPs), operation and maintenance of NPPs, engineering, decommissioning of nuclear facilities, as well as the processing of spent nuclear fuel and radioactive waste.

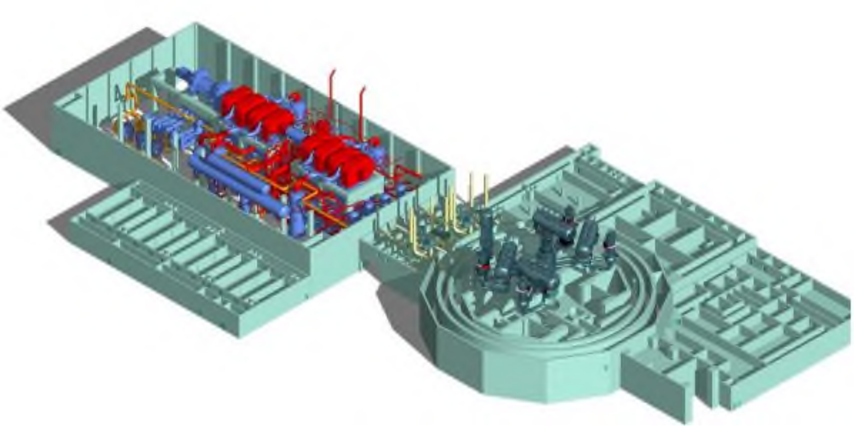


**Figure 446: VVER 1200 – Layout[5]**

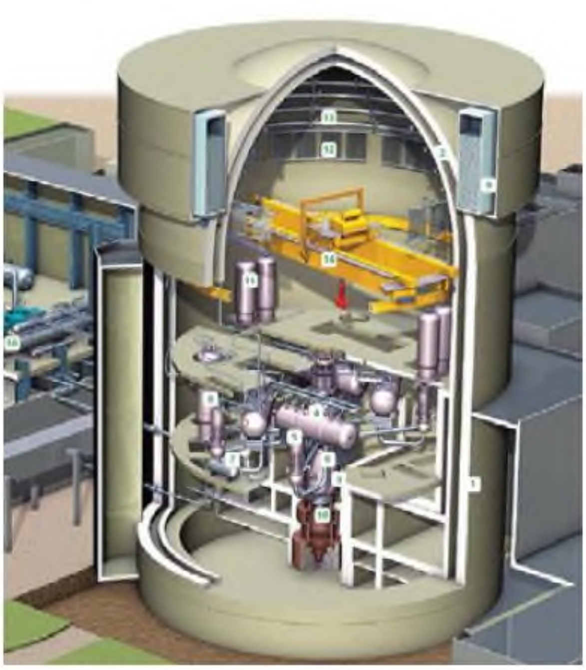


**Figure 557: Cross Section of VVER Containment**Error! Bookmark not defined.Erreur ! Signet non défini.

[5] Source: IAEA ARIS Database

The VVER-1200 (AES-2006) is an advanced Generation III+ pressurized water reactor (PWR) developed by ROSATOM, representing an evolution of the VVER-1000 with significant enhancements in safety, efficiency, and operational flexibility while adhering to international nuclear safety standards. The AES-2006 design exists in two main versions:

- V-491 Model – Implemented in Leningrad 2, this version features double containment, advanced passive safety systems, and high seismic resilience, making it well-suited for deployment in diverse regulatory environments.
- V-392M Model – Used in Novovoronezh II, this version incorporates a compact containment structure, optimized for streamlined construction and cost efficiency, while maintaining all core safety and operational features of the VVER-1200 series.

For Serbia, the V-491 model is considered the most relevant, given its alignment with European regulatory standards, proven operational success, and robust safety features. The VVER-1200 is currently operational in multiple countries, including Russia and Belarus, with additional units under construction in Egypt, China, Hungary, and Bangladesh, as well as planned projects in India, Turkey, and Uzbekistan, reflecting its global acceptance and reliability.

Designed to comply with stringent international safety and seismic standards, the VVER-1200 is highly adaptable to a variety of site conditions and regulatory environments. With its advanced passive and active safety systems, extended fuel cycle options (12-24 months), and high availability factor (~90%), the VVER-1200 presents a strong case for consideration in Serbia's nuclear infrastructure development, offering a safe, cost-effective, and long-term energy solution.

## 4•3•4•1• Key Technical Features

| | |
|---|---|
| Nominal Thermal Power | 3200 MW |
| Nominal Electrical Power | 1198 MW |
| Efficiency (gross) | 37.5 % |
| Primary system pressure (nom/design) | 16,2 / 17,6 Mpa |
| Coolant Temperature (inlet/outlet) | 298 / 329 °C |
| Steam Pressure at SG outlet | 7,9 MPa |
| Active Safety Trains | 4x100% / 4x50%[1)] |
| Design Lifetime | 60 years |
| Containment | Double |
| Autonomy after accident | >72 hours |
| Number of FA / RCCA | 163 / 121 |
| Mass of $UO_2$ in the core | 87065 kg |
| Operational Cycle | 12 / 18 months |
| Airplan Crash (Design Basis / DEC) | Small / commercial |

1) Emergency Boron Injection System

Figure 668: Key Plant Design Features

#### 4•3•4•2• Pros and Cons

The VVER-1200 (AES-2006) is a proven Generation III+ reactor design that combines enhanced safety features, improved efficiency, and modular construction techniques to meet modern nuclear energy demands. As Serbia evaluates potential reactor technologies for its nuclear energy strategy, it is essential to assess both the advantages and challenges associated with this design.

On the positive side, the VVER-1200 offers advanced passive and active safety systems, high operational efficiency with an availability factor of up to 92%, and a strong track record in operational units across Russia, Belarus, and India. Additionally, government-backed financing options, scalability for different grid sizes, and localization potential make it an attractive option for emerging nuclear markets.

However, several challenges must be addressed. Geopolitical risks, dependence on Russian-origin components, and supply chain constraints pose potential hurdles for countries integrating this technology outside Russia and its allied markets. Additionally, licensing adaptation and potential EU regulatory restrictions may impact project feasibility in Serbia's context. For example, the PAKS II project in Hungary developed in cooperation with Rosatom has experienced multiple delays and regulatory scrutiny linked to EU competition rules and geopolitical concerns. Similarly, the Hanhikivi-1 project in Finland was ultimately cancelled in 2022 due to deteriorating political relations and risks associated with its Russian technology partner. These cases highlight the importance of factoring in geopolitical alignment, regulatory uncertainty, and long-term strategic resilience when evaluating technology options with Russian ties.

This section provides a detailed analysis of the key strengths and challenges of the VVER-1200, ensuring a balanced perspective on its technical, economic, and geopolitical suitability for Serbia's nuclear program.

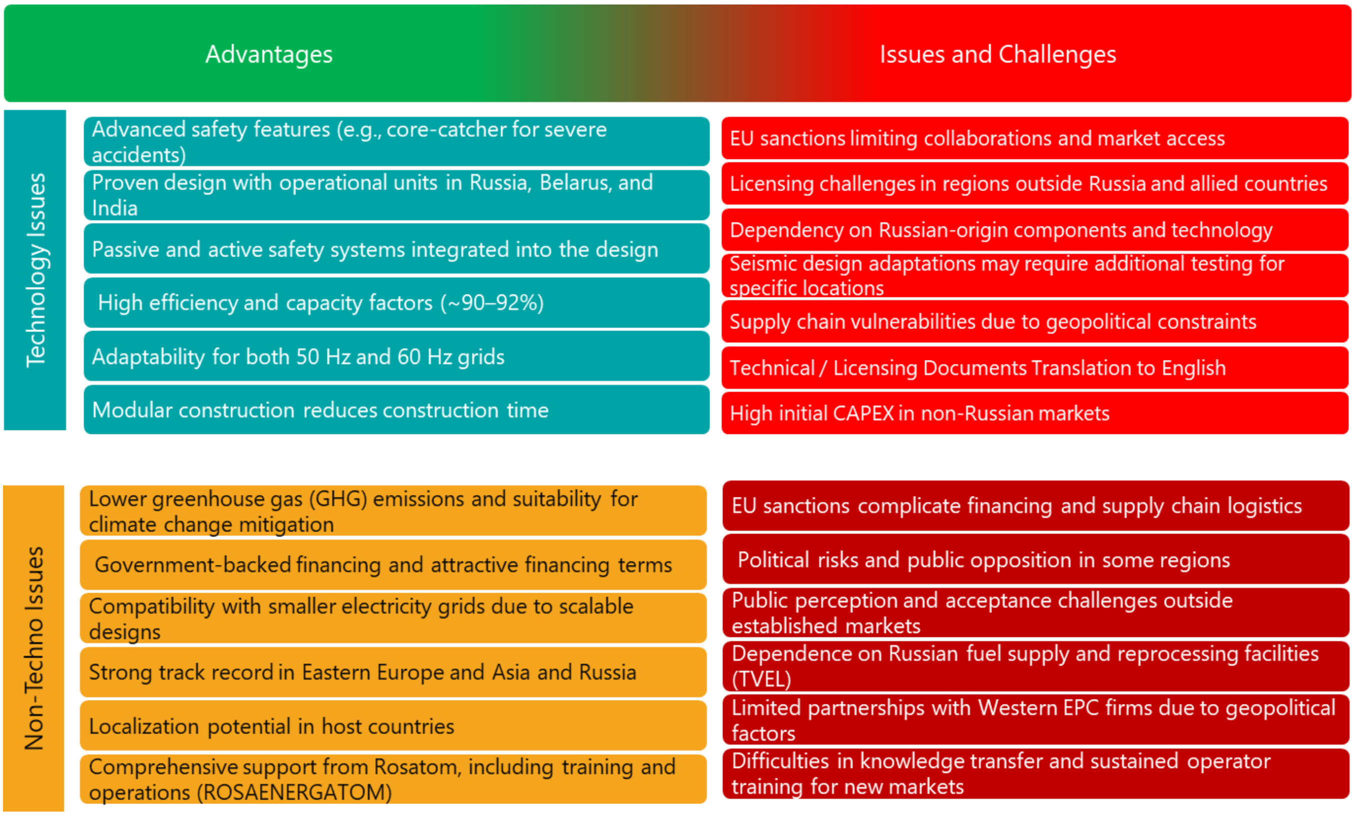



**Figure 779: VVER 1200 (AES 2006) Advantages and Challenges**

#### 4•3•4•3• Strategic Recommendations

The Technology Assessment Committee recognizes the VVER-1200 (AES-2006) as a promising and advanced nuclear technology that could play a key role in Serbia's clean energy future. Its proven track record, strong safety features, and modular construction make it an attractive option for long-term energy security and decarbonization goals. However, to ensure a successful implementation, a detailed technical technology study must be conducted as part of Phase 1 of Serbia's Nuclear Infrastructure Development Program to assess key regulatory, financial, and operational aspects.

Financing and cost optimization should be carefully planned, leveraging government-backed funding, export credit facilities, and potential international partnerships to ensure economic feasibility. The modular construction approach of the VVER-1200 offers a significant advantage in reducing project timelines and optimizing resource allocation, making it a cost-efficient and scalable solution.

To maximize local benefits, Serbia should explore opportunities for supply chain localization and workforce development. Partnering with ROSATOM and other experienced nuclear organizations can help create training programs, technology transfer initiatives, and long-term operational expertise, ensuring the country's self-sufficiency in nuclear operations.

While geopolitical considerations remain important, Serbia could position itself as a regional leader in nuclear energy by developing a well-structured, independent nuclear program. With strong government commitment, strategic planning, and a clear roadmap, the VVER-1200 can be a key driver of Serbia's energy transition, providing clean, reliable, and sustainable electricity for decades to come.

#### 4•3•4•4• Conclusion

The Technology Assessment Committee has conducted a high-level evaluation of the VVER-1200 (AES-2006), recognizing its strong safety features, modular construction, and proven global track record. As a Generation III+ reactor, the VVER-1200 offers enhanced passive and active safety measures, high efficiency, and long-term operational reliability, making it a strategic option for Serbia's nuclear energy program.

However, a structured approach must be followed in line with the IAEA's Nuclear Infrastructure Development Program (Phase 1), particularly given Serbia's current institutional readiness leve. The next phase should focus on a detailed technical technology study, ensuring a comprehensive assessment of regulatory requirements, financial structures, grid integration, and long-term fuel supply strategies. Close collaboration with IAEA experts, EU regulatory bodies, and international nuclear stakeholders will be essential to build a robust regulatory framework that meets global best practices.

From an economic perspective, the VVER-1200 benefits from government-backed financing options, which can significantly reduce capital burden for the host country. In terms of localization, the experience has varied by project and national context. India's Kudankulam project (VVER-1000 series), for example, demonstrates a relatively successful localization model: successive units have seen increased involvement of Indian industry in civil works, balance-of-plant systems, and auxiliary components. Similar efforts are ongoing at the El Dabaa site in Egypt and are planned for PAKS II in Hungary, where local contractors are expected to contribute significantly.

However, localization has not been consistent across all projects. At Akkuyu in Turkey, for instance, core components and major systems have been largely sourced from Russia, and the extent of local industry involvement has been more limited. Additionally, in EU member states, localization efforts may face challenges due to compatibility with European nuclear standards, regulatory barriers, and geopolitical scrutiny.

These examples suggest that while the VVER-1200 offers localization potential, it is highly dependent on early planning, local industrial capacity, and alignment with regulatory and geopolitical frameworks.

Although the VVER-TOI represents an advanced evolution of the VVER series featuring enhanced passive safety, improved seismic resilience, modular construction, and extended design life it has not been included in this final evaluation due to its limited international deployment and absence of reference plants outside Russia. Nonetheless, the Serbian Government may consider a more detailed review of the VVER-TOI design in future phases should the added features align with national long-term needs and if international references become available.

While geopolitical and supply chain factors require careful risk assessment and strategic planning, the VVER-1200 remains a strong candidate for Serbia’s clean energy transition. With proactive government support, phased regulatory development, and structured financing mechanisms, this technology can contribute to Serbia’s long-term energy security, decarbonization goals, and economic growth

Moving forward, the Technology Assessment Committee recommends that the Serbian Government undertake a focused technical and economic feasibility study on the VVER-1200 (AES-2006) as part of Phase 2 of the IAEA Nuclear Infrastructure Development Program. While VVER-TOI was not evaluated in this phase due to limited international references, its design enhancements may warrant future consideration depending on Serbia’s evolving strategic, regulatory, and industrial priorities.

### 4•3•5• APR 1000 – Advanced Power Reactor 1000

The APR1000 is a Generation III+ pressurized water reactor (PWR) developed by Korea Hydro & Nuclear Power (KHNP). It is based on the operational experience of APR1400 and OPR1000, integrating advanced safety, reliability, and economic efficiency while ensuring compliance with international safety and regulatory standards. The design is optimized for mid-sized grids, offering 1000 MWe of net electrical output, and incorporates passive safety features to enhance accident prevention and mitigation.

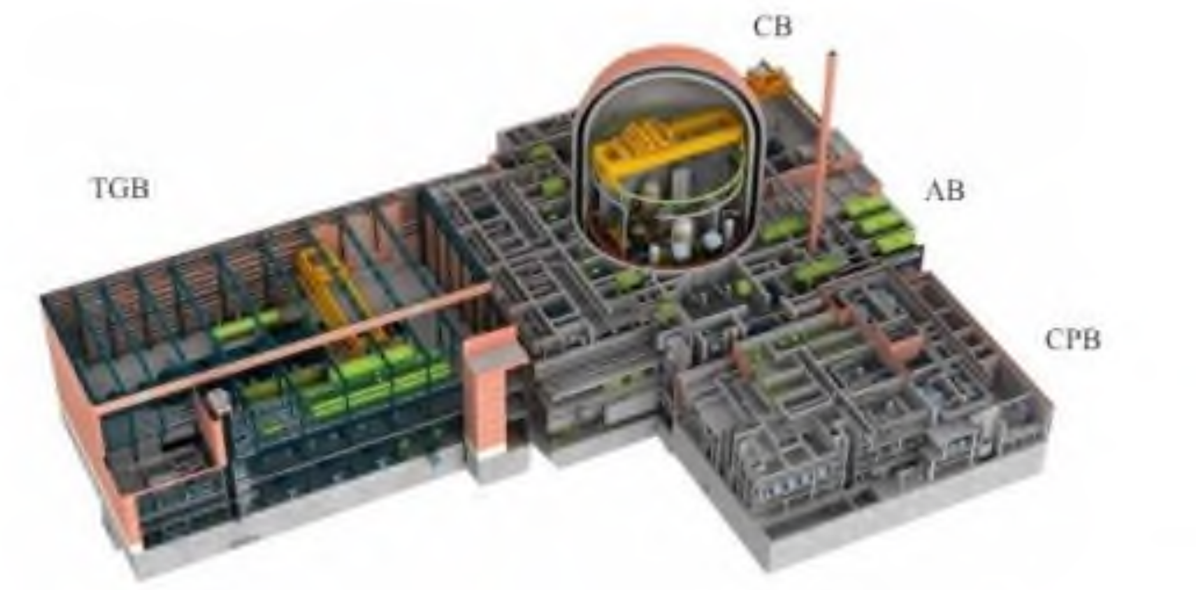


Figure 8810: Plant Layout of APR1000

Figure 9911: Site Plot Plan for APR 1000

### 4•3•5•1• Key Technical Features

The APR1000 integrates well-established technologies derived from the APR1400 and OPR1000 reactor families, ensuring high operational reliability and ease of maintenance. Its design prioritizes safety, efficiency, and adaptability, making it a competitive option for new nuclear infrastructure projects.

| Parameter | APR1000 Specification |
|---|---|
| Core Power | 2,815 MWt |
| Electrical Output (net) | 1,000 MWe |
| Containment | Single reinforced concrete, pre-stressed with a steel liner |
| Operation Cycle | 12 to 18 months, with an option for 24 months |
| Primary Coolant System | 2-loop system with four canned-motor reactor coolant pumps |
| Availability Factor | ≥ 90% (Designed for high reliability) |
| Design Plant Life | 60 years, with potential extension beyond 70 years |
| I&C (Instrumentation & Control) | Fully digital I&C system with reactor protection system (RPS) |
| Fuel Assemblies | 177 fuel assemblies (16x16 array) |
| Spent Fuel Storage Capacity | Approximately 10+ years onsite storage |
| Grid Connection | 50 Hz standard design (adaptable to 60 Hz) |
| Load follow flexibility | Designed for load-following with power modulation capability |

Table 556: Key Plant Design Features

### 4•3•5•2• Pros and Cons

The APR1000 nuclear reactor presents a balanced combination of advanced safety, efficiency, and economic considerations, making it a strong contender for nuclear deployment. As an evolution of the APR1400 and OPR1000 designs, it integrates proven reactor technology with enhanced safety and operational flexibility. However, like any large-scale nuclear project, the APR1000 has both strengths and challenges that need to be carefully assessed.

On the advantages side, the APR1000 features modular construction techniques that reduce on-site work, ensuring faster deployment timelines. Its robust safety measures, including passive auxiliary feedwater systems, core catchers, and advanced hydrogen mitigation systems, align with modern regulatory expectations. Additionally, the reactor demonstrates high availability factors and flexible load-following capabilities, supporting integration with renewable energy sources.

Despite these benefits, there are significant challenges to consider. The high capital expenditure (CAPEX) and complex design introduce financial and logistical barriers for prospective buyers. The reactor's reliance on high water usage presents deployment limitations in water-scarce regions. Moreover, the absence of a recognized country-of-origin regulatory certification raises concerns regarding licensing timelines and international acceptance.

This chapter systematically evaluates the key pros and cons of the APR1000, categorizing them into technical and non-technical aspects. By understanding these factors, stakeholders can make informed decisions regarding the feasibility of deploying the APR1000 within Serbia's Nuclear Infrastructure Development Program.

| | Advantages | Issues and Challenges |
|---|---|---|
| Technology Issues | Advanced Safety Systems – Features passive auxiliary feedwater, core catcher, and hydrogen recombiner | Cybersecurity Risks – Requires continuous updates to counter evolving threats |
| | Proven Reactor Lineage – Based on APR1400 and OPR1000, operational in South Korea and UAE. | Regulatory Barriers – No country-of-origin regulatory certification identified for APR1000. |
| | Resilient to External Hazards – Designed to withstand seismic shocks, floods, and aircraft impacts. | Cooling System Demand – High water usage may limit deployment in arid regions. |
| | High Availability Factor – Designed for 90%+ operational availability, ensuring grid stability. | Seismic Adaptability – Additional modifications may be needed for high-seismic regions. |
| | Load-Following Capability – Can adjust power output from 25% to 100%, integrating well with renewables. | Grid Integration Issues – Load-following requires significant infrastructure upgrades. |
| | Standardized Components – Optimized parts reduce supply chain risks. | Technical / Licensing Documents Translation to English |
| | | Complexity of Design – Advanced systems require highly skilled personnel for maintenance. |
| Non-Techno Issues | Low Carbon Emissions – Zero operational $CO_2$ emissions support climate goals. | Knowledge Transfer – Training programs needed for new nuclear markets, increasing costs. |
| | Experienced Operator Support – Backed by KHNP's technical expertise. | Economic Viability – High upfront costs |
| | Government Financing – South Korean export credits and partnerships reduce financial risks. | Supply Chain Complexity – Managing multiple contractors increases risks of delays and cost overruns |
| | Localization Opportunities – Potential for local supplier involvement. | Regulatory Delays – APR1000 lacks pre-approved certifications, extending licensing timelines. |
| | Secure Supply Chain – KHNP ensures stable fuel and component availability. | Limited partnerships with Western EPC firms |
| | | Difficulties in knowledge transfer and sustained operator training for new markets |

Figure 101~~12~~: APR 1000 Advantages and Challenges

### 4•3•5•3• Strategic Recommendations

The APR1000 presents a promising nuclear technology option for Serbia, combining proven reactor design, advanced safety features, and modular construction advantages. To ensure a successful evaluation and potential deployment, several strategic actions are necessary. First, since the Technology Assessment Committee has not identified any country-of-origin regulatory certification for APR1000, Serbia should engage with relevant international regulatory bodies and KHNP to establish a clear certification pathway. Early discussions on licensing requirements will facilitate smoother regulatory approvals and minimize potential delays.

Additionally, while the APR1000 claims benefits from modularization, no factual or implemented references have been identified. A structured technical validation program, including assessments of APR1400 operational units, should be undertaken to confirm these claims. Simultaneously, a comprehensive feasibility and localization study is needed to determine Serbia's capacity to integrate local suppliers, workforce, and infrastructure into the project. Strengthening local industrial participation will maximize economic benefits and support job creation.

As a relevant precedent, in the Barakah Nuclear Power Plant project in the UAE, KHNP's delivery model included very limited localization. One example is the involvement of Hilal Bil Badi[6] and Partners Contracting, a UAE-based firm responsible for constructing critical reinforced concrete water intake structures. This illustrates that while some local participation was enabled in non-nuclear civil works, overall localization was minimal and highly dependent on the host country's regulatory and industrial context.

From a financial perspective, securing cost-effective funding mechanisms will be crucial, as high initial capital expenditure can pose challenges. Exploring South Korea's government-backed nuclear export credit facilities and public-private partnerships could provide Serbia with competitive financing solutions. Furthermore, long-term knowledge transfer and workforce development strategies should be established in collaboration with KHNP to build Serbia's nuclear expertise. Operator training programs and technical collaborations will ensure smooth plant operation and maintenance. However, past experiences, such as the delay of the UAE's Barakah nuclear plant due to operator training gaps[7], highlight the need for Serbia to develop a robust operator training program early in the project. Addressing workforce readiness will be critical to avoiding potential delays and ensuring successful project execution.

Finally, Serbia should evaluate necessary grid integration measures, as APR1000's load-following capability offers flexibility in a mixed-energy environment. However, infrastructure investments may be required to optimize its performance within Serbia's energy grid. By addressing these strategic recommendations, Serbia can strengthen its nuclear infrastructure planning and position APR1000 as a viable and competitive option for future deployment.

### 4•3•5•4• Conclusion

The APR1000 offers a technologically advanced, high-performance nuclear power solution that aligns with Serbia's long-term energy security and decarbonization objectives. With its strong reactor lineage based on APR1400 and OPR1000, it presents a well-established and reliable design. The reactor's advanced safety features, high availability factor, and modular construction elements contribute to its appeal as a modern nuclear energy solution. However, key areas such as licensing, localization, and financial structuring require further assessment before any deployment decisions are made.

The Technology Assessment Committee has identified the need for further validation of the modular construction claims, as no concrete implemented references have been found. Additionally, the absence of pre-existing regulatory approvals for APR1000 presents a challenge that must be addressed through structured engagement with regulatory bodies. These factors highlight the importance of conducting a detailed technical feasibility study in the next phase of Serbia's Nuclear Infrastructure Development Program.

Despite these challenges, APR1000 remains an attractive option due to its strong safety performance, adaptability to grid requirements, and potential for localization benefits. With proactive regulatory engagement, structured financial planning, and robust knowledge transfer initiatives, Serbia can leverage the APR1000 technology as part of a resilient, sustainable, and future-ready nuclear infrastructure program.

[6] https://www.power-technology.com/projects/barakah-nuclear-power-plant-abu-dhabi/

[7] Source: https://www.reuters.com/article/markets/currencies/exclusive-arab-worlds-first-nuclear-reactor-delayed-again-over-training-sour-idUSKBN1GY1XS/

### 4•3•6• LNPP Overall Comparison

The Technology Assessment Committee has conducted a high-level evaluation of EPR 1200, AP 1000, VVER 1200, and APR 1000, examining their key technical and operational characteristics. Each reactor design offers unique advantages in terms of safety, operational flexibility, fuel cycle efficiency, and construction methodologies.

The following table presents a structured comparison of the four reactor technologies, highlighting their respective strengths and suitability for Serbia's nuclear infrastructure development. This high-level evaluation is intended to guide decision-makers in selecting the most viable option for further in-depth studies in Phase 1 of the Nuclear Infrastructure Development Program.

The assessment considers crucial parameters, including design lifetime, electrical capacity, fuel cycle length, seismic design, containment features, and grid compatibility. The findings emphasize that all four technologies are well-established in the global nuclear industry, with proven operational performance and strong vendor support. However, certain aspects such as localization potential, regulatory certification, and construction timelines require further validation in the Serbian context.

| Parameter | EPR 1200 (France, EDF/Framatome) | AP 1000 (USA, Westinghouse) | VVER 1200 AES-2006 (Russia, ROSATOM) | APR 1000 (South Korea, KHNP) |
|---|---|---|---|---|
| Design Lifetime | 60 years (extendable to 80) | 60 years | 60 years (potential for 70+ with inspections) | 60 years (extendable) |
| Plant Capacity (MWe) | 1200 | 1115 | 1170 | 1000 |
| Fuel Cycle Length | 12–24 months | 18 months | 12–24 months | 12–18 months |
| Enrichment Level | Up to 4.95% | Up to 5% | Up to 5% | Up to 5% |
| Spent Fuel Management | Wet & dry storage, reprocessing option | Wet & dry storage | Wet & dry storage, potential reprocessing | Wet & dry storage |
| Core Catcher | Yes | Yes | Yes | Yes |
| Safety Trains | Four independent trains | Passive safety, gravity-driven | Active & passive safety integration | Four-train safety system |
| Diversity & Redundancy | High | High | High | High |
| Main I&C System | Digital control with cybersecurity | Digital I&C | Digital I&C with cybersecurity features | Digital I&C |
| Severe Accident Management | Advanced containment & mitigation | Passive core cooling | Passive & active severe accident control | Core melt retention system |

| Parameter | EPR 1200 (France, EDF/Framatome) | AP 1000 (USA, Westinghouse) | VVER 1200 AES-2006 (Russia, ROSATOM) | APR 1000 (South Korea, KHNP) |
|---|---|---|---|---|
| Containment Design | Single-layer containment | Single-layer containment | Double-layer containment | Reinforced containment |
| Containment Volume | Not Available | Compact | Large | Compact |
| Electrical Backup | Diesel & passive backup | Passive battery & diesel | Diesel & mobile generators | Diesel backup |
| Nuclear Island Size | Compact | Small footprint | Large | Compact |
| Concrete Volume (m³/MWe) | Not Available | Not Available | Not Available | Not Available |
| Grid Frequency Compatibility | 50 Hz & 60 Hz compatible | 50 Hz & 60 Hz compatible | Designed for 50 Hz, adaptable for 60 Hz | 50 Hz standard, adaptable to 60 Hz |
| Safety Philosophy | Redundant active safety + passive | Passive safety emphasis | Combination of active and passive | Hybrid safety approach |
| Fuel Type | $UO_2$ & MOX | $UO_2$ & MOX | $UO_2$ & MOX | $UO_2$ |
| Seismic Design | 0.3g SSE | 0.3g SSE | 0.25g SSE, adaptable | 0.3g SSE |
| Country of Origin & Vendor | France, EDF/Framatome | USA, Westinghouse | Russia, ROSATOM | South Korea, KHNP |

Table 667: LNPP Overall Comparison Table

## 4•3•7• Summary and Key Takeaways

The comparative analysis underscores that all four reactor technologies are **mature, advanced, and capable of meeting Serbia's long-term energy needs.** Each design has specific **technical and economic advantages,** which should be carefully weighed against Serbia's regulatory, financing, and grid integration requirements during Phase 1 Nuclear Infrastructure Development Program.

- **EPR 1200** offers high power output, advanced safety, and strong European regulatory alignment, making it suitable for European deployment. However, its construction costs and complexity are challenging.
- **AP 1000** is designed for cost-effective and simplified deployment, utilizing passive safety as a key feature. It has a proven track record but requires further assessment for local supply chain integration due to export control issue and Technology provider strategy.

- **VVER 1200** has extensive operational experience, particularly in Eastern Europe and Russia, and offers strong localization potential. However, geopolitical considerations and export control regulations should be reviewed.
- **APR 1000** builds on South Korea's nuclear expertise and is being positioned for global markets, though the Technology Assessment Committee has not identified country-of-origin regulatory certification for this reactor.

Given Serbia's current status in nuclear infrastructure development, **further technical feasibility assessments** should be conducted to evaluate each design's suitability for local conditions. **The Technology Assessment Committee could continue to refine the analysis in Phase 1,** ensuring that Serbia's nuclear strategy aligns with international safety, regulatory, and economic best practices.

### 4•3•7•1• Final Considerations and Long-Term Vision Including the Roadmap

The evaluation of Large Nuclear Power Plant (LNPP) technologies in Pre-Phase 1 of the Nuclear Infrastructure Development Program has provided a high-level comparison of EPR 1200, AP 1000, VVER 1200, and APR 1000. However, further detailed technical and economic assessments are essential to refining technology selection, financial structuring, regulatory alignment, and project implementation strategies.

The Technology Assessment Committee has emphasized that the next phase must include a holistic and multidimensional evaluation that extends beyond reactor design and focuses on feasibility, infrastructure readiness, financing, safety, localization, regulatory compliance, and long-term sustainability. Phase 1 and beyond will serve as a roadmap to ensure that Serbia's nuclear program aligns with global best practices and meets national energy demands.

#### ✦ Strategic Focus for the Next Phase

As Serbia advances into Phase 1 of its Nuclear Infrastructure Development Program from the Pre-Phase 1, the Technology Assessment Committee (TAC) has identified key focus areas that require in-depth evaluation to ensure the technical, economic, and regulatory feasibility of Large Nuclear Power Plant (LNPP) deployment. This phase will build on the preliminary technology assessment, shifting towards a comprehensive feasibility study that considers **site conditions, fuel cycle strategies, nuclear safety, balance of plant (BOP) integration, technology readiness, and financial structuring**.

A thorough site and environmental evaluation shall be conducted to determine factors such **as seismic resilience, land requirements, cooling system options (wet vs. dry cooling), and emergency planning zones (EPZs).** Ensuring the selected technology aligns with Serbia's geographical and environmental conditions is a critical priority for regulatory approval and long-term operational safety. Additionally, the **fuel cycle must be examined in greater detail, including fuel supply agreements, uranium enrichment requirements, spent fuel storage, and waste management strategies**, ensuring compliance with IAEA and EU non-proliferation and environmental standards.

Nuclear safety assessments shall focus on evaluating the reactor core design, containment structures, passive and active safety features, core damage frequency (CDF), and overall risk mitigation strategies. The Technology Assessment Committee is recommended to validate each technology's ability to meet international licensing requirements and ensure robust emergency preparedness measures during Phase 1. Furthermore, a review of nuclear island design and performance shall be undertaken, assessing steam generator capacity, thermal energy efficiency, operational reliability, and grid stability.

Beyond electricity production, the Balance of Plant (BOP) design shall be examined to explore additional applications such as district heating, hydrogen generation, and industrial steam production. This broader multi-use potential ensures that Serbia maximizes the economic and industrial value of its nuclear investment. Additionally, grid integration studies shall be conducted to assess how LNPP deployment will interact with Serbia's electricity transmission network and support the flexibility of a renewable-heavy grid.

Security and regulatory compliance shall also be a major focus, with a detailed safeguards and protection strategy to address physical security, cybersecurity, and nuclear material accountability. The Technology Assessment Committee recommended to ensure that the alignment with EU, IAEA, and WENRA safety guidelines, ensuring Serbia's nuclear program meets the highest international security standards.

A comprehensive technology readiness assessment shall be validated the maturity, deployment history, and reliability of each reactor technology, ensuring Serbia selects a proven, well-supported technology with a strong operational track record. Additionally, the execution and delivery strategy must be defined, covering procurement plans, modular construction feasibility, workforce development, and supplier localization strategies.

From an economic and financial perspective, Phase 1 shall refine CAPEX and OPEX cost modeling, investment strategies, and funding mechanisms. Serbia must explore public-private partnerships, sovereign guarantees, export credit facilities, and EU funding opportunities to secure the financial sustainability of the project. The Technology Assessment Committee is recommended to evaluate cost risks, financing structures, and economic feasibility to ensure Serbia's nuclear program is both financially and strategically viable.

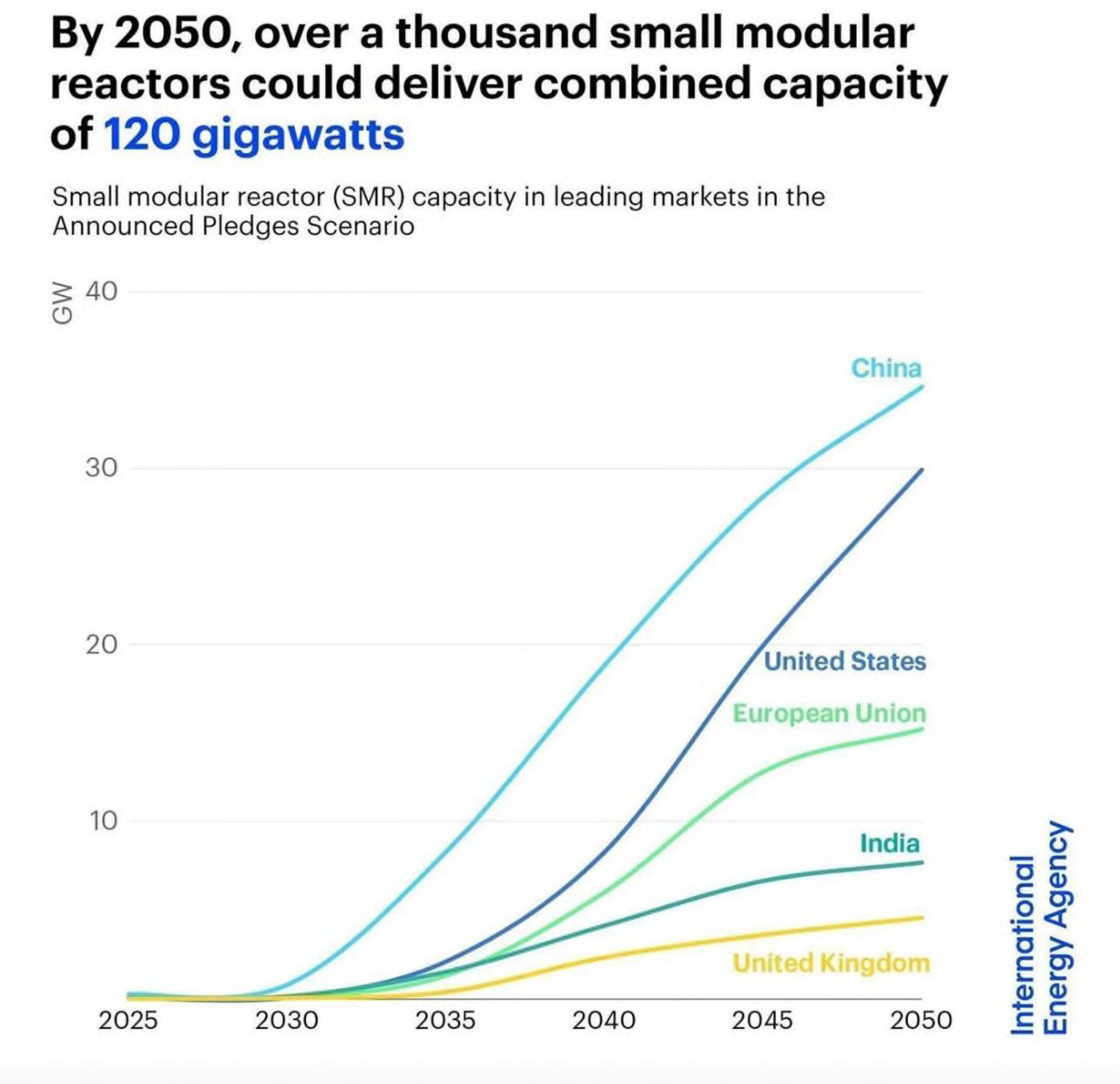
By addressing these strategic focus areas, Serbia can establish a strong foundation for long-term nuclear deployment, ensuring that its LNPP program is technically sound, economically sustainable, and aligned with national energy security and decarbonization goals. The Technology Assessment Committee can contribute to continue the oversee this process, ensuring that all critical factors are comprehensively evaluated before advancing to the next stage of nuclear infrastructure development.

## 4•4• Emerging Small Modular Reactors (SMRs)

### 4•4•1• Introduction

Small Modular Reactors (SMRs) emerge as a promising solution, complementing the role of Large Nuclear Power Plants (LNPPs). SMRs offer flexibility, modularity, and cost-effectiveness, making them attractive for Serbia's grid stability, industrial applications, and potential coal-to-nuclear transitions.

SMRs, as classified by the International Atomic Energy Agency (IAEA), are reactors with an electrical capacity of up to 300 MWe, designed for modular manufacturing and factory-based production. Unlike traditional large-scale reactors, which require extensive on-site construction, SMRs follow a "product-based" model, allowing for assembly at existing power plant locations or deployment in remote and industrial areas. This modular approach enhances cost predictability, reduces construction time, and minimizes project risks.



The level of detail provided in the assessment of Small Modular Reactors (SMRs) is intentionally more extensive than for large nuclear power plants (LNPPs). This reflects several key contextual factors rather than a difference in importance or relevance. First, SMRs represent a rapidly evolving segment of the global nuclear landscape, with multiple vendors advancing designs at varying stages of maturity, from conceptual development to licensing and early deployment. As such, more space is required to characterize and differentiate technologies that are often less well understood and more diverse in design philosophy, size, and deployment model.

Second, because most SMR designs are not yet commercially operational, this assessment draws heavily on vendor data, public project announcements, licensing submissions, and early feasibility studies to ensure all relevant technical, economic, and strategic variables are transparently presented. In contrast, LNPP technologies such as AP1000, EPR, and VVER-1200 are already deployed or under construction globally, with well-documented reference plants and more consolidated design histories, allowing for a more concise evaluation based on validated experience.

Finally, the Serbian context specifically envisions SMRs as a potential pathway for phased decarbonization, coal replacement, and flexible grid integration, which necessitates deeper consideration of implementation models, regulatory readiness, and localization potential. While the evaluation remains balanced across both categories, the broader variability, earlier development stage, and strategic novelty of SMRs naturally require a more detailed exploration to support evidence-based decision-making.

#### 4•4•1•1• Technological Maturity and Deployment Considerations

Globally, SMR deployment is still in the early stages, with limited operational experience and a lack of established supply chains. While certain designs, such as China's ACP-100, are under construction, and Russia's KLT-40S has demonstrated operational success, most Western SMR designs have yet to reach commercialization. Among them, NuScale is the only Western SMR to receive final design approval from the U.S. Nuclear Regulatory Commission (USNRC)[8].

For Serbia, careful evaluation of **technology readiness, supply chain feasibility, and regulatory compatibility** is essential before committing to SMR deployment. Given that Serbia currently under development of dedicated nuclear regulatory body, developing a clear licensing and regulatory framework aligned with EU and IAEA standards will be a crucial prerequisite for SMR adoption.

### 4•4•2• The Role of Small Modular Reactors (SMRs)

Small Modular Reactors (SMRs) have emerged as a compelling alternative to conventional Large Nuclear Power Plants (LNPPs). SMRs offer greater deployment **flexibility, lower capital investment, and enhanced scalability**, making them an attractive option for countries seeking decarbonization, energy security, and cost-effective nuclear deployment.

Traditional large-scale nuclear plants require **high upfront capital investments** often ranging between $8 to $10 billion for a 1,200 MWe facility which can pose financial and logistical challenges for nations with smaller energy grids or limited investment capacity. In contrast, SMRs are **designed to reduce financial risk and construction complexity, enabling gradual, phased investments** that align with national energy demand growth.

[8] https://www.energy.gov/ne/articles/nrc-approves-first-us-small-modular-reactor-design

A key advantage of SMRs is their ability to leverage **modular construction techniques, significantly reducing on-site construction time and costs.** Unlike conventional reactors, which require extensive civil works and large-scale infrastructure, SMRs are often factory-assembled and transported to the deployment site. This approach minimizes construction risks, enhances quality control, and accelerates deployment timelines a critical advantage for nations like Serbia, which are establishing their first nuclear power program.

Most SMR designs focus on pressurized water reactor (PWR) technology, which is well understood by regulators and has a proven safety record. By incorporating key reactor components such as the pressurizer, steam generator, and reactor core into a single, compact vessel, SMRs simplify plant design, reducing the number of external components and complex piping systems. This integral pressurized reactor configuration enhances operational efficiency, improves safety margins, and minimizes maintenance requirements.

Additionally, SMRs offer unmatched deployment flexibility, making them well-suited for various applications beyond electricity generation. These reactors can be used for district heating, desalination, hydrogen production, and industrial applications, providing multi-purpose energy solutions that align with Serbia's long-term energy diversification strategy. Some SMRs, such as Russia's floating power plant models, are even being designed for remote locations and off-grid energy supply, demonstrating their versatility in diverse operational environments.

Another key aspect of SMRs is their enhanced passive safety features, which significantly reduce reliance on external power sources for emergency cooling. Many modern SMRs incorporate gravity-driven cooling systems, self-contained emergency shutdown mechanisms, and advanced hydrogen recombination systems, ensuring that the reactor can maintain safety even in extreme accident scenarios.

### 4•4•2•1• Introduction

Small Modular Reactors (SMRs) present a strategic opportunity to overcome traditional challenges associated with large-scale nuclear power plants (LNPPs). The deployment of SMRs aligns with Serbia's objectives for energy independence, grid flexibility, and decarbonization, while addressing key concerns such as cost, construction timelines, and siting constraints.

- **Enhanced Safety and Advanced Passive Safety Features**

SMRs are designed to incorporate over 60 years of nuclear industry experience, integrating enhanced safety systems and passive cooling mechanisms. Unlike large nuclear plants that rely on active safety systems requiring external power sources, SMRs utilize passive safety mechanisms, reducing the risk of human error and operational failures.

Due to their smaller core size and advanced reactor designs, SMRs achieve higher safety margins and can rely on large water inventories for passive cooling in extreme conditions, such as loss of offsite power. This minimizes reliance on complex external systems and enhances accident resilience.

For Serbia, passive safety and simplified operation would help facilitate regulatory acceptance, as the country establishes its first nuclear regulatory framework. The potential for reduced offsite emergency planning zones (EPZs) can streamline licensing, lower public safety concerns, and facilitate flexible plant siting options closer to demand centers, enhancing energy distribution efficiency.

## Flexibility in Grid Integration and Multi-Purpose Energy Use

Serbia's energy transition plan envisions a low-carbon power mix, where nuclear energy complements variable renewable sources like wind and solar. SMRs provide critical grid flexibility, enabling Serbia to phase out fossil fuel-based plants while maintaining grid stability and baseload power.

SMRs have the potential to operate in load-following mode, adjusting power output from 25% to 100% to accommodate fluctuations in renewable energy generation. This feature makes SMRs particularly well-suited for Serbia's evolving energy landscape, where the demand for dispatchable, low-carbon energy sources is increasing.

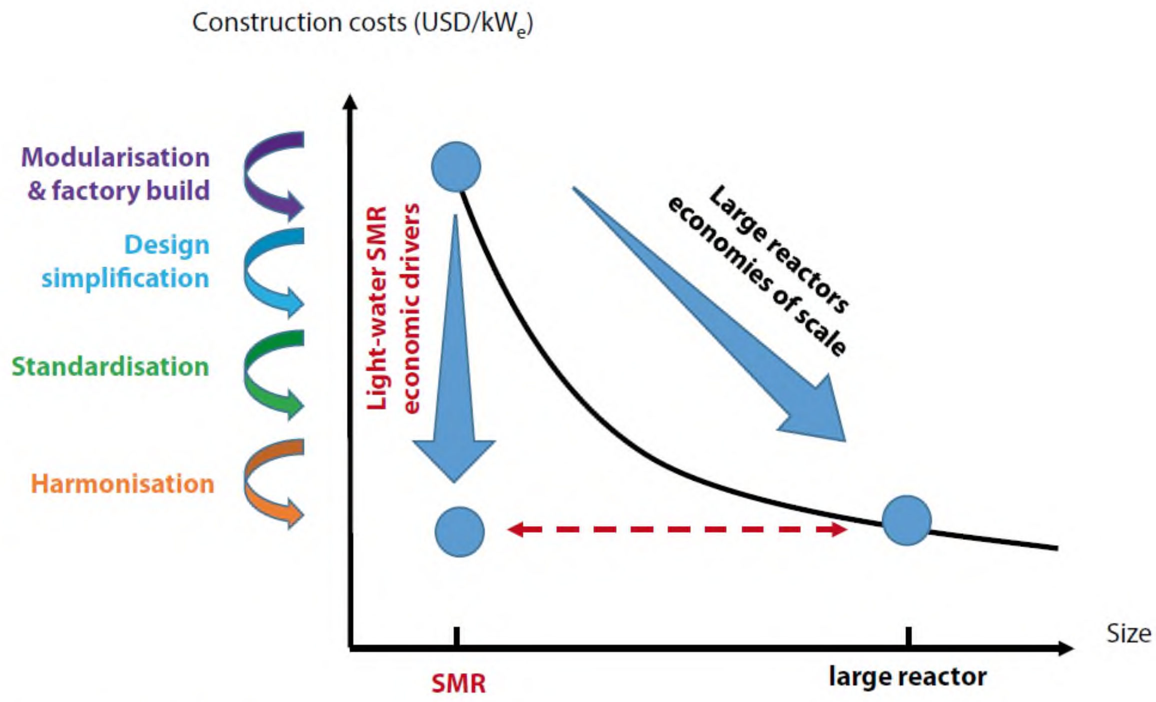
Beyond electricity generation, SMRs also support multi-purpose applications, including:

- District heating and industrial heat supply for urban centers and manufacturing sectors.
- Desalination for water-scarce regions, ensuring fresh water supply security.
- Hydrogen production for clean energy storage and transport decarbonization.

By integrating these capabilities, SMRs provide Serbia with a diversified clean energy solution that supports both power generation and industrial decarbonization goals

## Cost Competitiveness and Investment Advantages of SMRs

One of the most compelling aspects of Small Modular Reactors (SMRs) is their ability to transform the economic model of nuclear power, shifting away from the high capital costs of traditional large-scale nuclear plants towards incremental, scalable investments. For Serbia, where financial feasibility and investment structuring are critical for long-term energy planning, SMRs provide a unique opportunity to gradually build nuclear capacity while managing economic risks effectively.




Source: NEA (2021b).

Figure 11113:SMR key economic drivers to compensate for diseconomies of scale

Unlike conventional large nuclear reactors, which require multi-billion-EURO upfront investments, SMRs allow phased deployment, enabling Serbia to spread costs over time rather than committing to massive capital expenditures in a single stage. This phased investment approach aligns well with Serbia's economic planning framework, offering a financially sustainable pathway to nuclear energy expansion.

Another key advantage of SMRs is their standardized modular design, which reduces construction risks and site-specific complexities [Figure 31:SMR key economic drivers to compensate for diseconomies of scale]. Factory-built reactor modules can be prefabricated and assembled on-site, ensuring higher precision, quality control, and schedule predictability. This streamlined construction process translates to lower project costs and reduced delays, which are common challenges in traditional nuclear power plant projects.

Additionally, SMRs introduce faster deployment timelines compared to conventional reactors. The use of modular construction techniques and factory fabrication can reduce on-site work by up to (Average 20% to 40%)[9][10], significantly minimizing construction delays, cost overruns, and financing risks. This approach is particularly advantageous for Serbia, as it accelerates the realization of nuclear energy goals without overwhelming the country's financial resources.

Furthermore, SMRs present an attractive investment opportunity for private sector participation. Due to their smaller project size and scalability, SMRs are more accessible to private investors, institutional lenders, and commercial financing partners. This opens the door for public-private partnerships (PPPs), export credit arrangements, and innovative financing mechanisms, making nuclear investment more flexible and commercially viable for Serbia.

By leveraging the cost competitiveness and investment advantages of SMRs, Serbia can gradually develop its nuclear energy capacity without the financial burden of mega-scale nuclear projects. The economic flexibility reduced financial risk, and faster deployment capabilities of SMRs position them as an ideal solution for Serbia's long-term energy security, clean energy transition, and sustainable economic growth.

### Standardisation in SMR Design and Deployment

Small Modular Reactors (SMRs) offer a significant opportunity for standardization, which is essential for cost reduction, regulatory efficiency, and supply chain optimization. Standardization of reactor designs and associated delivery processes has proven to be an effective strategy in large nuclear projects, fostering learning-by-doing, streamlining construction timelines, and enabling long-term supply chain engagement. By extending these principles to SMRs, nuclear developers can achieve economies of scale, improved project execution, and reduced uncertainties in licensing and deployment.

Standardization in SMR technology does not imply that all units must be identical, but rather that they should share a common global architecture, specifications for nuclear steam supply systems, and harmonized safety systems, as highlighted by the World Nuclear Association's (WNA) CORDEL Working Group[11]. This approach ensures that variability in construction and operational performance is minimized, while still allowing for adaptations to site-specific conditions.

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[9] World Nuclear Association: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors

[10] Small Modular Reactors: Challenges and Opportunities – NEA Report 2021 (https://www.oecd-nea.org/upload/docs/application/pdf/2021-03/7560_smr_report.pdf )

[11] "The concept of standardized reactor designs does not require units to be completely identical. Rather all units that use the standardized design technology should at least share the same global architecture and the same specifications for the nuclear steam supply system design and components, and associated safety systems" WNA 2015

A key advantage of integral SMR designs is that their reactor modules and primary safety systems are engineered to meet this standardization definition. Additional design features such as underground deployment and seismic isolation systems further enhance replication potential, reducing the need for extensive site-specific modifications. This is particularly valuable for regions with seismic activity or environmental constraints, as it enhances design repeatability and construction efficiency across multiple deployment sites.

Further enhancements to standardization can be achieved by incorporating Commercial Off-The-Shelf (COTS)[12] components, reducing reliance on custom-built parts and ensuring supply chain continuity. This strategy simplifies procurement, component certification, and regulatory approvals, fostering greater industrial scalability and lower capital costs for future SMR deployments.

As SMRs transition from design finalization to demonstration and commercial deployment, the early involvement of the nuclear supply chain will be essential in supporting the standardization process. Collaboration between vendors, regulatory bodies, and industry stakeholders will enable the development of consistent manufacturing practices, harmonized regulatory frameworks, and optimized supply chain logistics.

For Serbia's nuclear strategy, standardization in SMR design presents a compelling opportunity to enhance construction predictability, lower costs, and accelerate deployment schedules. By adopting a standardized SMR model with harmonized safety and regulatory approvals, Serbia can leverage global best practices, integrate into international supply chains, and streamline its nuclear licensing framework for efficient implementation of SMR technology.

### Fuel Cycle Strategies for LWR-SMRs

The importance of fuel cycle strategies in determining the long-term viability, sustainability, and economic competitiveness of Light Water Reactor Small Modular Reactors (LWR-SMRs). These reactors are designed to integrate seamlessly into existing nuclear fuel cycle infrastructures, ensuring compatibility with conventional uranium enrichment, fabrication, and reprocessing strategies. This compatibility allows LWR-SMRs to leverage established fuel supply chains, reducing regulatory complexity and ensuring reliable fuel procurement.

LWR-SMRs typically operate with uranium enrichment levels below 5%, aligning with current commercial enrichment and fabrication capabilities. This ensures that fuel supply remains consistent with existing industrial processes, facilitating easier market entry and streamlined regulatory approval. Additionally, the fuel types and assembly designs in LWR-SMRs are similar to those used in conventional large LWRs, which supports efficiency in manufacturing and cost-effective supply chain integration.

In nations with established closed fuel cycle strategies, LWR-SMRs offer the potential for spent fuel reprocessing, enabling fuel sustainability through the reuse of fissile material. While some developers have considered MOX (Mixed Oxide) fuel utilization for LWR-SMRs, this remains a long-term option rather than an immediate deployment priority. Most reactor designs continue to prioritize traditional uranium fuel cycles, ensuring a stable and widely available supply.

A key differentiating factor of some LWR-SMRs is their potential for extended refueling cycles compared to conventional LWRs, provided the designs adopt strategies such as higher uranium enrichment levels (above 5%), advanced burnup techniques, or innovative core configurations. For current LWR-SMR concepts maintaining enrichment levels below 5%, refueling cycles remain broadly consistent with traditional large LWRs unless supported by alternative strategies like increased fissile loading or optimized fuel utilization. This distinction is crucial in evaluating the applicability of LWR-SMRs to Serbia's fuel cycle and regulatory environment..

[12] IAEA IAEA-TECDOC-2034

Certain reactor designs, such as floating SMRs, have explored higher enrichment levels, with Russian floating SMRs utilizing enrichment levels close to 20%. While this presents potential advantages in extending fuel cycles and improving energy density, it also introduces additional regulatory and non-proliferation considerations, requiring stringent oversight. Other advanced LWR-SMR designs may optimize fuel performance by incorporating higher burnup strategies, alternative fuel materials, and reactor operation cycle extensions to improve overall fuel utilization efficiency.

### Spent Fuel and Waste Management: A Forward-Thinking Approach

Spent nuclear fuel and waste management are critical components of Serbia's long-term nuclear energy strategy. While Small Modular Reactors (SMRs) generate smaller total volumes of nuclear waste per reactor unit, their fuel cycle management must be carefully evaluated because some designs may produce higher volumes of waste per megawatt of installed capacity (MWe) due to their lower thermal efficiency. This factor highlights the need for optimized fuel strategies and waste minimization approaches when considering SMR deployment.

One of the most effective models for high-level waste disposal is the use of deep geological repositories (DGRs), successfully implemented in Finland, Sweden, and France. These repositories provide a permanent, secure solution for the disposal of high-level radioactive waste, and their methodologies can serve as a reference for Serbia's waste strategy. Additionally, some emerging SMR designs are exploring fuel recycling and waste reduction technologies, which could further optimize the country's approach to long-term sustainability and environmental impact minimization.

To establish a comprehensive waste management framework, Serbia's nuclear program must carefully evaluate spent fuel storage solutions, interim disposal facilities, and long-term geological repository development. This will require detailed feasibility assessments, policy alignment with EU standards, and potential collaborations with international partners for knowledge exchange and technology transfer. Furthermore, Serbia may explore fuel reprocessing strategies that are economically and environmentally viable, ensuring that its nuclear energy program remains sustainable, secure, and aligned with the highest global safety standards.

### Potential Challenges and Considerations for SMR Deployment

While SMRs offer numerous advantages, their **deployment is still in the early stages globally**, with **limited operational experience and relatively few commercial construction projects completed**. Serbia must carefully consider the following **challenges and mitigation strategies** to ensure a **smooth and successful** SMR implementation:

- **Regulatory and Licensing Uncertainty:** Unlike large reactors, which have established licensing pathways, SMRs require new regulatory frameworks to address their novel design features, modular deployment approach, and integrated safety systems.
- **Limited Operational Experience:** Most SMR designs remain in development or early-stage construction, with only a few operational reactors worldwide (such as Russia's floating power plants and China's demonstration units). Without extensive operational data, there are still uncertainties regarding long-term performance, maintenance strategies, and real-world cost savings.
- **Supply Chain and Localization Challenges:** Given their relatively low production volume, SMRs have yet to develop the fully established supply chains that conventional reactors benefit from. Many critical components are still sourced from a limited number of vendors, creating potential risks in procurement, lead times, and cost predictability. Serbia should evaluate **localization opportunities** to support domestic manufacturing and workforce development, reducing dependency on external suppliers.

- **Cost Competitiveness and Financing Risks:** While SMRs promise lower upfront capital costs than large reactors, their per-MWe cost is still higher due to a lack of economies of scale. Many first-of-a-kind (FOAK) projects are facing cost overruns and schedule delays, making financial feasibility an important consideration.
- **Grid Integration and Energy Market Adaptation:** The flexibility of SMRs in load-following and hybrid energy systems is a major advantage, but existing grid infrastructure may require upgrades to fully integrate SMR capabilities.
- **Technology Readiness and Construction Risk:** While modular construction is a key selling point for SMRs, many vendors claim shorter construction timelines using modular assembly, but real-world execution remains unproven at scale.
- **Spent Fuel Management and Waste Disposal:** SMRs produce less nuclear waste per unit, but their fuel cycle strategies differ depending on the reactor type (PWR, fast neutron reactors, molten salt, etc.).
- **Cybersecurity and Digitalization:** As SMRs rely on advanced digital control systems, cybersecurity threats become a major concern. Ensuring robust digital protection against cyber intrusions, hacking risks, and data integrity attacks will be essential for maintaining operational security. This includes IAEA-recommended cybersecurity frameworks and continuous threat monitoring protocols.

### 4•4•3• Why SMRs Are Suitable for Serbia?

Serbia's pursuit of nuclear energy is driven by the need for energy security, decarbonization, and economic sustainability. While Large Nuclear Power Plants (LNPPs) offer high power output and proven operational experience, their high capital costs, long construction timelines, and grid integration challenges present significant barriers. Small Modular Reactors (SMRs) emerge as a compelling alternative, addressing these challenges while enhancing flexibility, cost-effectiveness, and deployment efficiency.

SMRs offer a scalable, modular, and innovative nuclear energy solution that aligns with Serbia's grid capacity, financial investment capabilities, and future energy policy goals. With the potential to replace aging coal plants, integrate with renewables, and support industrial applications, SMRs provide an adaptive and future-proof energy strategy for Serbia.

In alignment with Serbia's long-term energy transition strategy, this assessment has focused on larger Small Modular Reactors (SMRs) typically in the 300 MWe class or higher as these technologies are best positioned to meet the country's near-term needs for centralized, low-carbon baseload power. Serbia's electricity system is characterized by a moderate-sized but integrated national grid, which requires replacement solutions that can provide stable output and compatibility with existing transmission infrastructure. Furthermore, the country is committed to phasing out aging coal-fired power plants, many of which operate in the 300–600 MWe range. Larger SMRs are uniquely suited to serve as one-to-one or modular replacements for these units, offering a low-carbon alternative with flexible deployment timelines and proven scalability.

While smaller-capacity SMRs and microreactors offer exciting potential for niche or off-grid applications, the current focus reflects Serbia's ambition to pursue grid-connected nuclear capacity that contributes meaningfully to national baseload generation, industrial resilience, and decarbonization targets. Future phases may explore a wider range of SMR sizes and configurations depending on evolving needs and deployment scenarios. However, the current selection of larger-capacity SMRs aligns with Serbia's strategic priorities, energy security objectives, and realistic implementation pathway.

#### 4•4•3•1• Key Advantages of SMRs for Serbia – A Brief Overview

**✦ Grid Compatibility and Decentralized Energy Production**

SMRs (50–300 MWe) can be seamlessly integrated into Serbia's existing coal-fired and hydroelectric power grid without requiring extensive upgrades. Their modularity allows for incremental expansion, reducing grid instability and enabling regional energy resilience through decentralized deployment.

**✦ Cost-Effectiveness and Financial Feasibility**

SMRs offer lower initial investments compared to large reactors, allowing for phased deployment and reduced financial risk. Their factory-built modular components shorten construction timelines (3-4 years vs. 8-12 years for large reactors), while streamlined production and economies of scale will further reduce long-term costs.

**✦ Coal Replacement and District Heating Applications**

SMRs like NUWARD, BWRX-300, and Rolls-Royce SMR are designed to support the replacement of aging coal plants by utilizing existing infrastructure such as grid connections, cooling systems, and licensed brownfield sites. These reactors can effectively provide electricity and support district heating or low- to moderate-temperature industrial steam, helping decarbonize local energy systems. However, as light water reactor (LWR) designs, their thermal output is generally limited to temperatures below 300°C, making them unsuitable for high-temperature process heat applications such as hydrogen production or certain industrial chemical processes

**✦ Load-Following Capabilities for Renewables**

SMRs can rapidly adjust power output, complementing renewable energy fluctuations without requiring expensive energy storage. Their hybrid compatibility with solar, wind, and hydro enhances grid stability and supports Serbia's decarbonization targets.

**✦ Advanced Safety and Regulatory Alignment**

SMRs incorporate passive and active safety systems, ensuring safe operation even during external disruptions. Their smaller reactor cores and advanced accident prevention measures align with IAEA and EU safety standards, facilitating a smoother regulatory approval process.

**✦ Energy Security and Geopolitical Flexibility**

SMRs provide Serbia with access to a diverse range of international technology partnerships (including France, USA, UK, South Korea, China, and Russia), offering potential flexibility in procurement models, reactor sizes, and deployment timelines. While conventional large-scale nuclear power plants (LNPPs) also offer multiple vendor options, SMRs are typically designed with standardized modular units, which may enable a more distributed and diversified supply chain across multiple countries. This modularity could reduce dependence on a single geopolitical supplier.

While the SMR market is still emerging and several technologies remain in licensing or FOAK (First-of-a-Kind) phases, this also presents an opportunity for Serbia to engage early, shape vendor localization strategies, and participate in the development of a new generation of nuclear infrastructure. With these advantages, SMRs offer Serbia a potentially more flexible, scalable, and future-facing nuclear solution, aligned with long-term sustainability, energy security, and industrial competitiveness goals.

### 4•4•4• Assessment of Technology Options for SMRs

#### 4•4•4•1• Introduction

Small Modular Reactors (SMRs) have emerged as a strategic option for energy diversification, providing scalable, low-carbon, and flexible solutions tailored to Serbia's evolving energy needs. Small Modular Reactors (SMRs) offer modularity, passive safety features, and simplified deployment models, characteristics that make them particularly suited to Serbia's grid structure, site flexibility, and phased decarbonization objectives.

In the **Technology Selection Assessment Phase**, a broad range of **SMR designs were evaluated**, covering **Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) concepts**. Following rigorous screening based on **technical maturity, economic feasibility, regulatory readiness, and deployment adaptability**, the **Technology Assessment Committee** has shortlisted five (5) leading SMR technologies for further evaluation in **Pre-Phase 1 Technology Assessment:**

- NUWARD (France) – A European SMR designed by EDF with a focus on scalability, low-carbon electricity, and compliance with EU regulatory frameworks. [Chapter 6.5]
- BWRX-300 (USA) – A cost-effective boiling water SMR developed by GE-Hitachi, featuring simplified construction and advanced operational efficiency. [Chapter 6.6]
- Rolls-Royce SMR (UK) – A UK-backed modular SMR leveraging standardized factory production and rapid deployment methodologies. [Chapter 6.7]
- AP300 (USA) – A scaled-down variant of the AP1000, emphasizing passive safety, modularity, and grid adaptability. [Chapter 6.8]
- Holtec SMR-300 (USA) – A highly secure, passive safety-focused design featuring Walk-Away Safe™ technology and rapid construction timelines. [Chapter 6.9]

Each selected technology offers distinct advantages and potential deployment pathways for Serbia, considering factors such as **grid stability, phased investment feasibility, licensing adaptability, and local supply chain integration.**

While none of the shortlisted SMR technologies currently have operational reference units, the assessment does not treat this as a primary readiness indicator due to the emerging nature of the SMR market. Instead, the evaluation emphasizes other key factors that better reflect deployment viability, such as licensing status particularly alignment with EU regulatory frameworks supply chain integration, and the presence of industrial partnerships with manufacturing capacity.

The assessment also considers First-of-a-Kind (FOAK) project maturity, including evidence of siting, client engagement, and concrete project timelines. For instance, BWRX-300 is under active development at the Darlington site in Canada, while Holtec's SMR-300 is linked to the Palisades reactivation project in the USA. In contrast, other vendors such as Rolls-Royce and NUWARD are at earlier stages with no announced deployment site. These factors will continue to inform Serbia's phased evaluation and risk mitigation approach.

U.S.-based SMR vendors are subject to export control requirements under 10 CFR Part 810, which governs the transfer of certain nuclear technologies and technical assistance from the United States to foreign entities. While this regulation introduces a formal review and authorization process, particularly for countries not listed under the "generally authorized" destinations, it is a well-established and routinely managed procedure for U.S. vendors.

For Serbia, this would mean that vendors such as GE Hitachi, Westinghouse, and Holtec would need to obtain a specific Part 810 authorization from the U.S. Department of Energy for the transfer of certain technical data. However, this requirement is commonly integrated into project planning, and recent international SMR projects including those in Canada and Poland have successfully progressed through this process without major delays.

As such, while Part 810 considerations should be factored into early engagement and procurement timelines, **they are not viewed as a barrier to U.S. SMR deployment in Serbia**. Vendors are highly experienced in navigating this regulatory framework, and early coordination will ensure that the necessary approvals are obtained in a timely and coordinated manner.

## 4•4•5• NUWARD: A Next-Generation Small Modular Reactor

### 4•4•5•1• Introduction

The NUWARD SMR, developed by EDF and its industrial partners, represents a strategic evolution in European nuclear technology, designed to enhance energy security, decarbonization, and industrial heat applications. The reactor's latest design iteration features a single-reactor configuration delivering 400 MWe, with an option for cogeneration of up to 100 MWth of heat, supporting district heating, industrial applications, and hydrogen production.

As part of its ongoing design refinements, NUWARD has shifted its focus to proven technologies, optimized manufacturing, and a modular construction approach to reduce costs and deployment risks. The Technology Assessment Committee (TAC) has assessed NUWARD's potential relevance for Serbia, considering its technical advancements, licensing strategy, and alignment with European regulatory frameworks.

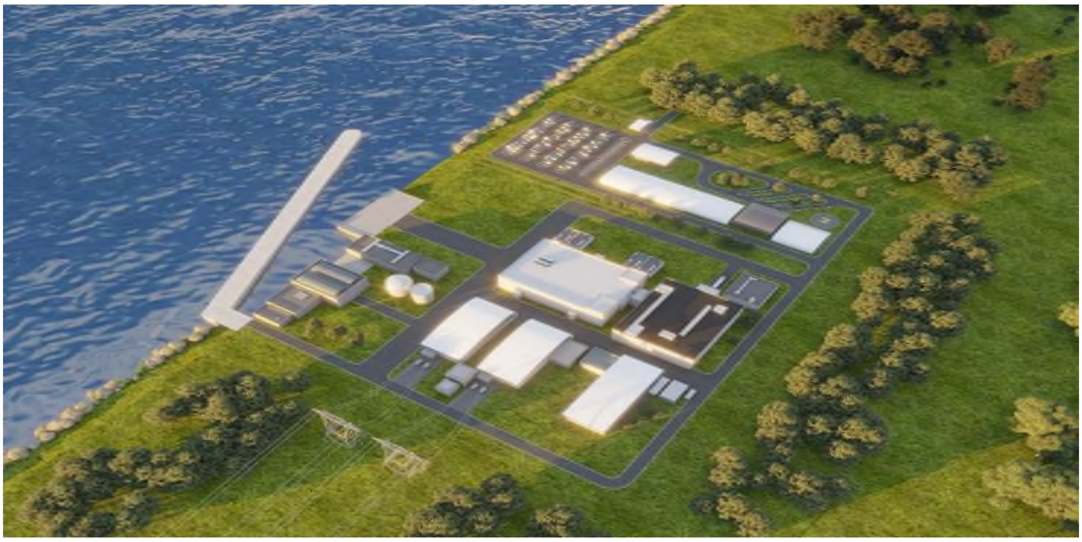

Figure 121214: Layout of NUWARD SMR[13]

| Parameter | Description |
|---|---|
| Reactor Type | Pressurized Water Reactor (PWR) |
| Electrical Output | 400 MWe |
| Thermal Output | Up to 1,000 MWth, supporting cogeneration (district heating, industrial steam, hydrogen production) |
| Core Coolant | Light water ($H_2O$) |
| Cooling Method | Configurable open or semi-closed cooling towers for site-specific adaptability |

[13] Source: NUWARD

| Parameter | Description |
|---|---|
| Primary Circuit | Two-loop design, each with steam generator, pressurizer, and primary pump, ensuring redundancy |
| Fuel Type | Standard $UO_2$ PWR fuel, <5% enrichment, with potential for 24-month fuel cycle |
| Containment Type | Pre-stressed concrete containment for enhanced safety and impact resistance |
| Safety Architecture | Active safety systems with redundant cooling circuits, boron-free core design, hydrogen recombiners, and core catcher |
| Load-Following Capability | Power variation from 25% to 100%, allowing seamless integration with renewables |
| Seismic Design | Designed for 0.3g Safe Shutdown Earthquake (SSE) compliance |
| Grid Compatibility | 50 Hz & 60 Hz compatible, supporting international deployment |
| Refueling Interval | 24 months, optimizing uptime and minimizing operational downtime |
| Expected Availability | >92% operational capacity factor, ensuring reliable baseload power |
| Deployment Timeline | FOAK deployment expected post-2030, following design finalization and regulatory approval |
| Modular Construction Approach | Factory-built components with prefabrication for reduced on-site assembly time |
| Spent Fuel Management | Designed for compatibility with existing European fuel cycle infrastructure and reprocessing |

Table 778: Key Technical Parameters of NUWARD SMR[14]

#### 4•4•5•2• Pros and Cons

NUWARD integrates proven reactor technologies, modular construction efficiencies, and enhanced safety features, positioning it as a strategic option for Serbia's energy transition. The Technology Assessment Committee (TAC) acknowledges NUWARD's strong European backing, regulatory harmonization efforts, and potential for local economic benefits, particularly in industrial job creation and workforce development, as demonstrated by EDF's experience with large-scale nuclear projects such as Hinkley Point C[15].

However, TAC highlights several deployment risks, including first-of-a-kind (FOAK) licensing challenges, high capital costs, and cooling system constraints. The following table outlines NUWARD's key advantages and challenges from both technical and non-technical perspectives.

[14] Source: IAEA ARIS and NUWARD
[15] https://www.burnham-on-sea.com/news/3000-new-jobs-to-be-created-at-hinkley-point-c-as-it-hits-peak-construction/

| Category | Advantages | Issues and Challenges |
|---|---|---|
| Technology Issues | Modular and Prefabricated Construction – Factory-based pre-assembly reduces on-site construction risks and cost overruns. | First-of-a-Kind Deployment Risk – No operational reference unit exists; first FOAK planned for France. |
| | Established PWR Technology – Uses proven components from the EPR2 supply chain, ensuring regulatory familiarity. | Transition from Passive to Active Safety – Earlier passive safety concepts were replaced, requiring adaptation to existing regulatory reviews. |
| | Two-Loop Primary System – Ensures redundancy and optimized heat transfer, improving efficiency and safety margins. | Seismic and Cooling Adaptability – Modifications may be required for deployment in high-seismic zones or arid regions, potentially increasing infrastructure costs. |
| | Load-Following and Cogeneration Flexibility – Power output can vary from 25% to 100%, allowing integration with renewables and industrial heat applications. | Cooling System Requirements – Water-based cooling systems may require semi-closed configurations, increasing infrastructure needs. |
| | Long Refueling Interval (24 months) – Reduces operational downtime, ensuring high availability. | Waste Management Strategy Needs Further Definition – Spent fuel storage and reprocessing alignment with Serbia's policies must be assessed. |

| Category | Advantages | Issues and Challenges |
|---|---|---|
| Non-Technical Issues | Strong European Backing – Supported by EDF, Framatome, and the EU energy ecosystem, reinforcing supply chain stability. | High Initial CAPEX (~€80–100/MWh electricity cost[16]) – May require structured financing or public-private partnerships. |
| | Proven Localization and Job Creation Track Record – EDF has demonstrated successful local workforce integration and economic benefits through projects. | Serbia's Future Regulatory Adaptation Required – Licensing alignment with Serbia's framework needs further study. |
| | Eligible for EU Energy Transition Funding – NUWARD aligns with European nuclear investment policies, increasing financing options. | Public Perception and Nuclear Acceptance – Requires strong public engagement and policy support to ensure project approval. |
| | Heat Production for Industrial Use (150–280°C) – Supports district heating, hydrogen production, and industrial steam needs. | FOAK Deployment Costs May Vary – Until real-world cost data from the first deployment is available, financial risk remains. |

[16] https://sfeninenglish.org/nuward-new-smr-design/

| Category | Advantages | Issues and Challenges |
|---|---|---|
| | Targeted Standardization for Serial Production – Designed for mass production, reducing costs over time. | |

**Table 88~~9~~: NUWARD Advantages and Challenges**

### 4•4•5•3• Strategic Recommendation

The NUWARD SMR offers a versatile and modern nuclear technology option for Serbia, characterized by its innovative modular design, advanced safety systems, and compatibility with renewable energy integration.

A structured technical validation program should be implemented (Phase 1) to verify the claims made about NUWARD's modular construction and safety features, possibly by reviewing operational data from similar reactor designs or early adopters. Additionally, conducting a detailed feasibility and localization study will determine the capacity of Serbia to integrate local suppliers, workforce, and infrastructure into the NUWARD project, thereby maximizing economic benefits and promoting local job creation.

From a financial perspective, addressing the high initial capital expenditure is crucial. Exploring financing options such as European Union grants, loans, and potential public-private partnerships could provide Serbia with viable funding solutions. Moreover, establishing long-term knowledge transfer and workforce development strategies in collaboration with EDF will enhance Serbia's nuclear expertise and ensure operational efficiency. However, the experiences from other regions, like the UAE's Barakah nuclear plant, underscore the importance of developing a robust operator training program early to avoid delays and ensure smooth project execution.

Finally, Serbia must assess necessary grid integration measures to accommodate NUWARD's load-following capabilities, ensuring the reactor can operate efficiently within Serbia's evolving energy grid. By addressing these strategic recommendations comprehensively, Serbia can enhance its nuclear infrastructure planning and position NUWARD as a sustainable and efficient solution for its future energy needs.

### 4•4•5•4• Conclusion

NUWARD represents a technologically sophisticated and operationally flexible nuclear power solution that aligns with Serbia's long-term goals for energy security and decarbonization. With its roots in modern European nuclear technology and its strong emphasis on safety and environmental sustainability, NUWARD stands as a forward-thinking option in nuclear energy. The reactor's advanced design features contribute to its attractiveness as a cutting-edge solution in the nuclear sector.

However, areas such as licensing, technical validation, and financial structuring demand meticulous planning and proactive management before any deployment decisions can be finalized. The lack of pre-existing regulatory approvals and the initial high financial outlay represent challenges that need structured responses, including engaging with regulatory authorities and securing adequate funding.

Despite these challenges, the NUWARD SMR maintains significant appeal due to its high safety standards, operational flexibility, and potential for significant local industrial participation. With dedicated regulatory engagement, strategic financial planning, and committed knowledge transfer initiatives, Serbia can effectively incorporate NUWARD technology into a robust, sustainable, and future-ready nuclear infrastructure program.

### 4•4•6• BWRX-300 - GE Hitachi's Small Modular Reactor (SMR)

Figure 131315: Layout

The BWRX-300 is a significant evolution within the domain of nuclear reactors, especially in its technical design that combines practical engineering, safety, and economic efficiency. Developed by GE Hitachi, the BWRX-300 leverages the technology foundations laid by the Economic Simplified Boiling Water Reactor (ESBWR), focusing on simplifying the design and minimizing the operational complexity which, in turn, enhances its economic attractiveness and safety margins.

| Parameter | Description |
|---|---|
| Reactor Type | Boiling Water Reactor (BWR) |
| Capacity | 300 MWe (MegaWatt electrical) |
| Core Coolant | H2O (Water) |
| Cooling Method | Natural Circulation |
| Primary Circulation | Natural, no pumps required |
| Fuel Type | Low enriched Uranium (3-5% U-235) oxide fuel in metal cladding |
| Containment Type | Single |

| Parameter | Description |
|---|---|
| Design Life | 60 years |
| Refueling Cycle | 12 - 24 months, depending on operational strategy |
| Safety Systems | Multiple passive safety systems including an Isolation Condenser System (ICS) |
| Operational Availability | Designed for a lifetime capacity factor of 95% |
| Seismic Design | Safe-Shutdown Earthquake (SSE) level at 0.3g |
| Emergency Planning Zone (EPZ) | Targeting minimization to site boundary through enhanced safety measures |
| Licensing Status | Ongoing in multiple countries including the U.S (Construction Permit Application) ., Canada (PSAR Submitted), UK (GDA Initiated), and others |
| Passive Safety Features | Capable of maintaining safety functions without power or human intervention for extended periods |
| Major Outages | Planned for every 12-24 months for refueling and maintenance |
| Innovative Features | Simplified design to reduce construction materials and streamline maintenance |
| Fuel Handling | Designed for ease of assembly and disassembly, supporting efficient refueling processes |
| Number of Fuel Assemblies | Approximately 240 fuel assemblies, consisting of a mix of full-length and part-length fuel rods |

**Table 99~~10~~: BWRX-300 Technical Parameters and Description Table**[17]

### 4•4•6•1• Pros and Cons

The BWRX-300, designed by GE Hitachi, offers a compelling proposition. This Small Modular Reactor (SMR) blends advanced nuclear technology with the practicalities required for modern energy systems, aligning well with Serbia's energy strategy. This section provides a detailed examination of the advantages and disadvantages of deploying the BWRX-300 in Serbia, focusing on how it meets the country's specific energy needs and challenges.

[17] Source: ARIS IAEA

| Category | Advantages | Issues and Challenges |
|---|---|---|
| Technology Issues | Passive Safety Design – Requires no operator intervention, ensuring high safety and reliability. | High Initial Capital Costs – Significant investment required, necessitating structured financing models. |
| | Modular Construction – Enables flexible deployment and phased investments. | Regulatory Uncertainty – Strict licensing requirements may extend deployment timelines. |
| | High Operational Availability (>95%) – Provides reliable baseload power. | Seismic Adaptability Concerns – Site-specific modifications may increase engineering complexity. |
| | Near-Zero Emissions – Aligns with Serbia's decarbonization goals. | High Water Consumption – Deployment in arid areas may require costly alternative cooling solutions. |
| | Cybersecurity & Control Enhancements – Advanced digital protection measures. | Hydrogen Risk Assessment Required – Hydrogen accumulation studies need further validation. |
| | Load-Following Capability – Can adjust power output to complement renewables. | Skill Development & Workforce Training – Requires significant investment in technical expertise. |
| Non-Technical Issues | Economic Growth & Job Creation – Boosts local workforce in construction, operation, and maintenance. | Knowledge Transfer & Training Costs – Significant investment required for workforce development. |
| | International Collaboration Potential – Opens doors for government incentives and global partnerships. | Economic Competitiveness – High initial costs may challenge competitiveness with other energy sources. |
| | Public Engagement & Transparency – Supports community involvement and nuclear awareness. | Logistical Challenges – Large module transportation and infrastructure constraints could be limiting factors. |
| | Alignment with Environmental Goals – Meets Serbia's safety and sustainability commitments. | Long-Term Waste Management Considerations – Spent fuel disposal requires structured policy planning. |
| | Project Advancing Toward Deployment – Demonstration at Darlington supports commercialization. | Supply Chain Readiness – Local manufacturing and supply chain development strategies need to be assessed. |

### 4•4•6•2• Strategic Recommendation

The Technology Assessment Committee (TAC) recognizes that the BWRX-300 presents an advanced, cost-effective, and modular SMR solution, potentially aligning with Serbia's long-term energy security and decarbonization goals. However, as a first-of-a-kind (FOAK) reactor, its real-world deployment, cost efficiency, and operational performance require further assessment before Serbia commits to its integration into the national energy framework.

## Key Strategic Focus Areas for Serbia

### ✦ Validation of Factory-Built Modularity and Deployment Strategy[18]

The BWRX-300's design relies on an estimated 90% modular factory-built approach, aiming to drastically reduce on-site construction time and costs. However, real-world validation of this claim remains limited, as no BWRX-300 unit has yet been commissioned. Serbia must conduct further assessments with GE Hitachi and monitor global pilot projects, particularly the Darlington SMR project in Canada, to confirm whether this manufacturing approach will yield the intended CAPEX and deployment efficiencies.

### ✦ Regulatory Licensing and Compliance Alignment

BWRX-300 is advancing through regulatory licensing in multiple jurisdictions, including the Nuclear Regulatory Commission (NRC) in the U.S. and the Canadian Nuclear Safety Commission (CNSC) in Canada. Given that Serbia will need to establish its nuclear regulatory framework in accordance with IAEA and European Utility Requirements (EUR), aligning with these ongoing licensing efforts could facilitate a smoother regulatory adaptation process. Early collaboration with GE Hitachi and regulatory bodies will help identify potential licensing hurdles and determine how the BWRX-300 can comply with Serbia's nuclear safety requirements.

### ✦ Financing Mechanisms and Investment Strategies

Positioning it as a cost-competitive nuclear solution. However, securing investment remains a key factor in determining feasibility. Serbia should explore financing options such as EU energy transition funds, vendor-backed investment models, and public-private partnerships (PPP). Additionally, leveraging export credit agencies and international lending institutions, such as the European Investment Bank (EIB) or the World Bank, could help mitigate initial financial risks and ensure project sustainability.

### ✦ Supply Chain and Localization Potential

The BWRX-300's modular approach presents an opportunity for local industrial involvement, potentially boosting Serbia's manufacturing, assembly, and operational workforce capabilities. Serbia must assess whether its industrial sector can support component fabrication, site preparation, and reactor maintenance. Engagement with local suppliers, universities, and training institutions will be necessary to develop a skilled workforce, ensuring that the long-term operational requirements of the BWRX-300 can be met domestically.

### ✦ Operational Performance and Grid Integration

The BWRX-300 is designed with load-following capabilities, allowing integration with Serbia's growing renewable energy sector. Further grid compatibility studies must assess how the reactor's flexible output (from 25% to 100% power capacity) aligns with Serbia's energy demand and transmission infrastructure. The availability of cooling water resources and potential deployment in water-scarce regions should also be analyzed, given that BWRX-300's default cooling method relies on water circulation

[18] Source: https://small-modular-reactors.org/ge-hitachi-nuclear-energy-bwrx-300/

#### 4•4•6•3• Conclusion

The BWRX-300 represents one of the most advanced small modular reactor technologies under development, leveraging simplified design, passive safety features, and modular construction techniques to reduce deployment time and capital costs. As a technology based on the well-established Boiling Water Reactor (BWR) platform, the BWRX-300 is uniquely positioned as a scalable and commercially attractive nuclear power solution.

For Serbia, the BWRX-300 aligns with national energy goals, providing a flexible, grid-responsive nuclear option that can enhance energy security while supporting decarbonization policies. The reactor's compatibility with renewable energy sources further strengthens its role as a stabilizing baseload provider.

However, as a first-of-a-kind (FOAK) technology, its deployment timeline, financial feasibility, and supply chain localization require further validation. The Technology Assessment Committee (TAC) recommends continued engagement with GE Hitachi, monitoring the performance of early BWRX-300 deployments in Canada and Poland, and conducting in-depth Phase 1 feasibility studies to confirm its suitability for Serbia.

### 4•4•7• Rolls-Royce SMR

The Rolls-Royce Small Modular Reactor (SMR) is a 470 MWe pressurized water reactor (PWR) designed to provide a cost-effective, modular, and scalable nuclear power solution. Developed by Rolls-Royce SMR Ltd. (UK), this reactor leverages proven Gen III+ nuclear technology to deliver low-carbon, reliable baseload power, aligning with Serbia's long-term energy security and decarbonization goals.

The Rolls-Royce SMR offers a factory-manufactured, road-transportable design, reducing construction time and overall project risk. The reactor is designed for multi-use applications, including electricity generation, industrial heat, hydrogen production, and district heating, making it adaptable for Serbia's energy diversification strategy.

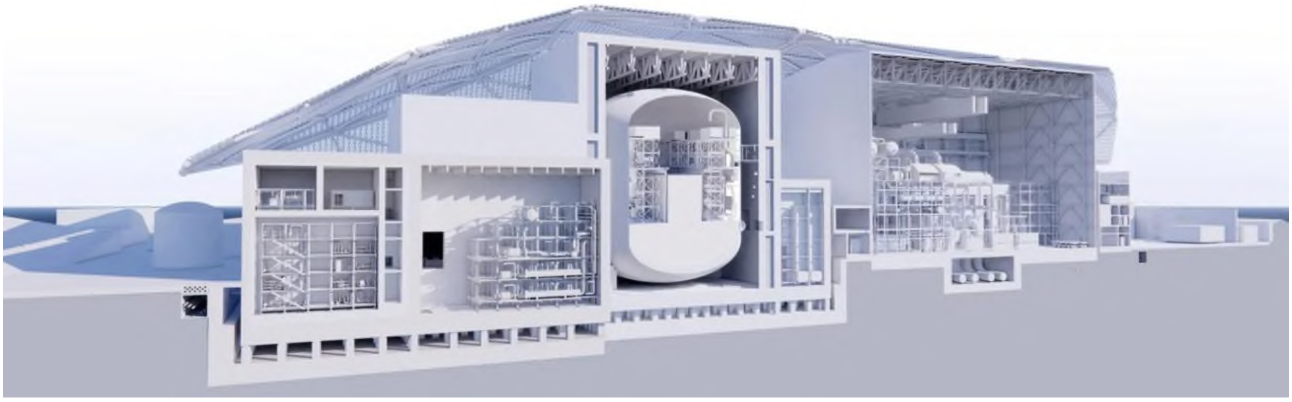

**Figure 141416: SMR LAYOUT[19]**

#### 4•4•7•1• Technical Features of Rolls-Royce SMR

| Parameter | Description |
|---|---|
| Reactor Type | Pressurized Water Reactor (PWR) |
| Capacity | 470 MWe (MegaWatt electrical) |
| Core Coolant | $H_2O$ (Water) |
| Cooling Method | Indirect Cooling System |
| Primary Circulation | Forced circulation with 3 reactor coolant pumps |
| Fuel Type | Standard 17x17 $UO_2$ fuel assemblies with 4.95% enrichment |
| Containment Type | Single robust containment |
| Design Life | 60 years |

[19] Source: https://gda.rolls-royce-smr.com/our-technology

| Parameter | Description |
|---|---|
| Refueling Cycle | 18 - 24 months, depending on operational strategy |
| Safety Systems | Passive and active safety systems, including gravity-driven cooling and emergency core cooling |
| Operational Availability | Designed for a lifetime capacity factor of 95%+ |
| Seismic Design | Aseismic bearings to insulate reactor from seismic events |
| Emergency Planning Zone (EPZ) | Designed to minimize EPZ to the site boundary through enhanced safety measures |
| Licensing Status | Undergoing UK Generic Design Assessment (GDA), with discussions in Canada, EU, and other markets |
| Passive Safety Features | Features gravity-driven cooling and natural convection for core heat removal |
| Major Outages | Planned for every 18-24 months for refueling and maintenance |
| Innovative Features | Factory-fabricated, road-transportable modules for efficient assembly and cost reduction |
| Fuel Handling | Standard PWR fuel handling, designed for ease of assembly and disassembly |
| Number of Fuel Assemblies | Approximately 150 fuel assemblies, using standard PWR fuel configurations |

**Table 101011: Technical Parameters of Rolls-Royce SMR**

### 4•4•7•2• Pros and Cons

The Rolls-Royce Small Modular Reactor (SMR) offers a next-generation nuclear power solution, emphasizing modularity, cost efficiency, and rapid deployment. With its factory-based production model, the design aims to lower construction risks and reduce capital costs, making it a competitive option for Serbia's nuclear expansion. However, as with any new technology, challenges exist, including regulatory uncertainty, supply chain complexities, and financing considerations.

The following Pros and Cons Table categorizes the key advantages and challenges associated with Rolls-Royce SMR under technical and non-technical aspects, helping decision-makers evaluate its suitability for Serbia's energy strategy.

| Technology Issues | Advantages | Issues and Challenges |
|---|---|---|
| Advanced Safety Systems | Features **passive cooling, boron-free operation, and in-vessel retention**, minimizing accident risks. | First-of-a-kind design may face **regulatory delays** in global markets. |

| Technology Issues | Advantages | Issues and Challenges |
|---|---|---|
| Modular Construction & Deployment | **Up to 95% factory-built**, reducing construction risks and enabling **faster deployment**. | **Limited global experience** with factory-based nuclear production, potential learning curve. |
| Grid Compatibility & Load-Following | **Compatible with 50 Hz grids**, designed for **load-following** and renewable integration. | Load-following may require **additional grid infrastructure investment** in Serbia. |
| High Energy Efficiency | Designed for **over 90% availability**, ensuring **stable and reliable baseload power**. | **Long lead times for first deployment** due to regulatory approval and licensing processes. |
| Scalability & Site Adaptability | Suitable for **multi-unit deployment**, adaptable for industrial and urban energy hubs. | **Cooling system dependency** may require access to large water sources. |
| Standardized Fuel Supply | Uses **conventional $UO_2$ fuel (4.95% enriched)**, ensuring **fuel security** through existing suppliers. | **Spent fuel management** and waste disposal require clear policy and infrastructure. |

| Non-Technical Issues | Advantages | Issues and Challenges |
|---|---|---|
| Economic Viability | Lower CAPEX and competitive LCOE compared to traditional reactors. | **High initial investment** still required, financing may be challenging for smaller nations. |
| Global Market Expansion | Interest from **Czech Republic, Canada, Finland, Sweden, and Ukraine**, demonstrating international confidence. | **No commercial unit deployed yet**, making real-world performance unverified. |
| Supply Chain Resilience | UK-based **industrial supply chain ensures stable component availability** for serial production. | **Localization challenges** in Serbia if local industries are not integrated early or Technology provider can keep some criteria. |
| Job Creation & Workforce Development | Potential for **local workforce training and nuclear expertise transfer**. | **Longer-term operator training** needed, increasing project costs. |
| Government & Private Investment | Backed by **UK government and private investors**, enhancing financial security. | **Export limitations & geopolitical risks** may affect long-term procurement strategies. |
| Environmental & Carbon Reduction Benefits | **Zero-carbon power generation**, aligns with Serbia's **clean energy and EU decarbonization targets**. | **Public perception & nuclear opposition** may require proactive community engagement. |

#### 4•4•7•3• Strategic Recommendation

The Technology Assessment Committee (TAC) conducted an independent evaluation of the Rolls-Royce SMR based on publicly available data, GDA assessment reports, and official statements from the technology provider (Technology Provider website). However, due to the lack of direct engagement with the technology provider and the absence of operational demonstration units, several key claims require further validation in the next phase of the assessment.

One of the most significant claims made by Rolls-Royce SMR is its "*95% factory-built modularity*," which is a key driver for reducing construction costs, minimizing site risks, and accelerating deployment timelines. While this claim is fundamental to the project's feasibility, there is no currently available operational reference to verify its effectiveness in real-world conditions.

- **Key Areas for Reassessment in Phase 1**

In the next phase of evaluation (Phase 1), the Technology Assessment Committee (TAC) recommend that a detailed reassessment of several critical areas before making strategic commitments regarding Rolls-Royce SMR. Given the lack of operational references and direct engagement with the technology provider, further validation is necessary to confirm the feasibility of key claims such as safety evaluation, technical detailed evaluation, factory-built modularity, construction timelines, cost estimates, and regulatory readiness.

##### Verification of Factory-Built Modularity

A major claim by Rolls-Royce SMR is that up to 95% of the reactor is factory-built, allowing for reduced costs, faster deployment, and minimal on-site construction risks. In Phase 1, it is essential to assess the actual modularization strategies used in the production process and compare them with other SMR programs to determine technical and logistical feasibility. Additionally, potential challenges in transportation, on-site assembly, and supply chain dependencies should be identified to ensure Serbia can realistically integrate this technology into its nuclear energy strategy.

##### Deployment Timeline and Cost Validation

Rolls-Royce SMR has projected a 4-year construction timeline per unit, a significant reduction compared to traditional nuclear power plants. However, this estimate requires rigorous verification to assess whether such an accelerated deployment schedule is achievable given Serbia’s infrastructure and regulatory environment. Additionally, the estimated CAPEX and potential cost reductions through serial production must be analysed, considering financing mechanisms that could support Serbia’s nuclear investment.

##### Licensing and Regulatory Readiness

The UK Generic Design Assessment (GDA) process is expected to conclude by 2026, but its applicability to Serbia’s nuclear licensing framework must be evaluated. Identifying regulatory gaps and potential delays in approval processes outside the UK is crucial for ensuring a smooth licensing pathway. Furthermore, engagement with EU nuclear bodies and international regulatory institutions should be explored to leverage support mechanisms that may streamline licensing and approval procedures.

## Supply Chain and Localization Strategy

As Rolls-Royce SMR's supply chain is primarily UK-based, Serbia must determine whether it can secure participation in the production and assembly process. Phase 1 should focus on evaluating Serbia's industrial capacity to manufacture or assemble SMR components, ensuring economic benefits and job creation. Identifying potential partnerships with European nuclear firms would further enhance localization opportunities and supply chain resilience.

## Operational Performance and Risk Management

As no commercial Rolls-Royce SMR unit has been deployed yet, there is a lack of real-world operational data. This introduces risks related to first-of-a-kind deployment, such as unexpected technical challenges, maintenance complexities, and potential delays in achieving full functionality. A contingency plan must be developed to address these uncertainties and mitigate any performance risks that could impact Serbia's long-term nuclear strategy.

### 4•4•7•4• Conclusion

The Rolls-Royce Small Modular Reactor (SMR) represents an innovative and promising addition to the global nuclear technology landscape, offering scalable and flexible solution tailored for both industrialized nations and emerging nuclear markets. Its design emphasizes factory based modular construction, advanced passive safety systems, and multi-purpose applications such as electricity generation, hydrogen production, and district heating features that align closely with Serbia's long term energy diversification, decarbonization, and energy security goals.

The technology's strengths include a relatively compact footprint, grid compatibility with Serbia's 50Hz network, and robust design life of 60 years, coupled with a claimed huge amount of modular factory fabrication. These attributes suggest significant potential to minimize construction time and reduce overall project risks, particularly in countries seeking to deploy nuclear capacity rapidly. Furthermore, Rolls-Royce SMR's indirect cooling system and seismic resilience offer adaptability to varied Serbian site conditions.

However, several challenges warrant cautious consideration:

- The absence of an operational reference plant introduces uncertainties related to real-world deployment, cost predictability, and performance reliability.
- The UK-based supply chain and the technology's first-of-a-kind status globally raise questions about localization opportunities and Serbia's ability to integrate into the production ecosystem.
- The current CAPEX estimates and 4-year construction timeline, while attractive, remain to be validated in diverse regulatory and infrastructure contexts outside the UK.

The Technology Assessment Committee (TAC) considers the Rolls-Royce SMR a technically robust and strategically aligned option for Serbia's future nuclear program. However, as with all emerging SMR designs, further analysis is required to substantiate vendor claims regarding modularity, cost reductions, and deployment timelines.

In the next phase of evaluation, the TAC recommends:

1. Engaging directly with Rolls-Royce SMR Ltd. to obtain detailed technical, financial, and delivery information.
2. Conducting a comparative modularity feasibility study to evaluate factory-fabrication strategies and logistical considerations for Serbian infrastructure.
3. Assessing regulatory pathways and identifying alignment opportunities between the UK's Generic Design Assessment and Serbia's emerging nuclear licensing framework.

4. Exploring localization potential and European industrial partnerships to maximize domestic economic benefits and enhance supply chain resilience.

While further validation is required, the Rolls-Royce SMR offers a potentially attractive nuclear power solution for Serbia, supporting both near-term energy transition objectives and long-term sustainability targets. A cautious yet proactive engagement strategy is recommended to refine Serbia's understanding of this technology and position the country effectively in global SMR development initiatives.

## 4•4•8• AP 300 SMR

### 4•4•8•1• Introduction


**Figure 151~~17~~: AP 300 site Layout**

### 4•4•8•2• Technical Features of AP300 SMR

The AP300 SMR, developed by Westinghouse, is a 300 MWe (990 MWth) pressurized water reactor (PWR) derived directly from the AP1000® technology, making it the only SMR based on an already licensed and operational Gen III+ reactor design. This approach leverages decades of proven operational experience, ensuring a high level of safety, reliability, and efficiency.

| Parameter | Description |
|---|---|
| Reactor Type | Pressurized Water Reactor (PWR) |
| Electrical Output | 300 MWe |

| Parameter | Description |
|---|---|
| Thermal Output | 990 MWth |
| Core Coolant | Light water ($H_2O$) |
| Cooling Method | Forced circulation (primary loop) |
| Fuel Type | Standard Westinghouse 17×17 $UO_2$ fuel, <5% enrichment |
| Refueling Interval | Up to 36 months (extended fuel cycle capability) |
| Design Life | 80 years |
| Containment Type | Single steel containment with passive cooling |
| Seismic Design | Safe-Shutdown Earthquake (SSE) level of 0.3g |
| Grid Compatibility | 50 Hz & 60 Hz compatible |
| Load-Following | Yes – Designed for flexible grid integration |
| Passive Safety Systems | No active safety-grade pumps, relies on gravity-driven cooling |
| Expected Availability | >97% operational capacity factor |
| Deployment Timeline | First commercial unit targeted by early 2030s |
| Number of Fuel Assemblies | 121 fuel assemblies |

**Table 111112: Key Technical Parameters**[20]

### 4•4•8•3• Pros and Cons

**Introduction**

The Technology Assessment Committee (TAC) has conducted an in-depth evaluation of the AP300 SMR's advantages and challenges, categorizing them into technical and non-technical considerations. While the AP300 leverages proven AP1000 technology, passive safety, and modular construction, the lack of an operational reference unit means certain claims require further verification.

From a technical perspective, the AP300's high level of pre-fabrication, extended fuel cycles, and passive safety design provide key benefits, while grid integration challenges, cooling requirements, and regulatory uncertainties remain areas of concern. On the non-technical front, its lower capital cost compared to large reactors, economic scalability, and export potential make it an appealing investment, but financing constraints, localization challenges, and geopolitical considerations must be addressed.

[20] Source: IAEA ARIS

Additionally, supply chain localization is a critical factor for Serbia, as U.S. export control restrictions under 10 CFR Part 810 may limit access to certain critical technologies and expertise, necessitating strategic partnerships for knowledge transfer and local manufacturing.

The table below summarizes the AP300 SMR's key pros and cons, structured in a way that ensures a clear understanding of its feasibility within Serbia's nuclear energy strategy.

| Category | Advantages (Technical & Non-Technical) | Issues and Challenges (Technical & Non-Technical) |
|---|---|---|
| Technical Issues | Passive Safety Systems – Eliminates reliance on active cooling, reducing accident risk. | First-of-a-Kind Risk – No AP300 units are currently operational, requiring real-world validation. |
| | High Availability – Expected >97% capacity factor, ensuring stable baseload power. | Grid Integration Challenges – Load-following capability needs assessment within Serbia's energy market. |
| | Extended Refueling Cycle – Up to 36 months, reducing operational disruptions. | Cooling Requirements – Water-cooled system may require alternative strategies in water-scarce regions. |
| | Modular Construction – Up to 90% factory-built, reducing on-site work and improving project certainty. | Deployment Timeline Uncertainty – While targeting a 36-month construction timeline, real-world feasibility must be verified. |
| | Seismic Resilience – Designed for 0.3g Safe-Shutdown Earthquake (SSE) compliance, adaptable to Serbia's conditions. | Waste & Spent Fuel Management – Long-term disposal and recycling strategies need to be clearly defined. |
| | Flexible Grid Compatibility – Supports 50 Hz & 60 Hz, allowing deployment across diverse markets. | Licensing Adaptability – Requires regulatory alignment with Serbia's nuclear framework before deployment. |

| Category | Advantages (Technical & Non-Technical) | Issues and Challenges (Technical & Non-Technical) |
|---|---|---|
| **Non-Technical Issues** | Lower CAPEX Compared to Large Reactors – Estimated at ~€2.5 billion/unit, making it more financially feasible. | Financing Constraints – Requires a structured financing model, with EU or government-backed support for cost feasibility. |
| | Competitive LCOE (€45-55/MWh) – Economically viable compared to fossil fuels and certain renewables. | Localization Challenges – High dependence on US and European supply chains, requiring Serbian industry engagement. |
| | Proven AP1000 Supply Chain – Utilizes existing supply networks, reducing procurement risks. | Geopolitical Considerations – U.S. export control restrictions (10 CFR Part 810) may limit Serbia's access to critical technologies, requiring strategic partnerships. |

| Category | Advantages (Technical & Non-Technical) | Issues and Challenges (Technical & Non-Technical) |
|---|---|---|
| | Export Potential – Westinghouse's planned deployments in UK, Poland, Canada, and Czech Republic increase global credibility. | Public Acceptance & Nuclear Perception – Requires communication strategies to ensure public trust and local engagement. |
| | Shorter Construction Timeline (Target: 36 Months) – Faster return on investment compared to large reactors. | First Deployment Expected Post-2030 – No near-term commercial deployment for Serbia unless acceleration is proven feasible. |
| | Scalability & Multi-Unit Feasibility – Can be deployed incrementally, reducing upfront investment burden. | Unverified Serial Cost Reductions – Claims of declining costs with additional units remain theoretical until proven. |

Table 121213: AP300 SMR advantages and challenges

### 4•4•8•4• Strategic Recommendations

The Technology Assessment Committee (TAC) has identified key areas requiring further validation before Serbia can consider the AP300 SMR for deployment. While Westinghouse's claims regarding modularity, cost efficiency, and passive safety offer a compelling case, the lack of an operational reference unit necessitates a structured reassessment in Phase 1. The following strategic recommendations outline the critical next steps to ensure a data-driven and risk-mitigated approach to evaluating the feasibility of the AP300 SMR in Serbia.

#### Validation of Factory Modularity Claims

One of the most significant advantages highlighted by Westinghouse is the 90% factory-built modular construction approach, which is expected to reduce construction complexity, cost variability, and deployment timelines. However, given the absence of a fully deployed AP300 unit, these claims require direct engagement with Westinghouse and third-party industrial validation to assess:

- Actual modularization strategies used in the supply chain.
- Potential transportation challenges related to module size and assembly.
- Comparisons with other SMR programs to benchmark modular deployment feasibility.

Serbia must ensure that logistical and assembly constraints do not compromise the expected efficiency gains from a factory-fabricated approach.

#### Investment and Financing Models

To support the economic feasibility of AP300 in Serbia, a proactive financing strategy is essential. Based on the cost and LCOE ranges outlined in chapter 6.8.4.3, Serbia should:

- Explore EU funding channels (e.g., EIB clean energy instruments);
- Evaluate Public-Private Partnerships (PPPs) to mitigate upfront capital risks;
- Engage with Westinghouse on vendor financing options;

- Perform local financial modeling to test resilience under fluctuating input costs.

**Supply Chain & Localization**

Leveraging the AP300's factory-based modular design (chapter 6.8.4.1), Serbia should investigate opportunities for local participation in manufacturing, assembly, and supply chain services. This includes:

- Assessing national industrial readiness to fabricate AP300 components;
- Partnering with EU-based suppliers to enable partial localization;
- Addressing technology transfer constraints due to U.S. export control regulations (10 CFR Part 810), which may affect Serbia's access to critical know-how.

### 4•4•8•5• Conclusion

The AP300 SMR presents a technologically advanced and economically promising option for Serbia's nuclear energy strategy. Built on the proven AP1000 technology platform, the reactor offers passive safety features, long refueling cycles, and a modular design that could significantly reduce construction risks. Additionally, its competitive LCOE of €45-55/MWh and scalable deployment model position it as a potential candidate for long-term energy security and decarbonization efforts.

However, the TAC has identified several critical areas that require further scrutiny before any deployment decision can be made. The lack of an operational reference unit, uncertainty regarding modularization claims, long-term supply chain dependencies, and potential regulatory adaptation challenges mean that Phase 1 of the evaluation process must focus on detailed verification of these aspects.

Key areas requiring reassessment include:

- Validation of the factory-built modular approach to determine whether 90% off-site fabrication is achievable under real-world conditions.
- Licensing and regulatory alignment to ensure a smooth approval process under Serbia's nuclear safety framework.
- Comprehensive financing and investment planning to secure cost-effective funding options while minimizing financial risk.
- Supply chain localization strategy, particularly in navigating U.S. export control restrictions (10 CFR Part 810) and identifying potential European partnerships for manufacturing and operational support.

While the AP300 SMR holds strong potential, the TAC emphasizes that further technical and economic verification is essential before moving forward with deployment decisions. The next phase of assessment should focus on real-world validation, vendor engagement, and strategic policy planning to determine whether the AP300 is the right fit for Serbia's nuclear energy roadmap.

### 4•4•9• Holtec SMR-300

#### 4•4•9•1• Introduction

Figure 161618: SMR 300 Dual Unit (600MWe net)[21]

The Holtec SMR-300 is a 300 MWe pressurized water reactor (PWR) that integrates advanced passive safety systems, underground containment, and a modular transportable design. Developed with a focus on enhanced safety, flexible deployment, and reduced operational risks, the SMR-300 aims to provide a cost-efficient and resilient clean energy solution for both urban and remote locations.

One of the distinctive attributes of the SMR-300 is its subterranean containment design, which provides additional protection against external threats such as seismic events, aircraft impact, and extreme weather conditions.

| Parameter | Description |
|---|---|
| Reactor Type | Pressurized Water Reactor (PWR) |
| Electrical Output | 300 MWe |
| Thermal Output | 1000 MWth |
| Core Coolant | Light water ($H_2O$) |
| Cooling Method | Forced circulation with natural convection backup |

[21] Source: Holtec Websites

| Parameter | Description |
|---|---|
| Fuel Type | Standard 17×17 $UO_2$ PWR fuel, <5% enrichment |
| Refueling Interval | 18 months, extendable |
| Design Life | 80 years, with potential for 100-year operation |
| Containment Type | Underground steel containment, surrounded by METCON™ concrete |
| Seismic Design | 0.5g Safe-Shutdown Earthquake (SSE) compliance |
| Grid Compatibility | 50 Hz & 60 Hz compatible |
| Load-Following | Yes – Configurable for flexible grid integration |
| Passive Safety Systems | No operator action required for safe shutdown |
| Expected Availability | >95% operational capacity factor |
| Deployment Timeline | First unit targeted for commercial operation by 2030 |
| Number of Fuel Assemblies | 69 fuel assemblies |

Table 131314: Key Technical Parameters of SMR-300[22]

### 4•4•9•2• Pros and Cons

#### Introduction

The SMR-300 by Holtec International is presented as an advanced modular nuclear solution with a strong emphasis on passive safety, rapid deployment, and operational flexibility. The Technology Assessment Committee (TAC) has analyzed its advantages and challenges, particularly in the context of Serbia's nuclear energy strategy. While the reactor's modular design and passive cooling systems offer key benefits, there are also concerns related to licensing, supply chain localization, and first-of-a-kind deployment risks. The following table categorizes the key technical and non-technical advantages and challenges to provide a balanced evaluation of the SMR-300.

| Category | Advantages | Issues and Challenges |
|---|---|---|
| Technology Issues | **Advanced Passive Safety Features** – No active pumps required for cooling, ensuring reactor safety during power loss. | **First-of-a-Kind Deployment** – No operational reference unit exists; first deployment expected only by 2030. |

[22] Source: IAEA ARIS

| Category | Advantages | Issues and Challenges |
|---|---|---|
| | **Underground Containment** – Reactor housed in a METCON™ concrete structure for enhanced protection against external threats. | **Unproven Modularity Claims** – The claim of 90% factory-built modularity requires independent validation. |
| | **Air-Cooled Option Available** – Can operate with air-cooled condensers, making deployment feasible in water-scarce regions. | **Extended Licensing Timeline** – Serbia will need to establish a regulatory adaptation process, as the reactor is still in early licensing phases. |
| | **Long Design Lifetime** – 80-year operational life, with potential for 100 years under extended maintenance protocols. | **Seismic Adaptation Required** – The reactor's 0.5g Safe-Shutdown Earthquake (SSE) compliance may require site-specific modifications in Serbia. |
| | **Fuel Handling Optimization** – Uses standard 17×17 $UO_2$ PWR fuel with extended refueling intervals to minimize downtime. | **Spent Fuel Management** – On-site dry storage in Holtec's HI-STORM UMAX system requires long-term waste planning. |
| | **Rapid Construction Timeline** – FOAK projected for 30 months; potential to deploy in parallel multi-unit configurations. | **Thermal Efficiency Considerations** – Air-cooled operation may lead to efficiency losses compared to water-cooled systems. |
| Non-Technical Issues | **Flexible Deployment** – Compact land footprint (8 hectares for a two-unit site) supports urban and remote locations. | **Regulatory Adaptation Needed** – Serbia must evaluate how Holtec's licensing experience (US, UK, Canada) aligns with future domestic nuclear regulations. |
| | **Government-Backed Initiatives** – Holtec has secured U.S. federal support for its first deployment, reducing financial risk for future projects. | **Export Control Restrictions** – U.S. 10 CFR Part 810 regulations may limit Serbia's access to key reactor technologies, requiring strategic partnerships. |
| | **Job Creation & Localization Potential** – Modular approach allows potential Serbian industry participation in component manufacturing. | **Financing Uncertainty** – No established financing model for European deployments; Serbia must explore EU and international funding options. |
| | **District Heating & Hydrogen Production** – Designed for cogeneration, making it adaptable to Serbia's evolving energy mix. | **Public Perception & Acceptance** – Nuclear energy skepticism in Serbia may impact project approval and stakeholder engagement. |

| Category | Advantages | Issues and Challenges |
|---|---|---|
| | **Black Start & Island Mode** – Can self-start without grid power, increasing resilience in remote and off-grid scenarios. | **Dependency on U.S.-Based Supply Chain** – The need for imported components may lead to logistical challenges and longer lead times. |

Table 14~~15~~: SMR300 SMR ADVANTAGES AND CHALLENGES

### 4•4•9•3• Strategic Recommendations

The Technology Assessment Committee (TAC) has conducted a high-level evaluation of the SMR-300 based on publicly available data and Holtec's technical reports. While the reactor presents a promising solution for Serbia's nuclear energy strategy, several key aspects require further validation before considering deployment. The following strategic recommendations outline critical areas for reassessment in Phase 1.

- **Verification of Modular Construction Claims**

Holtec asserts that up to 90% of the SMR-300 components are factory-built, significantly reducing on-site construction time. However, no operational unit exists to validate this claim. The TAC recommends a comprehensive assessment of the modular supply chain, transportation logistics, and assembly efficiency to ensure feasibility in Serbia's infrastructure context. A comparative study with other modular reactor programs will further clarify its scalability and deployment viability.

- **Licensing Adaptation and Regulatory Feasibility**

The SMR-300 is currently undergoing licensing in the U.S., UK, and Canada. However, Serbia will need to determine how Holtec's regulatory approach aligns with its own future nuclear framework. Given the differences in licensing structures, Serbia may require additional regulatory adaptations, extended safety case reviews, and localized environmental impact assessments before considering reactor deployment.

- **Financial Viability and Investment Considerations**

While Holtec has secured U.S. federal backing for its first deployment, no established financial model exists for European markets. The TAC recommends exploring funding mechanisms such as EU nuclear energy grants, export credit financing, and potential public-private partnerships to support Serbia's nuclear investment strategy.

- **Supply Chain Localization and Export Control Challenges**

Holtec's SMR-300 supply chain is primarily U.S.-based, with key components subject to U.S. export control regulations (10 CFR Part 810). This may restrict Serbia's access to critical technologies unless appropriate knowledge transfer agreements or licensing arrangements are established. The TAC recommends assessing local industry participation in the reactor's supply chain, particularly for civil construction, auxiliary systems, and long-term operations & maintenance to enhance national energy security.

- **Risk Management for First-of-a-Kind Deployment**

As the SMR-300 has not yet been deployed commercially, Serbia must consider potential risks related to construction delays, first-of-a-kind operational uncertainties, and untested long-term performance metrics. The TAC suggests that Serbia establish a contingency framework to address potential challenges such as supply chain disruptions, cost escalations, and performance deviations from design expectations. A stepwise engagement strategy, beginning with regulatory and feasibility studies, will help mitigate uncertainties.

### 4•4•9•4• Conclusion

The SMR-300 represents a technologically advanced small modular reactor (SMR) solution with strong safety features, modular construction capabilities, and flexible deployment options. Its passive safety mechanisms, underground containment, and extended fuel cycle capabilities position it as a viable candidate for Serbia's long-term nuclear energy strategy.

However, the absence of an operational reference unit and the unverified nature of its modularity claims introduce significant uncertainties that must be addressed in the next phase of assessment. The alignment of licensing requirements, financial structuring, and supply chain localization remains critical before any deployment commitments can be made.

The TAC emphasizes that all assessments conducted thus far are based solely on publicly available data and Holtec's technical documents. Direct verification of technical, financial, and operational claims must be undertaken in Phase 1 of the feasibility study to confirm the reactor's suitability for Serbia's nuclear roadmap. The next phase should focus on:

- Verifying factory-built modularity claims through independent feasibility studies.
- Assessing licensing requirements and regulatory adaptations for Serbian future nuclear law.
- Exploring financial models and funding mechanisms to ensure cost-effective deployment.
- Developing localization strategies to reduce dependency on foreign supply chains.
- Establishing a risk management framework to mitigate first-of-a-kind deployment challenges.

While the SMR-300 presents an innovative nuclear energy option, its practical deployment in Serbia requires further validation and structured engagement with Holtec International and global regulatory bodies. The TAC recommends a phased approach, starting with licensing adaptation, financial planning, and site feasibility assessments, before proceeding with any commitment to reactor deployment.

## 4•4•10• SMR Overall Comparison

The Technology Assessment Committee (TAC) recognizes the increasing interest in Small Modular Reactors (SMRs) as a crucial component of global energy transition strategies. Each SMR technology presents unique attributes, advantages, and challenges that need to be assessed in the context of Serbia's energy objectives, regulatory framework, and market readiness.

The following section provides a comparative evaluation of leading SMR technologies, highlighting their key technical, economic, and regulatory aspects. This comparative analysis will serve as a basis for further refinement in the next phase of assessment, ensuring that Serbia makes informed decisions regarding the integration of SMRs into its energy portfolio.

A comprehensive comparison of leading SMR technologies is essential to evaluate their technical, economic, and regulatory suitability. The Technology Assessment Committee (TAC) has conducted a structured assessment, analyzing SMRs based on their reactor type, safety architecture, fuel cycle efficiency, deployment timeline, and cost considerations.

This comparative table highlights the distinguishing features, capabilities, and potential challenges of each SMR, providing a data-driven basis for further evaluation in Phase 1 of Serbia's SMR selection process. While all assessed SMRs emphasize modularity, enhanced safety, and operational flexibility, they differ in technological maturity, construction strategies, and market readiness.

The **NUWARD SMR, BWRX-300, AP300, Rolls-Royce SMR, and Holtec SMR-300** represent a range of pressurized water reactor (PWR) and boiling water reactor (BWR) designs, each offering unique deployment advantages. However, key factors such as licensing progress, construction feasibility, and cost competitiveness must be validated in real-world conditions before Serbia can commit to any specific technology.

This table serves as a decision-support tool, helping Serbia identify the most viable SMR options for integration into its national energy strategy, ensuring alignment with regulatory requirements, financial sustainability, and long-term energy security objectives.

| Attribute | NUWARD (EDF) | BWRX-300 (GE Hitachi) | AP300 (Westinghouse) | Rolls-Royce SMR | Holtec SMR-300 |
|---|---|---|---|---|---|
| Reactor Type | PWR | BWR | PWR | PWR | PWR |
| Electrical Output | 400 MWe | 300 MWe | 300 MWe | 470 MWe | 300 MWe |
| Thermal Output | ~1000 MWth | 990 MWth | 990 MWth | 1280 MWth | 1000 MWth |
| Cooling Method | Forced Circulation | Natural Circulation | Forced Circulation | Forced Circulation | Forced Circulation |
| Containment Type | Pre-stressed Concrete | Single Containment | Steel Containment | Single Containment | Underground Containment |
| Refueling Interval | 24 months | 12–24 months | Up to 36 months | 18–24 months | 18 months (extendable) |
| Design Lifetime | 60 years | 60 years | 80 years | 60 years | 80+ years |
| Seismic Design | 0.3g SSE | 0.3g SSE | 0.3g SSE | 0.3g SSE | 0.5g SSE |
| Grid Compatibility | 50 Hz & 60 Hz | 50 Hz & 60 Hz | 50 Hz & 60 Hz | 50 Hz | 50 Hz & 60 Hz |
| Passive Safety Features | PDHRS, IVR, Core Catcher | ICS, GDCS | No active pumps, gravity cooling | Passive heat removal | Passive cooling, walk-away safe |
| Projected Availability Factor | >92% | >95% | >97% | >95% | >95% |

| Attribute | NUWARD (EDF) | BWRX-300 (GE Hitachi) | AP300 (Westinghouse) | Rolls-Royce SMR | Holtec SMR-300 |
|---|---|---|---|---|---|
| Factory Prefabrication (%) | Targeted at 90% | Targeted at 90% | Targeted at 90% | Up to 95% | Estimated at 90% |
| Licensing Status | Conceptual / Basic Design Phase | Under review (GDA, Canada, U.S.) | Under review (U.S. NRC) | GDA (UK) Phase 2 | U.S. NRC application submitted |
| First Deployment | Targeted FOAK in France (2030) | Darlington (Canada) | Early 2030s | Early 2030s (UK) | Palisades (USA), 2030 |
| Cost Estimate (CAPEX per unit) | Estimated ~Confidential | Estimated ~Confidential | Estimated ~Confidential | Estimated ~Confidential | Estimated ~Confidential |
| Market Target | EU nations, industrial hubs | Canada, U.S., Poland | U.S., EU | UK, EU, Canada | U.S., Canada, UK |

Table 151516: SMR Overall Technical Comparison Table

### 4•4•10•1• Summary and Key Takeaways

SMRs offer a promising alternative to conventional large-scale nuclear reactors, with benefits such as modularity, improved safety mechanisms, reduced construction time, and enhanced grid integration potential. However, each design has its own level of maturity, market readiness, and regulatory challenges. The TAC has identified the following key takeaways from the comparative assessment of SMRs:

- Proven vs. Emerging Designs: Technologies like the AP300 (Westinghouse) and Rolls-Royce SMR leverage existing licensed reactor designs, providing a level of regulatory familiarity. Conversely, NUWARD (EDF) and BWRX-300 (GE Hitachi) are still undergoing detailed design and regulatory review, necessitating additional verification of deployment timelines.
- Cost and Construction Considerations: While modularity and factory fabrication are expected to reduce costs, actual savings will depend on supply chain readiness, serial production efficiency, and standardization of components.
- Safety and Regulatory Pathways: The integration of passive and active safety mechanisms varies across designs. Holtec SMR-300, for instance, utilizes an underground containment structure for enhanced security, whereas the BWRX-300 relies on simplified cooling systems to reduce reliance on active safety components.
- Market Readiness and Deployment: Some SMRs, such as the BWRX-300 and Rolls-Royce SMR, have ongoing licensing efforts in multiple jurisdictions, increasing their near-term commercial viability. Others, like NUWARD, have yet to finalize design certification but have strong industrial and governmental backing.

To facilitate a structured decision-making process, the TAC has developed a comprehensive SMR Technology Comparison Table covering the core attributes of each assessed technology.

## 4•4•11• Final Considerations and Long-Term Vision Including the Roadmap

Serbia's energy transition plan requires a nuclear solution that balances affordability, scalability, and long-term sustainability. The decision to integrate an SMR technology will depend on:

- **Technical Feasibility:** The ability of the selected technology to meet Serbia's grid requirements, safety standards, and site-specific constraints.
- **Regulatory Adaptation:** The alignment of selected technologies with Serbia's future nuclear regulatory framework and international licensing standards.
- **Economic Viability:** Evaluation of financing models, including EU funding opportunities, public-private partnerships, and risk-sharing mechanisms.
- **Supply Chain Readiness:** Localization potential for manufacturing, fuel supply security, and operational workforce development.
- **Strategic Partnerships:** Collaboration with global SMR vendors to ensure technology transfer, licensing support, and long-term operational reliability.

Cost estimates for Small Modular Reactors (SMRs) remain **indicative and highly variable**, influenced by factors such as project location, regulatory pathway, delivery model, and supply chain maturity. As most SMR designs are still in the pre-construction or early licensing phases, there is limited real-world data to validate capital cost benchmarks or deployment timelines.

International developments highlight that **early-stage financial assumptions are often subject to change,** particularly in the absence of first-of-a-kind (FOAK) deployment experience. This reinforces the need for **location-specific cost sensitivity analysis and risk modelling,** especially in areas such as site preparation, regulatory interface, and workforce availability.

For Serbia, adopting SMR technology will require a **cautious and well-informed financial planning approach**, integrating full lifecycle cost assessments, delivery strategies, and risk-sharing frameworks. These elements will be critical in shaping a robust procurement and financing architecture in future project phases.

A phased approach will be necessary to refine the selection process, with Phase 1 focusing on verification of vendor claims, regulatory analysis, and cost modeling, followed by Phase 1.1 involving pilot studies and site-specific engineering assessments.

### Strategic Focus for the Next Phase

As Serbia advances its nuclear infrastructure planning, the next phase of assessment will emphasize:

#### Validation of Factory-Modular Construction Claims

- Review actual modularization strategies and compare them against similar SMR deployments.
- Assess transportation, on-site assembly feasibility, and supply chain dependencies.

#### Regulatory Pathway Adaptation

- Engage with European and global regulators to streamline licensing for selected SMR technology.
- Determine necessary modifications in Serbia's regulatory framework to support SMR integration.

## Cost-Benefit and Risk Analysis

- Refine CAPEX and OPEX estimates using real-world cost data from operational or under-development SMR projects.
- Identify financing mechanisms, including EU nuclear funds and strategic investments.

## Supply Chain and Workforce Development

- Evaluate Serbia’s ability to manufacture SMR components locally and identify key industrial partners.
- Establish knowledge transfer and workforce training programs to ensure long-term operational sustainability.

By addressing these key focus areas, Serbia will strengthen its position as a forward-looking nuclear energy player, ensuring that its investment in SMR technology is strategically sound, economically viable, and aligned with national energy security objectives.

# 4•5• Potential Benefits and Challenges for Serbia

## 4•5•1• Introduction

The Technology Assessment Committee (TAC) acknowledges the transformative potential of nuclear energy for Serbia's long-term energy security, economic growth, and decarbonization goals. The evaluation of Large Nuclear Power Plants (LNPPs) and Small Modular Reactors (SMRs) highlights the strategic advantages of scalable, reliable, and low-carbon nuclear technologies while also recognizing the challenges associated with regulatory adaptation, financing, and workforce development.

This chapter explores how LNPPs and SMRs can contribute to Serbia's evolving energy mix, identifying key opportunities and considerations for successful deployment.

## 4•5•2• The Role of LNPPs and SMRs in Serbia's Energy Future

As Serbia seeks to transition from fossil fuels to a more sustainable and resilient energy system, nuclear power offers a long-term solution for energy independence, industrial competitiveness, and national security.

While Large Nuclear Power Plants (LNPPs) provide high-output, baseload power with proven operational performance, Small Modular Reactors (SMRs) offer scalable and flexible deployment for diverse applications, including district heating, hydrogen production, and remote energy supply. Together, these technologies form a complementary nuclear energy strategy, ensuring both large-scale grid stability and decentralized energy solutions.

| Category | LNPPs (Large Nuclear Power Plants) | SMRs (Small Modular Reactors) |
|---|---|---|
| Reliable Baseload Power & Grid Stability | Provides high-capacity, continuous electricity generation, stabilizing the grid and ensuring long-term energy security. | Offers load-following capabilities, making it ideal for balancing variable renewable energy sources like wind and solar. |
| Decarbonization & Climate Goals | Significantly reduces $CO_2$ emissions, supporting EU decarbonization policies and net-zero targets. | Deployable near industrial zones, replacing coal-fired plants with zero-carbon alternatives. |
| Economic Growth & Job Creation | Drives large-scale industrial investment, creating high-skilled jobs in engineering, manufacturing, and plant operations. | Supports modular manufacturing and local assembly, fostering regional supply chain development and skilled workforce expansion. |
| Strategic Energy Independence | Reduces reliance on imported fossil fuels, strengthening energy security and national resilience. | Distributed deployment enables flexible energy production, reducing dependency on centralized power plants. |
| Diverse Applications for Industrial Use | Supports large-scale energy-intensive industries, ensuring stable, cost-effective power for long-term industrial expansion. | Produces heat for industrial applications (150–280°C), including hydrogen production, district heating, and process steam. |

Table 36: Key Advantages of LNPPs and SMRs for Serbia

### 4•5•3• Challenges and Considerations for Serbia

The Technology Assessment Committee (TAC) recognizes nuclear power as a transformative solution for Serbia's long-term energy security, economic growth, and decarbonization efforts. However, successful deployment requires a structured and multi-faceted approach, addressing regulatory compliance, financing strategies, workforce development, supply chain readiness, and public perception.

Serbia's nuclear energy expansion whether through Large Nuclear Power Plants (LNPPs) or Small Modular Reactors (SMRs) must be built upon a foundation of robust regulatory alignment, sustainable investment models, and skilled workforce development. Additionally, the integration of local industries into nuclear supply chains and active public engagement will be crucial for ensuring project acceptance and long-term viability.

The following table outlines key challenges and strategic actions required for Serbia's nuclear deployment, ensuring a smooth and efficient transition toward nuclear power.

| Challenge | Description | Strategic Actions for Serbia |
|---|---|---|
| Regulatory Adaptation and Licensing Readiness | Serbia must align its future nuclear regulatory framework with international standards such as IAEA, EUR, and WENRA to ensure compliance with global safety requirements. | Regulatory Alignment Program – Establish a structured roadmap to integrate global nuclear safety guidelines into Serbia's national framework. |
| | The licensing pathway for SMRs is still evolving, requiring engagement with early adopters (Canada, UK, U.S., EU nations) and international nuclear regulators to streamline approvals. | Engagement with International Regulators – Collaborate with IAEA, EURATOM, and WENRA to accelerate Serbia's SMR regulatory process. |
| Financial Considerations and Investment Models | High initial capital costs (CAPEX) for LNPPs and SMRs require structured financing models, including EU grants, vendor financing agreements, and sovereign investment frameworks. | Explore EU and International Funding Mechanisms – Secure financing through EU Green Energy Funds, European Investment Bank (EIB) nuclear investments, and vendor-backed financing models. |
| | Levelized Cost of Electricity (LCOE) projections must be competitive, ensuring affordability in the long-term nuclear investment cycle. | Independent Cost Benchmarking – Conduct detailed LCOE assessments and cost comparisons with alternative energy sources to validate economic feasibility. |
| Workforce Development and Nuclear Expertise | A skilled workforce is critical for reactor operations, regulatory oversight, and long-term nuclear infrastructure management. | National Nuclear Talent Pipeline – Establish academic partnerships, vendor-led training programs, and specialized engineering education to cultivate Serbia's next-generation nuclear workforce. |
| | Serbia must invest in training nuclear engineers, reactor operators, and safety inspectors to ensure long-term sustainability. | Workforce Development Fund – Collaborate with global SMR and LNPP vendors to provide hands-on training and internship programs. |
| Supply Chain Localization and | LNPP projects require large-scale civil construction and high-value component manufacturing, whereas SMRs enable | Serbian Nuclear Supply Chain Strategy – Identify potential domestic suppliers and manufacturing partners to localize reactor |

| Challenge | Description | Strategic Actions for Serbia |
|---|---|---|
| Infrastructure Readiness | greater modularization and local assembly. | component production and reduce dependency on foreign imports. |
| | Serbia must develop nuclear servicing and maintenance capabilities to support long-term operational efficiency and cost-effectiveness. | Infrastructure Readiness Program – Assess Serbia's industrial capacity to manufacture and assemble SMR/LNPP components, ensuring local job creation and economic benefits. |
| Public Perception and Policy Support | Public acceptance of nuclear energy is crucial for project success, requiring transparent communication on safety, environmental impact, and long-term waste management strategies. | Public Awareness and Education Campaigns – Launch nationwide outreach programs, expert discussions, and media engagements to build trust and promote the benefits of nuclear energy. |
| | Serbia needs clear government policies and roadmaps to provide long-term regulatory and financial certainty for investors and stakeholders. | Nuclear Policy Roadmap – Develop a comprehensive long-term nuclear energy strategy, ensuring policy continuity and investment confidence. |

Table 161617: Key Challenges and Strategic Considerations for Serbia

# 4•6• Conclusion

This high-level technology assessment represents a foundational step in Serbia's structured exploration of nuclear power as a pillar of its long-term energy strategy. Conducted under the framework of Work Package 2 and informed by institutional inputs from Work Package 1, the study integrates comparative technical analysis, global deployment experience, and Serbian national priorities to present a clear path forward.

## 4•6•1• Summary of Findings

The following key conclusions have emerged from the multi-stage assessment process:

- **Nuclear Power is a Viable Strategic Option**

  Serbia faces a dual challenge of decarbonizing its power sector while ensuring secure baseload supply. Nuclear energy offers a dispatchable, low-carbon alternative to coal, and is technically feasible within the Serbian grid structure, especially when supported by load-following designs or phased deployment strategies.

- **Both Large-Scale and SMR Technologies Present Opportunities**

  The assessment included only Generation III/III+ technologies and identified a range of conventional and SMR reactor types that align with Serbia's technical, regulatory, and strategic needs. Large Nuclear Power Plants (LNPPs) provide economies of scale, while Small Modular Reactors (SMRs) offer modularity, lower upfront investment, and flexible siting potential.

- **Deployment Maturity Varies Across Vendors**

Technology readiness levels, licensing progress, and deployment plans vary significantly. Some vendors have active projects under construction or licensing, while others remain in early development. This diversity underlines the need for Serbia to maintain optionality in the next phase of vendor engagement.

- **Cost Estimates Remain Indicative and Context-Specific**

  Across all technologies, cost data remains variable and often unvalidated by first-of-a-kind (FOAK) projects. International experiences including project delays and cancellations—highlight the importance of conducting detailed, Serbia-specific cost sensitivity analyses in the next feasibility phase.

- **Regulatory and Owner/Operator Readiness is Critical**

  Successful deployment will require capacity building within Serbia's regulatory authority (SRBATOM) and the establishment of a competent Owner/Operator entity. Both streams are already addressed under WP1 and should remain national priorities in the coming years.

- **Technology Selection Must Be Integrated with Broader Infrastructure Planning**

  Technology choice must be harmonized with grid compatibility (400kV), siting constraints, environmental impact, localization strategies, and financing architecture. The final decision must be informed not only by reactor design but by system-wide deployment feasibility.

This assessment has been developed exclusively based on publicly available information from technology developers, regulatory authorities, and international nuclear institutions. While efforts have been made to present deployment status, performance indicators, and supply chain context for each technology, the availability and granularity of data vary significantly across vendors. As a result, certain aspects such as exact project partner structures, unit-level CAPEX benchmarks, or quantified supply chain localization metrics are discussed to the extent disclosed in the public domain.

A more detailed and quantified evaluation of technical, economic, and partnership-related criteria will be undertaken in the subsequent project phases through vendor engagement, due diligence, and site-specific validation. This phased approach ensures that technology comparison remains evidence-based ensure fair technology assessment while respecting data access limitations at the pre-feasibility stage.

## 4•6•2• Disclaimer

This Technology Assessment Report has been prepared by EGIS (Technology Assessment Committee - TAC) for the Serbian Government as part of a high-level, Phase 1 pre-feasibility evaluation of advanced nuclear reactor technologies [Contract Reference: JN- 14/24]. The assessment has been conducted based on publicly available documents, interactions with some of the technology providers, and the professional experience and expertise of the TAC members. This report is intended **for informational and strategic evaluation purposes only** and does not constitute a legally binding commitment, endorsement, or recommendation for any specific technology provider or vendor.

The TAC emphasizes that this report is a high-level Phase 1 pre-feasibility study and, as such, does not provide a quantitative, comparative analysis of the technologies in key areas such as CAPEX (Capital Expenditure), OPEX (Operational Expenditure), safety metrics, or technology maturity levels. Due to the limitations of publicly available data (data classified by the Technology Provider - Confidential) and the preliminary nature of the assessment, no definitive conclusions regarding cost competitiveness, deployment timelines, or technical maturity should be drawn at this stage. The Committee firmly believes that a more detailed technical evaluation should be conducted during Phase 1 of Serbia's Nuclear Infrastructure Program, in close cooperation with technology providers, regulatory bodies, and industry stakeholders.

Furthermore, this report has been prepared without prejudice and is non-binding to EGIS or any of its members. The conclusions and observations presented are based on the best available information at the time of assessment but do not represent a final investment decision, policy directive, or contractual obligation for Serbia’s nuclear development strategy.


## WORK PACKAGE #3

# SUPPLY-DEMAND ANALYSIS TO DEFINE POTENTIAL POWER FUTURE (2045) DISPATCHES IN SERBIA

# 5• Work Package #3: Supply-demand analysis to define potential power future (2045) dispatches in Serbia

## 5•1• Context

Given the significant increase of energy needs foreseen in the next decades, nuclear energy is perceived as a plausible option to provide dispatchable low carbon electricity. In this regard, the Government of the Republic of Serbia is already laying out the groundwork to make informed assessments regarding the potential for deploying a civil nuclear power program. In particular, they are evaluating the prerequisites for implementing a civil nuclear program in the country in a structured and systematic manner, using the IAEA milestones approach prior to deciding to launch a nuclear program. During this process, Serbia has solicited the expertise and experience of the international nuclear community resulting in EDF, in partnership with Egis, being awarded a contract by Serbia's Ministry of Mining & Energy to conduct a preliminary study on the potential role of nuclear power in Serbia’s energy future following a public procurement process ref JN-14/24.

This study was segmented into three work packages (WP) each focusing on an aspect of the development of civil nuclear program. Work Package number 3 (WP#3) focused on a preliminary supply-demand analysis to define potential power future (2045) dispatches in Serbia.

The following sections detail the assumptions, methodology and results from the aforementioned tasks along with recommendations for next steps.

## 5•2• Study limits and possible extensions

This study is a preliminary supply-demand analysis. As such, it comes with the following limitations:

- The model is updated to meet forecasted load and generation for 2045 in Serbia in line with the official data available to Serbian TSO at the time of data collection; on the contrary neighbouring countries are modelled using a 2034 forecast. The resulting equilibrium, especially in terms of imports/exports with the neighbours has thus to be treated with caution
- This analysis was performed on one of the available climatic years datasets available. It is designed to generate realistic power dispatches for a given generation fleet and load profile, but it does not cover all potential climatic variability. Hence, it cannot be treated as an adequacy assessment from the security of supply side for the selected generation fleet. This aspect will need to be analyzed further in the upcoming stages of the project.

# 5•3• Supply-demand analysis

## 5•3•1• Documents and assumptions

The considered study year is 2045, consistent with the timeframe of a nuclear program and with the milestones already set by the Serbian authorities.

The simulations were run with the ANTARES Simulator© software, on a model provided by experts from Elektromreža Srbije (EMS) and otherwise used for the National Development Plan. To remain consistent with the TYNDP process, it was decided jointly with EMS to select a relevant climatic year, representing specific assumptions, notably regarding the load curve and levels of renewable power generation. Six scenarios were considered, based on the agreed combinations of the selected nuclear unit types (Table 5-11~~Table 5-1~~).

| Unit Type | Unit Nominal Capacity (MWe) | Min Stable Power (MWe) | Marginal Cost (€/MWh) |
|---|---|---|---|
| **1** | 1 200 | 300 | 10 |
| **2** | 1 000 | 250 | 10 |
| **3** | 400 | 100 | 45 |

**Table 5-11~~1~~ - Considered nuclear unit types**

| Scenarios | Unit Nominal Capacity (MWe) | Number of units | Total Nominal Capacity (MWe) |
|---|---|---|---|
| **Base case** | - | - | - |
| **A** | 400 | 2 | 800 |
| **B** | 1 000 | 1 | 1 000 |
| **C** | 1 200 | 1 | 1 200 |
| **D** | 400 | 4 | 1 600 |
| **E** | 1 200 | 2 | 2 400 |

**Table 52 - Nuclear capacity scenarios**

## 5•3•2• Load

Since provided model represents year 2034, load time series had to be scaled to meet official load forecasts. The load profile remained constant, with hourly load values varying depending on the target demand. The latest *Integrated national energy and climate plan* [1], or INECP served as a source for future projections of energy demand in Serbia. Three main scenarios are presented in this document:

- *With Existing Measures* (WEM) scenario, which has a projection of the development of the energy sector and other emissions under existing policies and measures. This scenario does not lead to the accomplishment of the INECP targets and objectives, but is used as a reference,
- *With advanced measures* (WAM) scenario includes all the planned additional policies and measures that contribute to the achievement of the targets and the objectives of the INECP. This scenario is called Scenario S, it is described in INECP Chapter 5, and it is compared with the WEM scenario in order to show the additional effort which is needed for it to materialize,
- A variation of scenario S, denoted as *Scenario S-N* considers the introduction of Nuclear Power Plants of a total capacity of 1,000 MW after 2040 in the Serbian power system, to examine their possible contribution to the decarbonization pathway towards 2050. In the next sections, the projections for Scenario S are compared with the projections of scenario WEM (described in detail in Chapter 4) to show the extra effort which is required in each dimension for the achievement of the targets and objectives of the INECP.

The forecasted electricity generation for each of these scenarios are as follows:

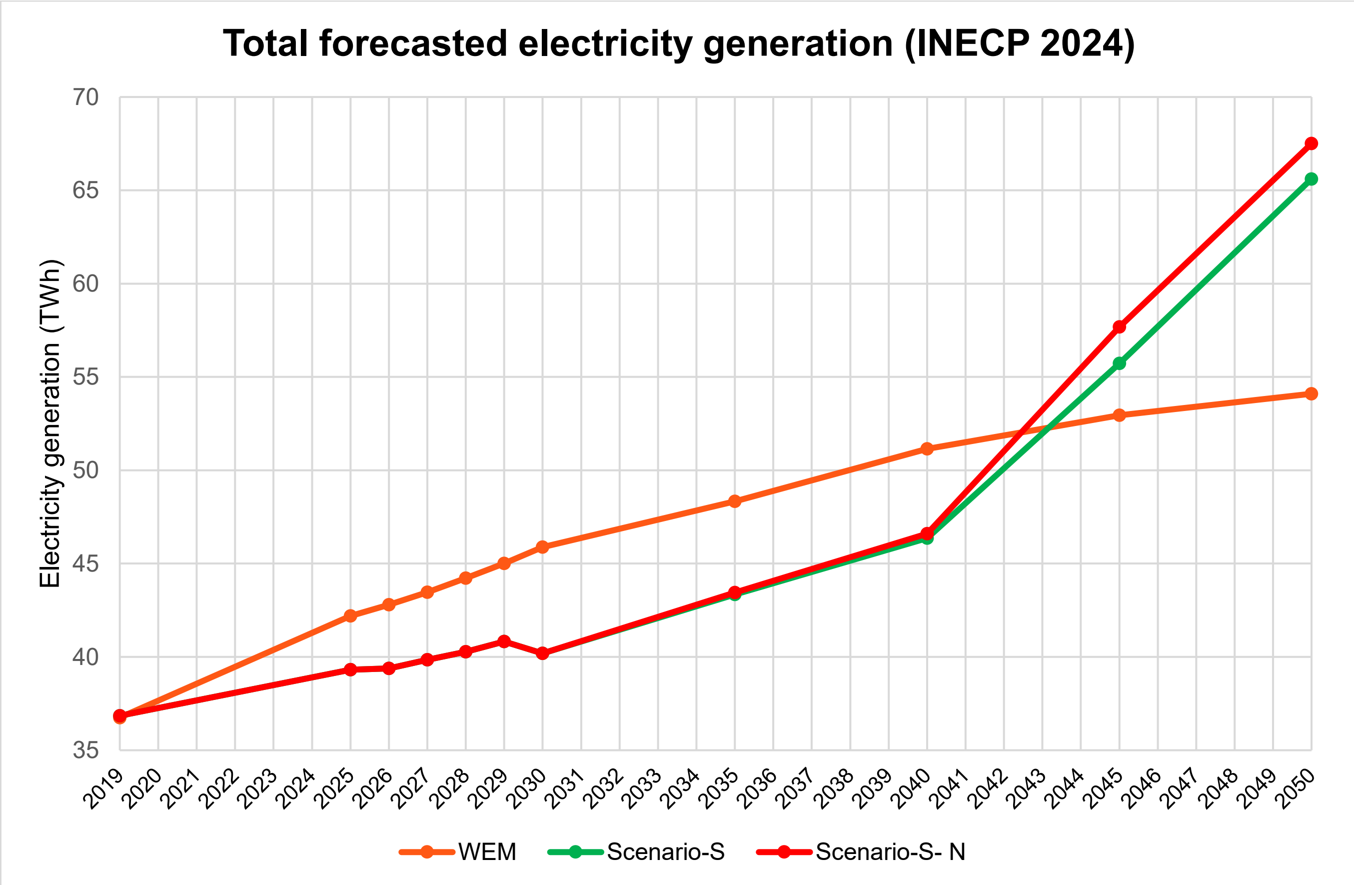


**Figure 5-111 - Total forecasted electricity generation (INECP 2024)**

To be conservative, while remaining neutral regarding the installed capacity, Scenario S was selected and the electricity generation value served as a proxy for the total electricity demand, thus considering that all electricity generation is destined to national consumption. The 2034 hourly load curve for the selected climate year present in the ANTARES© model was scaled up to account for an annual energy consumption of 55.73 TWh, a 14% increase.

The following graphs present the new load curve under two different visualizations. A clear daily pattern with two peaks is visible, along with a strong winter-peaking behavior.

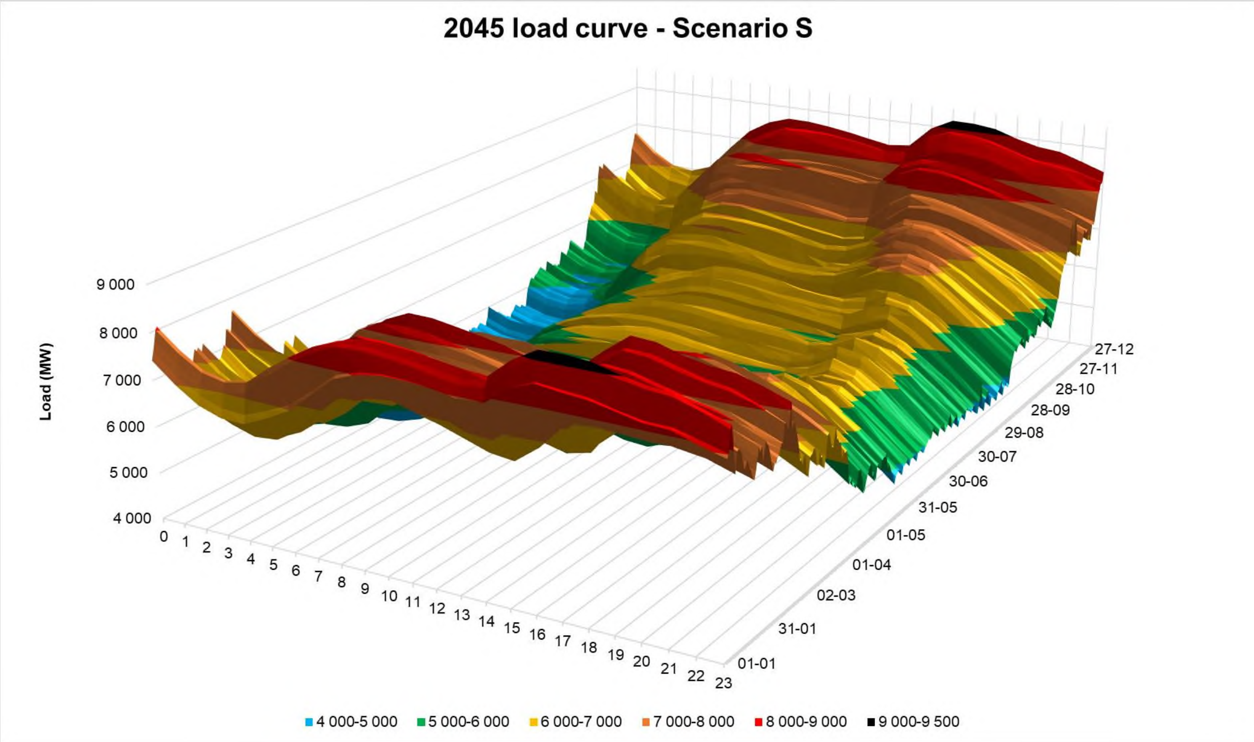


Figure 5-222 – Three-dimensional representation of the 2045 load curve

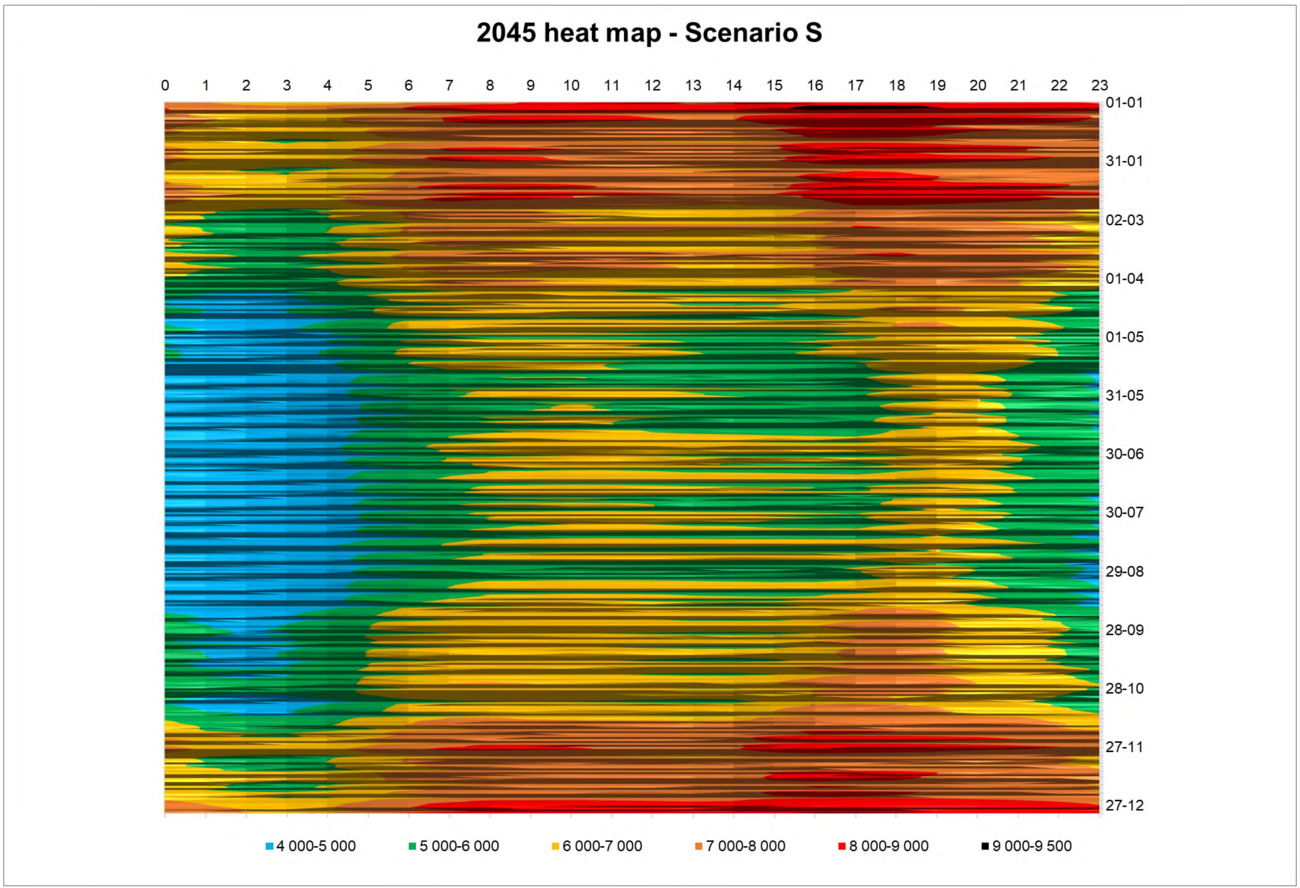


Figure 5-333 - Heat map representation of the 2045 load curve

### 5•3•3• Generation

Like the load, generation also needs to be updated to represent the 2045 generation fleet. Apart from the obvious addition of nuclear units, treated in scenarios as previously mentioned, two modifications were made to the model, the rest remained identical.

One important point to be noted is that the characteristics of the Serbian node in the model were updated, but all other nodes (countries) parameters remained unchanged. That is to say that the subsequent simulations were performed for a 2045 Republic of Serbia based on official information available to Serbian TSO at the time of data collection included in a 2034 vision of the rest of the interconnected European system. The resulting equilibrium, especially in terms of imports/exports with the neighbours has thus to be treated with caution.

| Unit type | Capacity (MW) | Comments |
|---|---|---|
| Nuclear | - | Depending on the scenario, |
| Lignite | 5 005.7 | Net capacity |
| Existing CCGT | 400.9 | Installed capacity: 3 units at Pančevo & 2 units at Novi Sad |
| Hydro run-of-river | 1 321 | *This is the maximum generation output per hour, not the installed capacity per se* |
| Hydro storage | 4 500 | *This is the maximum generation output per day (MWday), not the installed capacity per se* |
| Wind onshore | 6 436 | *This is the maximum generation output, not the installed capacity per se* |
| Solar PV | 5 580 | *This is the maximum generation output per hour, not the installed capacity per se* |
| Waste to power | 22.1 | |

**Table 5-222: Net generation capacity in the model (year 2045)**

## 5•3•4• Results

Complete hourly simulations, for the full 2045 year, were performed for all six scenarios (base case and 5 potential nuclear additions). Figures below show an analysis of the results.

Once again, it is necessary to emphasize the fact that these results must be considered with caution, as they represent only one climatic year, modified to reflect 2045 in Serbia only. A much deeper study is required to assess the adequacy of the system and the full impact of new nuclear units in the Serbian electricity system. This analysis would need to take into account a much higher number of potential climate years and consider both security of supply and system balancing points of view.

The following graphs are the aggregated results of the study and illustrate the points made above.

### 5•3•4•1• Generation mix

The following graphs show the annual production of each sector for the different scenarios studied.

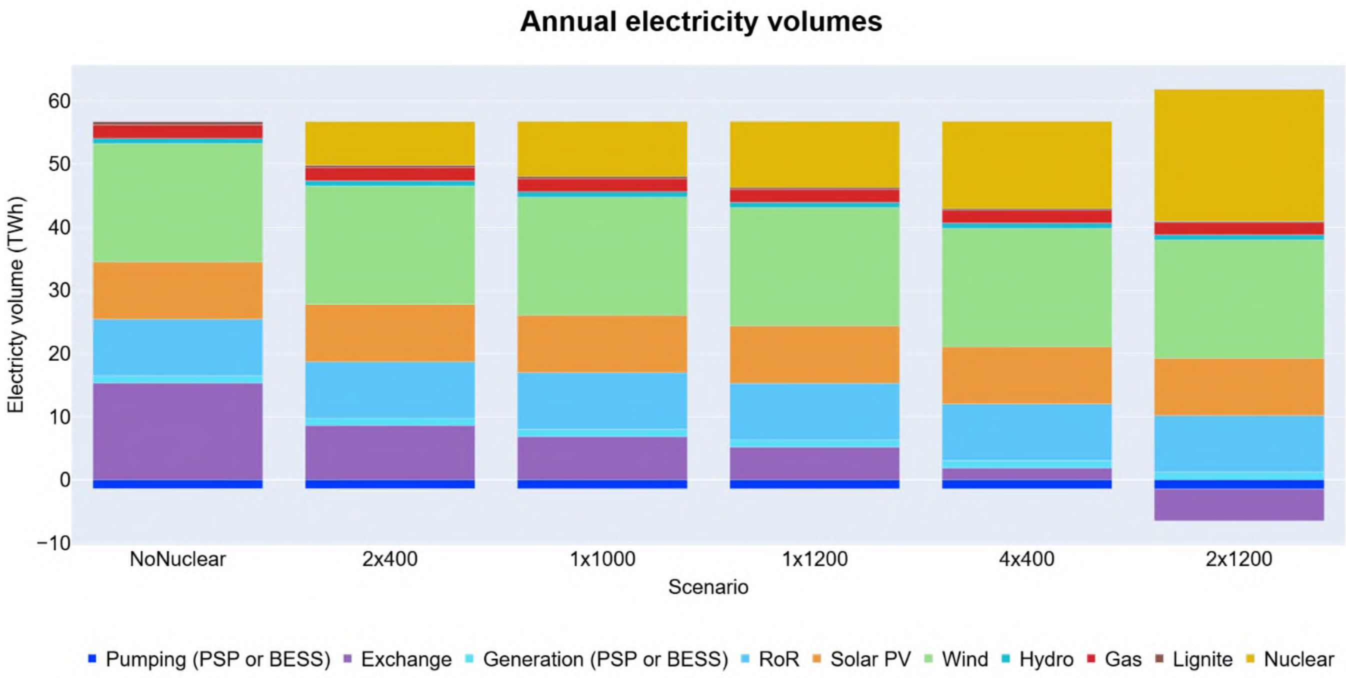


Figure 5-444: Total annual electricity volumes

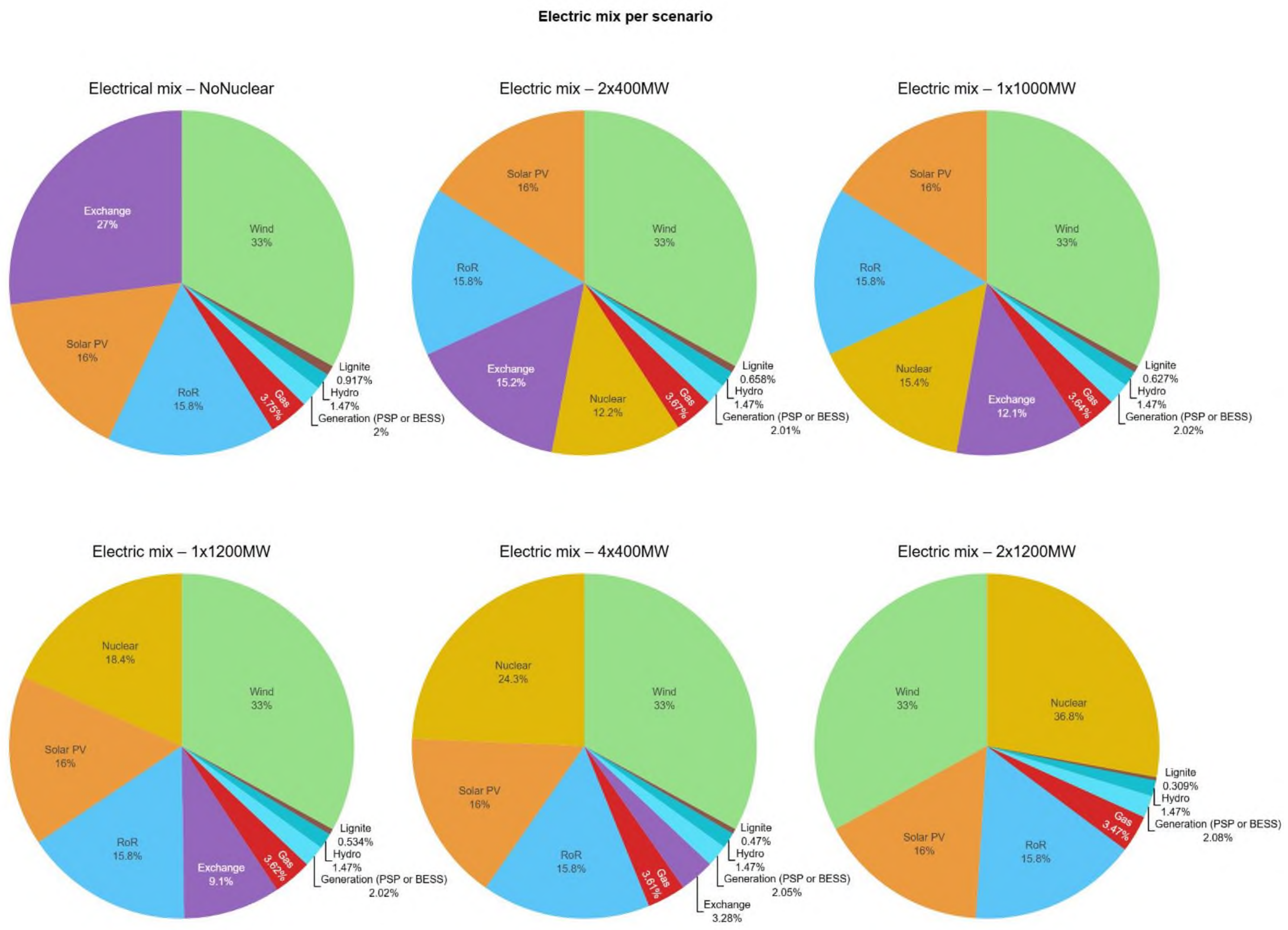


**Figure 5-555: Electric mix per scenario**

The main learnings are:

- Serbia becomes a net exporter of electricity in the 2*1200 MW scenario
- Nuclear power affects the generation of lignite and gas units in Serbia
  - Lignite generation part in the electric mix fell from 0.917% for the no nuclear scenario to 0.3% for the 2x1200MW scenario
  - Gas generation part in the electric mix fell from 3.75% for the no nuclear scenario to 3.47% for the 2x1200MW scenario

### 5•3•4•2• Variation between no nuclear and nuclear scenarios

It is interesting to look at the variation for each sector.

The following graph shows annual volumes by sector and scenario (bar, left y-axis) and the percentage change compared to the scenario without nuclear power (scatter, right y-axis).

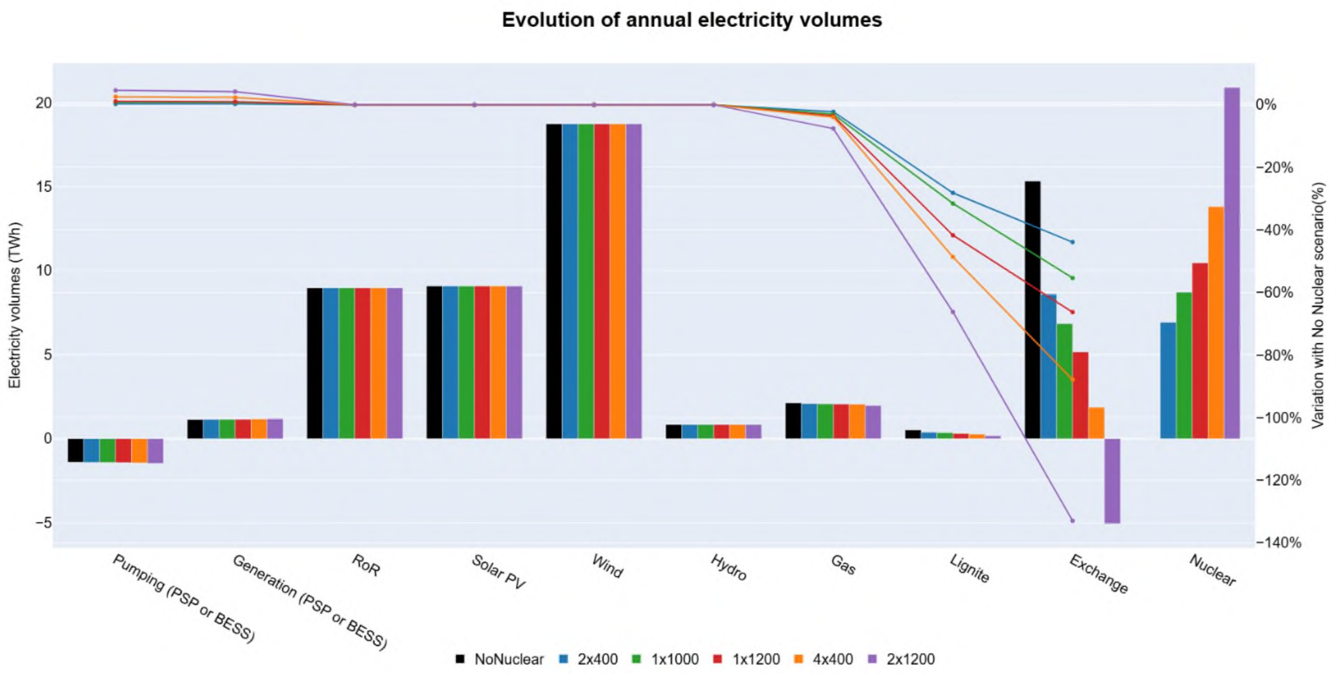


Figure 5-666 -Generation level variation compared to Base Case

The main learnings are:

- Nuclear power affects the generation of lignite and gas units in Serbia, respectively decreasing of 66% and 8% for the 2*1200MW scenario
- Serbia becomes a net exporter of electricity in the 2*1200 MW scenario. For the intermediate scenarios, Serbia’s imports are greatly reduced: they are reduced by 44% for 2x400MW scenario, 55% for 1x1000MW scenario, 66% for 1x1200MW scenario and 88% for 4x400MW scenario.

### 5•3•4•3• Exchanges with neighboring countries

The following graph shows exchanges with neighboring countries

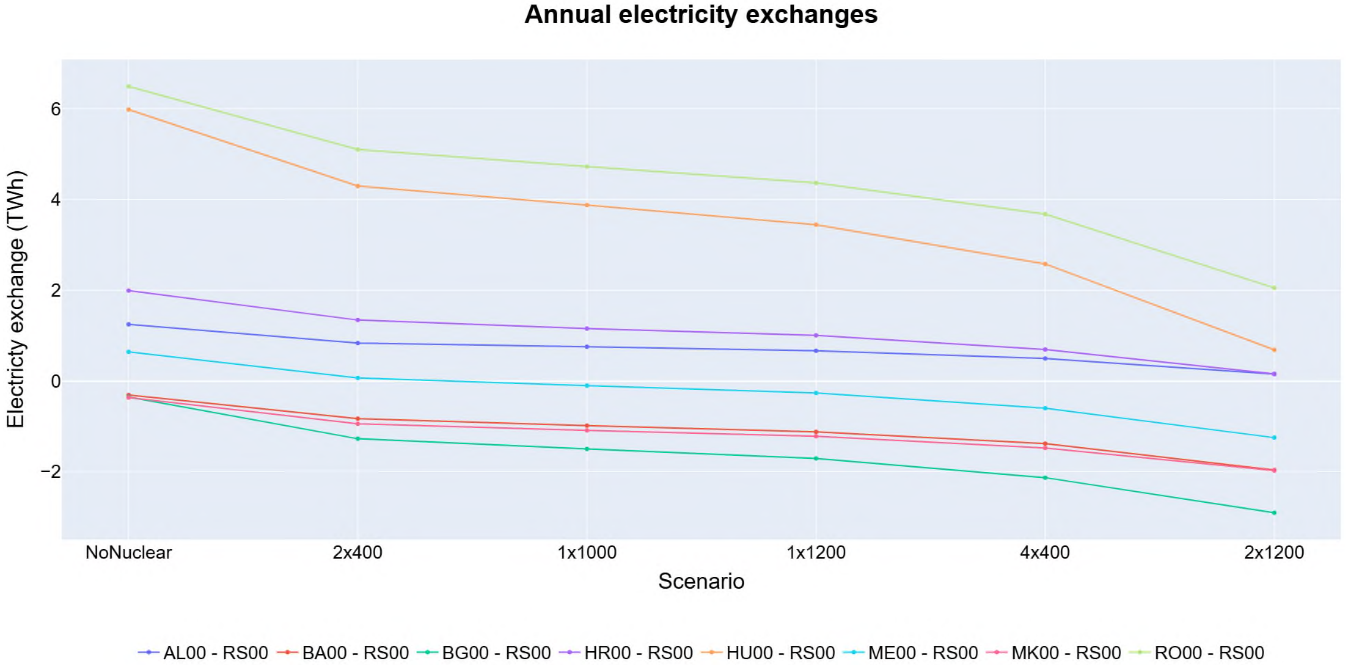


**Figure 5-777 - Total annual energy exchanges**

| AL00 | BA00 | BG00 | HR00 | HU00 | ME00 | MK00 | RO00 | RS00 |
|---|---|---|---|---|---|---|---|---|
| Albania | Bosnia and Herzegovina | Bulgaria | Croatia | Hungary | Montenegro | North Macedonia | Romania | Serbia |

**Table 5-333: Country codes table**

Main findings found on exchanges are the following:

- No matter the scenario, Serbia keeps importing from Romania, Hungary, Croatia and Albania
- No matter the scenario, Serbia keeps exporting to Bosnia and Herzegovina, North Macedonia and Bulgaria
- Montenegro changed its status from exporter to importer to Serbia following the addition of nuclear power

## 5•3•5• Conclusion of supply-demand analysis

The main conclusions of the supply-demand study are:

- Nuclear power affects the generation of lignite and gas units in Serbia, respectively decreasing of 66% and 8% for the 2*1200MW scenario
- Serbia becomes a net exporter of electricity in the 2*1200 MW scenario
- No matter the scenario, Serbia keeps importing from Romania, Hungary, Croatia and Albania

Once again, it is necessary to emphasize the fact that these results must be considered with caution, as they represent only one climatic year, modified to reflect 2045 in Serbia only. A much deeper study is required to assess the adequacy of the system and the full impact of new nuclear units in the Serbian electricity system.

# 6• Conclusion

The activities conducted by EDF and Egis under the contract "*Preparation of Preliminary Technical Study for the Consideration of the Peacetime Application of Nuclear Energy in the Republic of Serbia – JN-14/24"* have been successfully completed in alignment with the objectives set by Serbia's Ministry of Mining and Energy.

Launched in November 2024, this preliminary study produced three key outputs, each corresponding to a dedicated Work Package:

- Work Package #1: Development of a Nuclear Roadmap – This detailed report outlines priority actions, critical milestones, and key recommendations proposed by EDF to guide Serbia's nuclear energy planning.
- Work Package #2: Technology Assessment and Nuclear Market Survey – This description provides the Government of Serbia with an initial screening and comparison of reactor technologies suitable for future deployment. It offers a transparent and structured overview of the main technology options and identifies areas requiring further analysis, stakeholder engagement, and capacity-building.
- Work Package #3: Preliminary supply-demand analysis to define potential power future (2045) dispatches in Serbia – This study has enabled us to carry out an initial assessment of the inclusion of nuclear power in Serbia with five different profiles for new nuclear generation.

Among the key recommendations emerging from these Work Packages, the study acknowledges that significant efforts are still required moving forward. In particular, the study emphasizes the importance of building institutional, regulatory, and technical capacities. This integrated approach is essential to ensure that Serbia's nuclear energy ambitions are supported by a robust and adaptive enabling environment.

In addition, the results presented in this summary reflect the collective engagement, technical contributions, and constructive exchanges that have characterized the collaboration throughout the project.

EDF expresses its sincere appreciation for the opportunity to collaborate with the Republic of Serbia on this project.

The EDF Group stands as a key player in the nuclear sector, uniquely qualified as a vendor, operator, designer, and builder with a deep-rooted history of nuclear projects in France and abroad. Our experience, which spans several decades and encompasses the largest fleet of nuclear power plants in the world – 66 reactors in France and the United Kingdom – demonstrates our capabilities and our commitment.

EDF remain at the disposal of our Serbian counterparts and are open to exploring future avenues of cooperation in support of the country's nuclear energy development.

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