PRECONDITIONS FOR INITIATING A NUCLEAR ENERGY PROGRAMME IN THE REPUBLIC OF MOLDOVA: POLITICAL, LEGAL AND REGULATORY ASPECTS. IMPACT WITHIN REGIONAL BOUNDARIES ENERGY EXCHANGE WITH NEIGHBOURS ROMANIA AND UKRAINE

PREMISE PENTRU INIȚIEREA UNUI PROGRAM ENERGETIC NUCLEAR ÎN REPUBLICA MOLDOVA: ASPECTE POLITICO-JURIDICE ȘI DE REGLEMENTARE. IMPACTUL REGIONAL ÎN CONTEXTUL SCHIMBULUI DE ENERGIE CU ROMÂNIA ȘI UCRAINA

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Abstract: *The climate crisis is one of the defining challenges of this generation. However, countries are not on track in their efforts to limit global warming. To reduce greenhouse gas emissions in line with the pathways outlined by the Intergovernmental Panel on Climate Change (IPCC), all available options must be pursued. The deployment of new nuclear capacity will take place at the national level as part of each country's specific commitments to achieve net zero goals. With the initiation of nuclear energy program and the implementation of measures to meet all the challenges related to them, nuclear energy will be put on a credible path to make its full contribution to reducing greenhouse gas emissions to net zero by 2050, while maintaining high levels of security of supply as part of the successful energy transition both globally and nationally. This paper proposes concrete steps for the initiation of a Nuclear Programme in the Republic of Moldova. In addition, a preliminary analysis of the energy situation of the Republic of Moldova is carried out through synthetic*

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performance indicators (KPIs), in the framework of scenarios covering the past, current and future energy context, including the implementation of a small modular reactor (SMR) in the Republic of Moldova. The analysis also highlights aspects of the regional impact related to the electricity exchange of Moldova's power system with its neighbours Romania and Ukraine.

Keywords: energy security, energy transition, roadmap, nuclear energy, small modular reactors, key performance indicators, regional impact, energy crisis.

Rezumat: *Criza climatică este una dintre provocările definitorii ale acestei generații. Cu toate acestea, țările nu sunt pe drumul cel bun în eforturile lor de a limita încălzirea globală. Pentru a reduce emisiile de gaze cu efect de seră în conformitate cu căile evidențiate de Grupul Interguvernamental pentru Schimbări Climatice (IPCC), trebuie urmărite toate opțiunile disponibile. Desfășurarea de noi capacități nucleare va avea loc la nivel național în cadrul angajamentelor specifice fiecărei țări de a atinge obiectivele net zero. Odată cu inițierea programelor energetice nucleare și implementarea măsurilor pentru a răspunde tuturor provocărilor legate de acestea, energia nucleară va fi pusă pe o cale credibilă pentru a-și oferi întreaga contribuție la reducerea emisiilor de gaze cu efect de seră la zero net până în 2050, menținând în același timp niveluri ridicate de securitate a aprovizionării, ca parte a tranziției energetice de succes atât la nivel global, cât și la nivel național. Prezenta lucrare propune pași concreți pentru inițierea unui Program nuclear în Republica Moldova. În plus, este realizată o analiză preliminară a situației energetice a Republicii Moldova prin prisma unor indicatori sintetici de performanță, în cadrul unor scenarii care vizează contextul energetic anterior, actual și de viitor, care include și implementarea unui reactor modular de mici dimensiuni în Republica Moldova. Analiza pune în evidență și aspecte ale impactului regional legat de schimbul de energie electrică a sistemului electroenergetic din Moldova cu vecinii săi România și Ucraina.*

Cuvinte cheie: securitate energetică, tranziție energetică, foaie de parcurs, energie nucleară, reactoare modulare mici, indicatori esențiali de performanță, impact regional, criza energetică.

1. Introduction

Climate disruption and the threats to global energy security caused by the Russia-Ukraine war have clearly exposed the vulnerability of energy supply chains, underscoring the pressing need for robust and secure energy sources. In this context, some countries, notably in the European Union, have emphasized the essential role of nuclear energy production in addressing these concerns and ensuring energy security.

The global agreement, recently signed at COP 28, also emphasizes the importance of nuclear energy in the wider context of the energy transition and the acceleration of low and zero emission technologies [1]. As the forefront of the energy transition is moving unprecedentedly towards sustainable, low-carbon and environmentally responsible energy supply, nuclear-electric power is emerging as a compelling solution to the energy trilemma. However, the expanding role of nuclear-electric energy is far from straightforward, characterized by complex challenges that relate to economic viability, cost-effectiveness, fuel supply dynamics, evolving technologies, regulatory framework, societal acceptance and complex geopolitics intertwined with the expanding role of nuclear energy. This issue remains determined to underpin insightful research on nuclear energy, providing a diverse range of perspectives to enable a comprehensive exploration of the multifaceted role of nuclear-electric power.

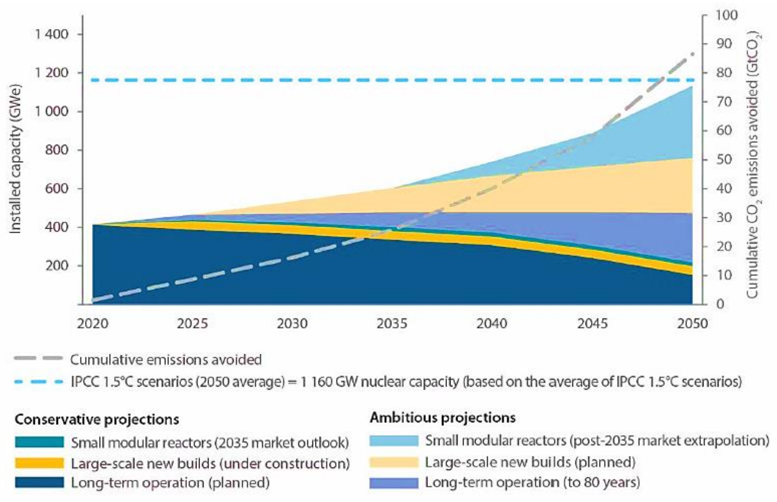

Figure 1: Contribution of nuclear energy to net zero for different scenarios [2]

Analysis by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) shows that tripling global installed nuclear capacity is part of a realistic pathway to achieve the "net zero" goals by 2050 and keep global average temperature increase below 1.5°C. This is an ambitious target for nuclear power, but one that is not being met. It can be achieved through a combination of long-term operation with large-scale new releases and deployment of Small Modular Reactors (SMRs), as shown in Figure 1.

Such an increase in nuclear capacity could avoid more than 80 gigatons of cumulative emissions between 2024 and 2050 through a combination of long-term operation of existing reactors, large-scale new reactors construction and deployment of small modular reactors (SMRs). By 2050, nuclear power could thus displace 5 gigatons of emissions each year, which is more than the annual emissions of the US economy today.

2. The role of nuclear energy in achieving “net zero”

Worldwide, 444 nuclear reactors with 394 gigawatts provide about 2,500 terawatt-hours of electricity per year, about 10% of total global supply [3, 4]. In addition, another 50 reactors are under construction to provide an additional 55 gigawatts of capacity and more than 100 additional reactors are planned. Widely accepted models show that nuclear energy has a decisive role to play in mitigating global climate change [5].

As already highlighted in the IPCC's 2018 Synthesis Report [6], the world is not on track to achieve the decarbonization goals of the Paris Agreement because sustained reductions in greenhouse gas emissions are not occurring at the required speed. Things have gotten worse since the Agreement was signed. Global emissions are expected to rise by 2030 rather than suffer the steep cuts demanded by leading climate scientists.

Indeed, numerous international studies show that the inclusion of significant shares of nuclear energy is, in the vast majority of cases, the most cost-efficient way to achieve these objectives. The precise level of the cost-minimizing share of nuclear energy in the generation mix depends on the following three country-specific parameters that affect the overall functioning of the power and energy systems:

1. the relative costs of nuclear compared to other low-carbon technologies such as hydro, wind and/or solar PV [7];
2. availability of flexibility resources to balance the intermittency of wind and solar PV generation [8];
3. matching wind and solar PV generation with electricity demand [9].

Even if the potential contribution of nuclear energy would correspond to what is needed to achieve net zero, both globally and nationally by 2050, it is clear that a number of challenges remain to achieve it, such as:

- Nuclear energy must become an attractive investment proposal for public and private investors.
- Ensuring a healthy and resilient supply chain where countries will be able to benefit from working together through public and private ways of

cooperation to avoid supply chain redundancies and improve cost competitiveness to achieve efficiencies at scale for a new industry.

- Increasing trust and confidence of society and citizens which requires sustained investment in open and transparent engagement and scientific communication to inform citizens about advances in nuclear technology, safety measures and waste disposal solutions through dialogue and education.
- Train the highly skilled workforce needed to sustain a tripling or more of global installed nuclear capacity requiring both familiar and new creative solutions to re-establish a robust nuclear education network.

With the implementation of these measures nuclear power will be put on a credible path to make its full contribution to reducing greenhouse gas emissions to net zero by 2050, while maintaining high levels of security of supply as part of a successful energy transition, both globally and nationally.

3. Results of the nuclear energy approach in Europe

Nuclear energy has been a battleground in inter-European relations, possibly the most fraught of tensions, but now a thing of the past. As the difficulty of achieving the stated ambitious decarbonization goals becomes increasingly clear, some EU member countries have managed to abandon ideological positions and pay attention to real results. The answer is clear and stark: only countries that have embraced nuclear power or are endowed with hydropower, or both, have achieved low-carbon electricity.

In the Europe of 2023 (see Table 1), only three countries have reached very low carbon for their electricity needs: Sweden, Norway and France. Sweden relies on a combination of hydro (40%), nuclear (30%) and wind (18%); Norway relies almost exclusively on hydro (74%) and France relies largely on nuclear (62% in 2023).

Table 1. **Average carbon content of electricity use in EU Member States (2023)** [10]

Country	CO_2 emissions (g/kWh)	Country	CO_2 emissions (g/kWh)
Sweden	37	Hungary	291
Norway	43	Ireland	304
France	53	Italy	323
Switzerland	87	România	335
Finland	104	Estonia	393
Portugal	105	Bulgaria	405
Spain	136	Greece	406
Belgium	147	Turkey	408

These figures reflect electricity use, including electricity imports and exports, rather than production. In the case of Norway and Sweden, their carbon intensity would be lower if they did not export "clean electricity" to Denmark and import "dirty electricity" (from coal or gas) from Denmark. Denmark is a country normally associated with strong policies in favour of renewables, especially wind power however, the carbon content of Denmark's electricity demand is 5.8 times higher than Sweden's and 5 times higher than Norway's.

In fact, Europe is that region of the world with the highest dependence on nuclear electricity (19% of total generation in 2022): among 15 countries in the world most dependent on nuclear power, 13 are in Europe (see Table 2), and 12 of these countries are EU members (the exception is Switzerland). Although some of these countries decided at some point to quite nuclear, only Germany has done so. It is difficult to believe that the remaining countries will eventually implement what they have decided, as this could only be possible by increasing reliance on coal or gas to compensate the intermittency of wind and solar power and contradicting emission reduction targets.

Table 2. **Share of electricity from nuclear energy** [11]

Country	Share, %	Country	Share, %
France	63	Bulgaria	33
Slovakia	59	Armenia	31
Hungary	47	South Korea	30
Belgium	46	Sweden	30
Slovenia	43	Spain	20
Czech Republic	37	Russia	19
Switzerland	36	România	18
Finland	35		

Nuclear energy was one of the pillars of the creation of the European Union. The success of the nuclear alliance's efforts was, in the first Instance, the EU's agreement in 2022 to include nuclear energy in the taxonomy (EU regulation to increase the level of environmental protection by diverting capital away from environmentally damaging investments towards greener alternatives). However, this is conditional on meeting environmental safety preconditions [12].

Additionally, in December 2023, the Council of the European Union adopted an amendment by the European Parliament to add nuclear energy to the list of strategic technologies under the Net Zero Industry Act. The regulation is intended to facilitate the financing of investments in zero carbon technologies, the reduction of CO2 emissions, access to markets and the promotion of innovation in zero carbon technologies in the EU. If this form of regulation is eventually adopted (the legislative process is still ongoing), it would meet the expectations of many countries that demand that nuclear energy and investments in this sector be treated like other areas. Also, significant is the declaration by 22 countries, adopted at COP 28, in support of tripling nuclear power generation capacity by 2050 [13], indicating that nuclear energy can play an important role in the energy transition.

4. National landscape on SMR technology approach

Over the last few years, there has been a growing discussion in the Republic of Moldova about the opportunity to invest in the new technology of small modular reactors. These discussions come against the background of multiple challenges to the country's energy security created by the insufficiency of its own power generation capacities, the almost total dependence on hydrocarbon imports, the vulnerability of the electricity transmission infrastructure, the lack of significant energy storage capacities, the modest share of renewable energy sources (RES) in the national energy mix, etc. In addition, there is the need to decarbonize the national economy, increase the share of clean electricity in the national energy mix, increase the use of cogeneration and achieve the climate objectives set by our country. The discussions are sporadic, being mainly conducted by some energy experts. However, as international practice shows, for the development of the nuclear energy sector, systemic efforts are needed under the aegis of a well-defined National Nuclear Energy Programme (NNEP). A precondition for the initiation of such Plan is a consensus at the political level, materialized by the inclusion of a nuclear energy objective in the country's strategic development documents.

5. The current political context in the Republic of Moldova

The lack of systemic approach with reference to the development of the nuclear energy branch can also be deduced from the absence of this topic in the main country’s strategic documents in the field, such as the Concept of the Energy Strategy of the Republic of Moldova 2050 [14], approved at the end of 2022, the National Integrated Energy and Climate Plan 2025-2030 (PNIEC) [15]. At the moment, the Energy Strategy of the Republic of Moldova 2050 is being developed, but it is expected that it will reflect the same approach as the Concept approved at the end of 2022.

It has to be recognized that periodically and with increasing frequency, some promising messages are also coming from the Ministry of Energy. But these messages are cautious and concrete action is lacking. A recent example is the signing on December 2, 2023, by the Republic of Moldova of the Declaration of the Group of 22 States at the UN Climate Change Conference (COP 28), which called on the international community to triple nuclear power generation capacity by 2050 [13]. Surprisingly, along with states with long experience in managing nuclear energy infrastructure, the Republic of Moldova was also a signatory country. Shortly, however, the Minister of Energy of the Republic of Moldova explained that the signing of this declaration is only a political step and does not mean that our country will immediately start developing a national nuclear energy programme.

In the absence of a clear vision and political support, we cannot expect stronger messages from the representatives of the Government in Chisinau, or certain systemic actions. However, we should note that all the states in the region, without exception, already have nuclear energy infrastructure (Ukraine, Romania, Slovakia, Czech Republic, Hungary, Bulgaria, Belarus, Armenia), or have recently started or are planning to start nuclear energy programs soon (Albania, Serbia, Poland, Lithuania, Latvia, Estonia, Georgia, Azerbaijan, Turkey) as shown in Figure 2.

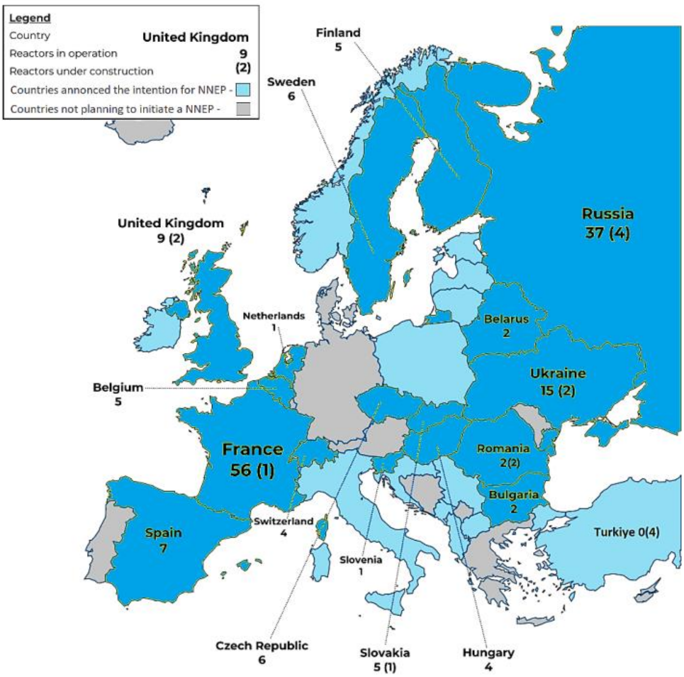

Figure 2: Countries of Europe operating nuclear energy infrastructure

In addition to conventional reactors, neighbouring countries are actively promoting new advanced small modular reactor technologies which offer several technical, economic, financial and safety advantages. These advantages are widely described in the specialized literature. As a consequence, referring to the particular case of the Republic of Moldova, where there are not even consistent discussions on nuclear energy, we will address other aspects, corresponding to the stage we are at, namely those related to the initial steps that our country will have to take in order to implement its own National Nuclear Energy Plan.

6. Methodological aspects of initiating a National Nuclear Programme

There is no doubt that the initiation of a National Nuclear Energy Programme is a major challenge for any State. For States planning to initiate a National Nuclear Energy Programme, the International Atomic Energy Agency (IAEA) provides a detailed methodology entitled "Milestones Approach" [15]. This methodology describes 19 nuclear infrastructure issues that need to be addressed consistently over three distinct stages of implementing a National Nuclear Energy Programme.

Stage I - pre-project, refers to a preliminary intention to develop a NNEP. This stage includes a set of activities to analyse and estimate current capabilities and future needs in terms of energy resources and infrastructure, should a decision be taken to implement a NNEP. At the end of the implementation of this stage a decision is taken whether or not to initiate a National Nuclear Energy Programme. A precondition for the successful launch and implementation of the first stage is the existence of a political consensus that would allow the inclusion in the country's energy strategy of the objective of developing nuclear energy in the future.

Phase II - the actual initiation of a NNEP, involves a set of actions necessary for the successful launch of the nuclear infrastructure construction process. These actions refer to the development of the legal and regulatory framework of the nuclear energy field, the establishment and definition of roles between the national actors involved in the implementation of the NNEP, the finalization of the technical concept of the future nuclear power plant, the adjustment of the existing energy infrastructure, the identification of potential sources of financing for the implementation of the NNEP, etc.

Phase III includes design, construction, commissioning and operation of the nuclear infrastructure. This phase also includes extensive capacity building activities for the national institutions that will own, operate and supervise the NPP activity after commissioning.

This staged methodology represents the roadmap that every country planning to implement a nuclear energy programme must follow. Superimposed on the current realities in the Republic of Moldova, this methodology helps us to understand where we are and what are the first steps to be taken in the perspective of implementing a NNEP.

7. Findings of the current situation

The retrospective analysis of previous initiatives in the field of nuclear energy allows us to state that the Republic of Moldova has not taken any essential steps towards the initiation of a NNEP so far. In fact, we are not even at the first stage. No actions have been taken to discuss and reach a political consensus on the subject of initiating an NNEP. The relevant objectives are also missing in the sectoral strategic documents. Both the Energy Strategy 2013-2030 and the Energy Strategy Concept 2050, and more recently the draft Integrated National Energy and Climate Plan 2025-2030, mention only in passing the prospect of developing the nuclear energy branch, without a measurable objective or establishing a clear time horizon.

Things are no better even in terms of the legal framework. Thus, in accordance with Article 77 of Law No. 1515 of 16.06.1993, "On environmental protection", the construction of thermonuclear power plants on the territory of the Republic of Moldova is prohibited [16]. As a result, the national regulatory framework, developed over the last 30 years, focuses almost exclusively on the regulation of ionizing radiation while the field of nuclear energy has remained uncovered.

On the other hand, it must be recognized that, during the period of independence, the Republic of Moldova signed and ratified most of the international agreements, treaties and conventions relevant to the field of nuclear safety, security and protection. Our country also became a member of the International Atomic Energy Agency in 1997. In accordance with the IAEA requirements, the National Nuclear Regulatory Authority, the "National Agency for the Regulation of Nuclear and Radiological Activities" was established. More recently, the "National Strategy on Radioactive Waste Management for 2017-2026" was approved. As a result, there is an initial regulatory basis that would facilitate the process of initiating a NNEP, if a political consensus on this issue could be reached.

8. Essential steps to be taken on the way to starting an NNEP

Being just at the beginning of the road, several steps are needed to initiate a National Nuclear Energy Programme. We will only touch on a few of the most important aspects.

A first step to be accomplished, which corresponds to the methodological approach proposed by the IAEA, is the formation of a "national position" [17]. This refers to the state's intention and commitment to develop, implement, operate safely and sustainably a NNEP. This step implies the availability of a strategic vision, political willingness and political consensus on the subject of implementing a national nuclear energy project. Political consensus is essential and acts as a triggering mechanism for the other processes in the whole chain of actions aimed to contribute to the initiation and operation of a NNEP.

As demonstrated by the example of other countries, an important role in formulating the "national position" could be played by academics and energy experts who could initiate debates on the given field, involving political actors in these discussions. Further, the Government should incorporate the objective of developing the nuclear energy branch in the relevant strategic documents, and this would be a first step towards initiating a National Nuclear Energy Programme.

Another important step needed at the initial stage is to adjust the national regulatory framework, which is currently not permissive for the development of nuclear energy in the Republic of Moldova. The first step would be the elimination of Article 77 of Law No. 1515 of 16.06.1993, "On environmental protection", which prohibits the construction of thermonuclear power plants on the territory of the Republic of Moldova.

As the experience of other countries demonstrates, a major challenge for the initiation of the NNEP is society's reluctance towards nuclear energy. In the Republic of Moldova, no complex social research has been carried out so far that could clearly clarify the degree of societal reluctance towards nuclear energy. However, we are willing to assume that it would be considerably negative, given the collective memory of the Chernobyl disaster in 1986. Social reticence is a latent challenge that cannot be diminished in a short period of time. However, it can be overcome by objectively and consistently informing society about the social, economic and energy security advantages that the new SMR's technology would offer to our country.

9. Research, development and deployment behind SMRs is picking up

Today's Republic of Moldova energy crisis and the existing situation regarding the gas transit contract that expired from the 1st of January, 2025 concerning the supply of Russian natural gas through Ukraine and also, reducing reliance on imported fossil fuels has become the top energy security priority.

In Republic of Moldova, while wind and solar PV are expected to lead the push to replace fossil fuels, they must be complemented by dispatchable resources. As global today's second largest source of low emissions power after hydropower, and with its dispatchability and growth potential, nuclear – in countries where it is accepted – can help ensure secure, diverse and low emissions electricity systems.

Another aspect in ensuring the energy security of supply is to provide the needed baseload, as Cuciurgani, the gas fired power plant used for stable electricity supply in the past, is not competitive if using gas at market prices. This power plant which produced constantly electricity at a power of 500 – 600 MW in the past cannot be replaced easily by variable wind and solar generation.

A good solution for the Republic of Moldova is to use small modular reactors that holds particular promise. Several SMR designs have inherent safety and waste management attributes that could support social acceptance and unlock significant private venture capital for research and development, as well as demonstration and deployment [18].

SMRs could also be used to meet the need for flexibility in power generation demanded by electricity systems with high shares of wind and solar. SMRs may be well suited for flexible operation, as is already the case for some traditionally largescale reactors, which in high renewable scenarios could improve profitability as captured electricity prices increases. In addition, flexibility could be achieved not only through load-following of electricity production, but also with flexible co-generation, for instance via hydrogen production or thermal storage [18]. According to the International Atomic Energy Agency (IAEA) Hybrid Energy Systems integrate energy conversion processes to optimize energy management, reliability, security, and sustainability. Also, Energy Supply Security is a reliable continuous supply of energy at an affordable cost. Options to Enhance Energy Supply Security using Hybrid Energy Systems based on SMR are presented in Figure 3 [19].

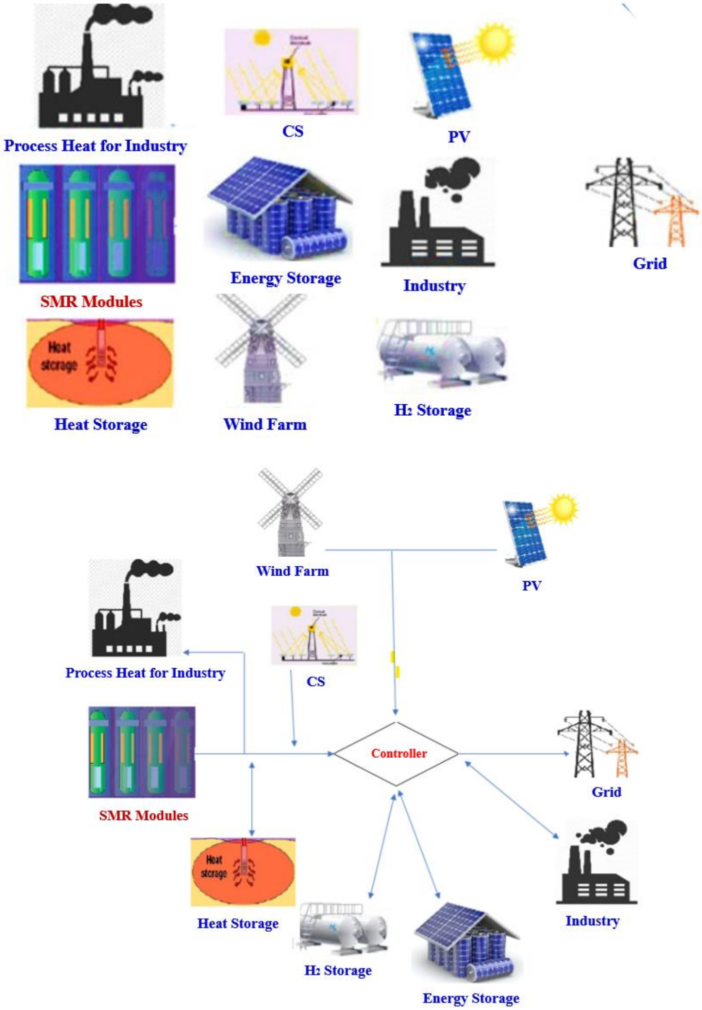

Figure 3: SMR Renewables Hybrid Energy System to Reduce GHG Emission [19]

Advanced technologies such as small modular reactors (SMRs) and microreactors (MRs) can produce baseload and dispatchable electricity as well as other clean energy products needed to decarbonize sectors and also it can facilitate for a robust country as Republic of Moldova to become energy independent with sufficient energy potential.

The main global trends reflected in [20], as regarding the major strategic energy pathways, must impose the Republic of Moldova to join these trends, if it is expected a successfully integration into the global energy transition.

The market for SMRs is developing very quickly, fuelled by technological innovations, growing energy demands and an increasing focus on clean and dependable power

Like other electricity generation technologies, SMRs can be evaluated using the levelized cost of electricity (LCOE) metric, which represents the per megawatt-hour cost of building and operating a plant over its lifetime. While a key challenge in SMR deployment is managing the high upfront capital expenditures (CAPEX) associated with construction, which significantly impacts LCOE, SMRs are designed for modular and standardized production of components, which can reduce construction times and costs [21]. Also, this modularity makes the technology affordable for countries without experience in building complex industrial systems.

In conclusion to be mentioned that SMRs will be a key part of the clean energy transition, and countries interested in this technology, especially the Republic of Moldova must ensure that have a solid understanding of what is needed to successfully implement SMR projects.

10. Potential impact of a small NPP on the Republic of Moldova energy mix and regional impact on energy exchange with neighbours Romania and Ukraine

The mix of the energy production and consumption in any country, as well as the impact on energy exchange with neighbours can be described by specific KPIs. In order to assess the impact of a SMR in the Moldavian energy system, several KPIs are introduced below, which are then calculated for four scenarios:

– Situation before 1st of January 2025, when Cuciurgani power plant was producing without fuel limitations; this has been considered as being Scenario 1.

– Situation after 1st of January 2025, when Cuciurgani power plant is producing electrical energy new fuel type (coal), thus bringing limitations (Scenario 2).

– Situation after 1st of January 2025, when Cuciurgani power plant is producing electrical energy with limitations, while a SMR of 300 MW is also considered to produce energy within the Republic of Moldova's borders; this has been considered as being Scenario 3.

– Situation after 1st of January 2025, without Cuciurgani power plant production of electrical energy (due to e.g. commercial reasons), while the 300 MW SMR of Scenario 3 is also considered to produce energy inside the Republic of Moldova border; this has been considered Scenario 4.

The following formulas are used for the proposed KPIs:

1) Coverage of country consumption with local production (KPI_1):

$$KPI_1 = E_{Local_{Cons\_coverage}}[\%] = \frac{E_{Prod_{Local}}}{E_{Cons_{Local}}} \times 100 \quad (1)$$

where $E_{Prod_{Local}}$ and $E_{Cons_{Local}}$ are obtained by integrating the average power of production and consumption on the same time interval, with the relations:

$$E_{Cons} = \sum_{K=1}^{K=Final\_Interval} P_{Cons_{IntervaL\,K}} \times T_{Interval} \quad (2)$$

$$E_{Prod} = \sum_{K=1}^{K=Final\_Interval} P_{Prod_{IntervaL\,K}} \times T_{Interval} \quad (3)$$

$$P_{Prod_{IntervaL\,K}} = P_{Prod_{TPP_{IntervaL\,K}}} + P_{Prod_{HPP_{IntervaL\,K}}} + + P_{Prod\_RES_{IntervaL\,K}} \quad (4)$$

2) the rate between the energy balance of the country and its consumption (KPI_2):

$$KPI_2 = E_{Local_{Cons\_balance}}[\%] = \frac{E_{Balance}}{E_{Cons_{Local}}} \times 100 \quad (5)$$

where the balance is the sum of energies exchanged with the two neighbours: Romania and Ukraine:

$$E_{Balance} = E_{Exchange\_RO} + E_{Exchange\_UKR} \quad (6)$$

3) the share of CO_2 free local production compared with the country consumption (KPI_3):

$$KPI_3 = E_{Local_{CO2\_Free\_consumption}}[\%] = \frac{E_{CO2\_free\_production}}{E_{Cons_{Local}}} \times 100 \quad (7)$$

where $E_{Prod_{Local}}$ and $E_{Cons_{Local}}$ are obtained by integrating the average power of production and consumption on the same time interval, with the relations:

$$E_{CO2\_free\_production} = \sum_{K=1}^{K=Final\_Interval} P_{CO2\_free_{IntervaL\,K}} \times T_{Interval} \quad (8)$$

where CO_2 free production is the sum of hydro + renewables + nuclear production in the studied interval of time:

$$P_{CO2_{free_{IntervaL\,K}}} = P_{Hydo_{IntervaL\,K}} + P_{Renewables_{IntervaL\,K}} + P_{Nuclear_{IntervaL\,K}} \quad (9)$$

Based on the data obtained from the transparency site of Moldelectrica [23], the following data have been obtained for Scenario 1, by using as studied time window (TW) the month of December 2024:

$$E_{Cons_{Dec2024}} = \sum_{K=1}^{K=Int_{Dec}} P_{Cons_{IntervaL\,K}} \times 0.25 = 566.1\,GWh \quad (10)$$

$$E_{Prod_{Dec2024}} = \sum_{K=1}^{K=Int_{Dec}} P_{prod_{IntervaL\,K}} \times 0.25 = 456.5\,GWh \quad (11)$$

$$E_{CO2\_free\_production} = \sum_{K=1}^{K=Int_{Dec}} P_{CO2\_free_{IntervaL\,K}} \times 0.25 = 456.5\,GWh \quad (12)$$

$$KPI_{1_{S1}} = E_{Local_{Prod\_coverage}}[\%] = \frac{456.5}{566.1} \times 100 = 80.63\,\% \quad (13)$$

$$KPI_{2_{S1}} = E_{Local_{Cons\_balance}}[\%] = \frac{107.6}{566.1} \times 100 = 19.01\% \quad (14)$$

$$KPI_{3_{S1}} = E_{Local_{CO2\_Free\_consumption}}[\%] = \frac{24.23}{566.1} \times 100 = 4.28\% \quad (15)$$

Similarly, the KPIs for Scenario 2, by using as studied TW the period 01.01.2025 - 21.01.2025, are:

$$KPI_{1_{S2}} = E_{Local_{Prod\_coverage}}[\%] = \frac{195.9}{351.3} \times 100 = 55.76\,\% \quad (16)$$

$$KPI_{2_{S2}} = E_{Local_{Cons\_balance}}[\%] = \frac{153.4}{351.3} \times 100 = 43.67\% \quad (17)$$

$$KPI_{3_{S2}} = E_{Local_{CO2\_Free\_consumption}}[\%] = \frac{20.2}{351.3} \times 100 = 5.22\% \quad (18)$$

The KPIs for Scenario 3, using as studied TW the same period 01.01.2025 - 21.01.2025 as in Scenario 2, but with a projected 300 MW SMR additional production deployed inside of the Republic of Moldova, with 91.7% full power functioning (equivalent to approximately 11 out of 12 months of nominal power operation per year), with the results presented in Table 3.

Scenario 4 is similar to Scenario 3, including a projected 300 MW SMR additional production deployed inside of the Republic of Moldova, but without considering energy contribution from Cuciurgani PP. For this scenario, the internal energy production with TPP has been reduced with a 160 MW average power, which approximates the current contribution of Cuciurgani PP, based on observations from [23].

$$KPI_{1_{S4}} = E_{Local_{Prod_{coverage}}}[\%] = \frac{195.9 + 138.7 - 80.64}{351.3} \times 100 =$$
$$= \frac{334.6}{351.3} = 72.27\ \% \quad (19)$$

For the KPI_2 calculation, the balance has the value:

$$KPI_{2_{S4}} = E_{Local_{Cons\_balance}}[\%] = \frac{351.3 - 334.6 + 80.6}{351.3} \times 100 = 27.73\ \% \quad (20)$$

where $E_{Prod_{Cuciurgani}} = P_{med_{Cuciurg.}} \times T_{Operation} = 80.6\ GWh$,

with $= P_{med_{Cuciurg.}} = 160\ MW$.

$$KPI_{3_{S4}} = E_{Local_{CO2\_Free\_consumption}}[\%] = \frac{158.9}{351.3} \times 100 = 45.22\ \% \quad (21)$$

Figure 4 shows the evolution of consumption, total Republic of Moldova's production and of SMR production for the Scenario 4 situation. It can be seen that the SMR production acts as a base-production which does never exceed the total consumption, which allows that other production means (TPP, renewables and import) to always cover the difference.

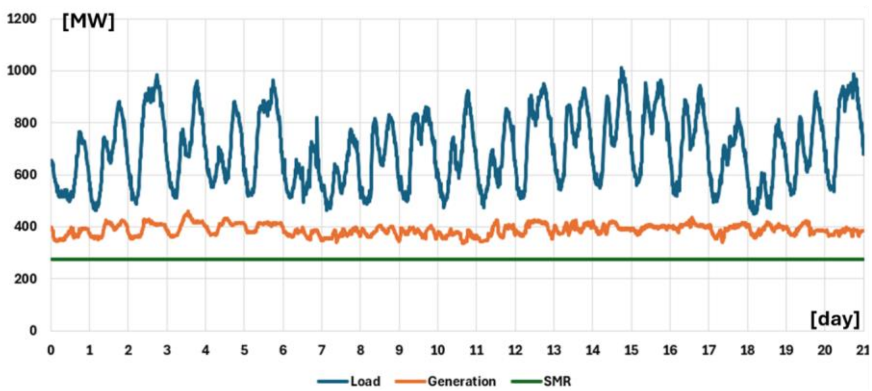

Figure 4: Evolution of consumption, total generation and SMR production over the Scenario 4 period (21 days)

Table 3 summarises the four Scenarios results and show the important benefits of having a SMR in the Republic of Moldova.

Table 3. **Results of Scenarios**

	KPI_1 [%]	KPI_2 [%]	KPI_3 [%]	Regional impact
Scenario 1	80.63	19.01	4.28	Low Import
Scenario 2	55.76	43.67	5.75	High import
Scenario 3	95.23	4.77	45.22	Very low import
Scenario 4	72.27	27.73	45.22	Moderate import

As can be seen in the Table 3, the Scenario 3 may bring better values for all the studied KPIs: The production is fully covering the consumption (KPI1), there is a small export due to the small excess of production (KPI2) and more than half of the production is CO_2 free, considering as an assumption that the TPP is producing at the same level as in the Scenario 2 (TPP production might be as well more reduced in other Scenarios).

As a conclusion, all studied KPIs are improved in the case of a SMR built in Republic of Moldova, which points that such an attractive solution needs further analysis related to other aspects, such as investment feasibility, location and energy transfer to the major consumption zones of the country.

In all considered scenarios, the baseload is still covered (Scenario 1) or partially covered (Scenarios 2 and 3) by Cuciurgani power plant. If Cuciurgani will be totally replaced by SMRs and renewables, the indicators will be even higher.

Another benefit of replacing Cuciurgani with SMRs is the reduction in greenhouse gases emissions. Considering the Cuciurgani power plant production of 3278 GWh in 2023 (latest annual data available [22]) and an emission factor of 0.5 tonnes CO_2 per MWh of produced electricity, the saved annual emissions will be: 3.278 mil MWh x 0.5 = 1.639 mil tonnes CO_2 saved/yr

11. Conclusions

Currently there are sufficient premises for the initiation of a Nuclear Energy Programme in the Republic of Moldova. These premises are generated by the challenges to the country's energy security, which require sustainable and long-term solutions.

Another prerequisite is the national strategic framework for the development of the energy sector up to 2050, which is currently in the process of being elaborated. This is the right time to incorporate a distinct, well-defined objective on the development of nuclear energy as a forward-looking measure to ensure the country's energy security.

A political consensus is needed to formulate specific nuclear energy objectives in national strategic documents. However, in the absence of discussions in the political environment on the opportunity of an NNEP, this consensus cannot be reached.

The process of accession of the Republic of Moldova to the European Union would facilitate the achievement of political consensus, starting from the fact that at the European Community level, the latest generation nuclear technologies enjoy support and are assigned to the category of low greenhouse gas emitting energy [23].

The process of initiating and implementing a NNEP is complex and lengthy. In a best-case scenario it could take at least 10-15 years. For this reason, concrete steps are needed even at this early stage if the new energy branch is to contribute to the long-term climate goals by 2050.

The nuclear generation could be part of the solution for current challenges in the energy supply of Republic of Moldova, replacing baseload electricity generation with a reliable and carbon-free source and also providing flexibility to the power system when needed. The financial modelling proved the use of SMRs as being feasible.

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Acknowledgements

This research is funded by Erasmus+, Action Jean Monnet Chair „Fostering European Union Leadership and Management for Sustainable Development in the context of European Integration”, EUleadSD, nr.101126990.

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