# PERSPECTIVES OF NON-ELECTRIC APPLICATIONS IN THE MARKET CONTEXT AND FUTURE DEVELOPMENT OF THE NUCLEAR SECTOR IN ROMANIA

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*Abstract*

The paper investigates the potential of non-electric application for the future nuclear development in the context of the energy market evolutions in Romania. Based on the current practice of district heating for Cernavoda town the potential to extend the nuclear cogeneration is analysed. The last advances in the material development for the heat transport are considered together with the existence of the heating networks and the interest of different stakeholders. At the same time, the potential of the market for industrial process heating is discussed. The synergy between variable renewables and nuclear is analysed considering hybrid system approach and hydrogen as an energy carrier. All of the applications are analysed in the context of the Small Modular Reactors development in Romania.

***Keywords:*** *Non-electric applications, Future energy market, Cogeneration, Hydrogen production, SMR*

## Introduction

The main civil application of the nuclear fission is the production of electricity. Nowadays around 10% of the total world's electricity production is nuclear power. A number of 440 nuclear power plants are in operation and more than 50 are under construction [1]. Nuclear sector produced 2503 TWh in 2017, and 2563 TWh in 2018, a slow positive trend of the nuclear power production being kept for the last 6 consecutive years [1].

Nuclear sector has a great potential to reduce the carbon dioxide emissions in the context of climate policies. In fact, nuclear is the second largest source of low-carbon power in the world (29% in 2017 [1]).

Important changes in electricity production are expected in the next decades due to decarbonisation policy of the energy sector. The old fossil fuel units, especially those based on coals have to be replaced by low-carbon units. There is a great potential for nuclear sector to increase, but despite the current large contribution to clean electricity there are opinions [2] to reduce drastically the nuclear production. The arguments are based on the radioactive waste issues, the impact of nuclear accidents on the environment, and the potentiality of the diverted radioactive materials for terrorists.

In response to these critics, many new nuclear systems were designed or are under development. Advanced nuclear systems such as the Generation IV systems are intended to improve safety, to reduce the amount of wastes and their radiotoxicity, to have better economics, and to enhance the non-proliferation features. Another group of nuclear systems, namely the Small Modular Reactors (SMR), are focused on better performances in term of flexibility, economics and safety [3].

The nuclear development is also oriented to the heat supply both for the buildings and industrial processes. A relevant experience in nuclear cogeneration already exists. In most of the Central and East European countries [4] a part of the wasted heat is used for district heating. In Asia, China General Nuclear (CGN) and China National Nuclear Corporation (CNNC) are both looking to develop small nuclear reactors for district heating [5]. CGN is developing the NHR200-II concept able to provide heat, water and steam for residential heating and industrial processes. Construction of the plant would take only 2 to 3 years if done on a mass scale. CNCC [5] developed DHR-400 concept able to supply the heat for 200,000 urban households. The investment was estimated at around 230 M$ and the duration of construction to 3 years [5].

The paper is focused on the analysis of the non-electric application potential with a focus on the case of Romania.

The paper is structured as:

- current experience of Romania in cogeneration, and
- analysis of the nuclear cogeneration potential in the context of the future market, grouped in three separate categories: the potential for district heating, the potential for industrial process, and the potential for hydrogen.

The district heating, the industrial process heating and the hydrogen production capabilities are discussed in order to increase the flexibility of nuclear energy production, including possible synergies with variable renewable production.

**National experience and good practices**

In Romania, the non-electric application of the nuclear energy was experienced since '90s by the use of a small fraction of wasted heat from Cernavoda NPP to supply the district heating system (DHS). The investment for the interface, networks, and also some commercial arrangements was stated as a component of the Cernavoda Socio-Economic Programme (SEP) [6]. The sitting of Cernavoda NPP was a decision mostly based on the technical criteria (water supply from the Danube, easy way to evacuate the cooling water to the Danube-Black Sea channel, soil characteristics) combined with some socio-economics elements (such as the low development of Cernavoda area). Therefore, the SEP emerged as a normal package to offer a set of benefits for the community in order to keep the acceptance for the project and to prevent possible delays or blockages.

SEP initially consisted of a set of investments defined as complementary works for planned Cernavoda 5x700 MWe NPP: (1) district heating, (2) hospital, schools, high-schools, (3) water supply plant, (4) better connectivity (new bridges). One of the most important messages of the SEP was ″cheapest heating for all inhabitants of Cernavoda town″.

From the ownership point of view, it has to be mentioned that, after the implementation, the results of investments were transferred without any payment to the beneficiaries mentioned in the Government Decision 454/1991. In 2003, the SEP was extended [7] by adding some socio-cultural investment, including modernization of the town road infrastructure, investment in new kindergartens, waste water treatment plant, youth centre for education and entertainment, public fountains, residential buildings.

The nuclear based DHS for Cernavoda town is schematically presented in Fig. 1. The interface between nuclear plant and local distribution system is in the property of the NPP owner. It includes the backup system needed to cover the planned or unplanned outages of the nuclear units. The distribution of the heat is in the responsibility of a local utility that owns the network and local heat exchangers (IHX).

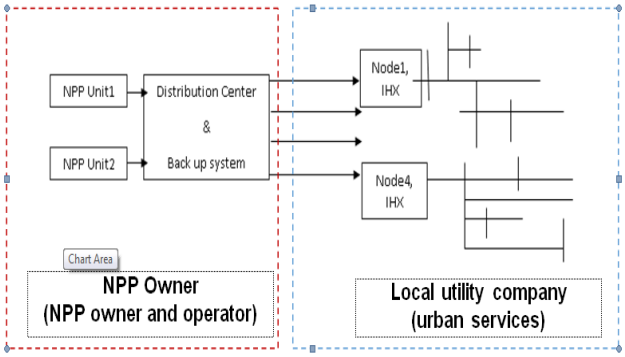



Fig.1. Block representation for district heating of Cernavoda town

The total distributed heat to final consumers in 2018 (70,600 Gcal = 82,053 MWh) [8] represents only 0.3% of the total thermal energy production (14,081,426 MWh for Unit 1 and 15,802,397 MWh for Unit 2) [9]. Due to this fact, in the Cernavoda NPP Annual Report [9] the cogeneration is not reported separately ″the income obtained due to heat is aggregated into electricity and mentioned as not relevant″. The value is not important for the business case, but has a great value for the local community and to keep public acceptance at a high level.

The price paid for the heating by the final consumer from Cernavoda town [8] is the cheapest in the country. Some comparative prices for inhabitants and companies are presented in Table 1. For inhabitants, the final price in Cernavoda is 22% of the maximum price in Romania, 24% of the price in Constanta (the district capital), and 63% of the price in Bucharest (national capital, where the price is strongly influenced by subsidies of local programme for heating). It has to be mentioned that, in Cernavoda, the prices in 2019 were much higher comparatively with those for 2018 (18.67 vs 13.45 €/MWh for inhabitants, and 37.40 vs 18.73 €/MWh for companies, respectively).

Table 1. The comparative prices of MWh for some DHS (in 2019, for final consumers)

| **DHS** | **Price of the heat for final consumers [€/MWh]** | |
|---|---|---|
| | ***Inhabitants*** | ***Companies*** |
| Cernavoda | 18.67 | 37.40 |
| Bucharest | 29.85 | 95.97 |
| Constanta | 78.17 | 84.03 |
| Maximum price in Romania | 86.23 | - |

The operation of Cernavoda nuclear based DHS revealed the following good practices:

- good quality of the service (amount of heat, temperature, stability, functionality in extreme weather conditions),
- constant lower price for the final consumers in comparison with other DHS in Romania,
- excellent public acceptance (no public concerns on nuclear heating),
- excellent cooperation of the stakeholders (NPP owner, NPP operator, local utility company, local regulators, local authorities, consumers) aimed to keep high performances of the system.

Based on these elements, during the last decade a gradual extension of heating network to almost all of the households was achieved.

As operational issues, during the winter time, it has to be mentioned only short-periods unplanned shutdowns. For example, in the winter season between 2017 and 2018, only two shutdowns were reported, namely: first one on March 25, Unit 1 - duration 43.6 h, and the second one on March 29, Unit 2 - duration 17.1 h. On the other hand it has to be mentioned that Cernavoda NPP is a CANDU type nuclear system with an intrinsic characteristic of high capacity factor. The averaged capacity factor for the plant (U1&U2), aggregated for the 2016-2018 period, was reported as 93.47%.

**Market potential for nuclear DHS**

Based on the good practice for nuclear DHS in Cernavoda and on the existing large amount of wasted heat at the NPP, a direct extension of the system may be approached. Exploring the nuclear DHS potential based on a retrofitting approach produced the following important elements:

- for Cernavoda town the new heat application potential is reduced (DHS almost completed to all buildings); only limited potential for low-temperature heat process (agriculture, food industry, paper industry) and it is strictly conditioned by a relevant future business development,
- heat supply for the DHS of the closed urban areas seems to be feasible; potential urban agglomerations to be considered are presented in Table 2,
- the most important urban area (the capital, Bucharest, with 2.2 mil. inhabitants) is 230 km far and, based on the present technical performances, the infrastructure cost and the loss of heat are too high.

Table 2. Potential urban areas as final users of nuclear DHS

| Urban area | Inhabitants | Distance to NPP [km] |
|---|---|---|
| Medgidia | 30,000 | 25 |
| Constanta | 350,000 | 50 |
| Slobozia | 60,000 | 60 |
| Calarasi | 70,000 | 60 |

Due to its magnitude and medium distance, Constanta metropolitan area seems to have the most important potential for the extension of nuclear cogeneration. However, some critical points should be mentioned:

- the transport of heat to such distance needs to use modern pipes (with losses < 5%),
- there are different interests of the stakeholders (local utilities, local authorities, NPP owner, NPP operator),
- large investment for the transport system is needed.

The last developments in the material science were implemented in the pipe technology. Currently, pipes having insulator conductivity $\lambda < 0.04$ W/(m·K) are used, leading to a loss of heat around 120 W/m, that makes possible the reduction of the total heat loss to about 2% of the transported power [10]. Therefore, for distances around 100 km, no technical constraints, only economic performances should be analysed.

From the decision making process point of view, it has to be noted that the stakeholders have a relatively broad spectrum of interests in the DHS business. The NPP owner may be interested to increase the plant overall efficiency by selling a part of the wasted heat, but technically, the heat extraction will produce an impact on the amount of electricity production. By nuclear cogeneration, the pressurized water reactors efficiency increasing from 33% to around 66% is very likely [11]. Generally, for the temperature range (80-120°C) useful to DHS, the amount of recovered thermal energy is 5-6 times greater than the electricity loses [12]. Certainly, there is a difference in the price of electricity (MWe) and price of heat (MWth), but the business case is favourable to sell wasted heat. For example, in [10], the business to buy the heat from the NPP and to sell it in a DHS at 100 km distance is discussed. Assuming an annual production of 9 TWh (monetary converted to 540 M€), a loss of electrical power production of -1.8 TWe (-180M€) resulted, and an overall annual gain of 360M€ was finally obtained [10].

Normally, the NPP owner will not be interested in the investment for the transport pipes, and also the DHS owner cannot support such investment for long distance transport. Other stakeholders such as the local authorities or local utilities may have interest in supporting other heating systems and/or different business models.

In this context, a national coordination is recommended to harmonize the interests with the aim to support the decarbonisation of heating. A national programme to support the heat transport network should be a practical approach. Also, the public money for modernization, improvement of the energy efficiency, measures of the national plan for climate changes may be a valuable and practical resource for funding.

However, the decision making process is complex and quite long due to the diversity of the stakeholders interests and also to the differences in understandings of the technical aspects, the business models, the outcomes, and the benefits and their sharing.

The second investigation direction, approached in this paper, is the potential of the new NPPs, possible to be built in Romania, especially the potential of the future SMR systems. In case of the retrofitting approach, there are difficulties generated by the need for technical adaptation of the existing configuration to one allowing the extraction of the wasted heat. In case of new plants, the concept of ″cogeneration readiness″ [13] is recommended to be used during the design phase. It is defined as the anticipating of the additional space requirements for pipelines and heat exchangers to allow the upgrading of the plant for a future use. According to [13], the cogeneration readiness has a cost representing approximately 10% of the total capital costs required for retrofitting adaptation.

Based on such design, the NPP may be operated in the electricity-only mode until the market, business and institutional conditions will be favourable for the cogeneration mode contributing to a significant reduction of the investment risks.

In case of Romania, the district heating has a great potential due to:

- high density of households in the urban areas, characterized by the dominance of block of flats, grouped into quartiers,
- existing networks for heating in many of the urban areas, based on cogeneration heat and power (conventional plants),
- long tradition of district heating systems (DHS) in the country,
- magnitude of the counties capitals (medium towns, with 200,000-400,000 inhabitants).

During the last two decades, the number of DHS suffered an important reduction (see Fig.2) [14]. In 2015, 70 DHSs remained in operation. Moreover, the total number of households connected to DHS drastically decreased to 1.2 mil. (in 2018) [15]. The last official census (2011) counted 8.5 mil. households in Romania, with 3.7 mil. connected to DHS (3.3 mil. in urban area, and 0.77 mil. in the rural area, respectively).

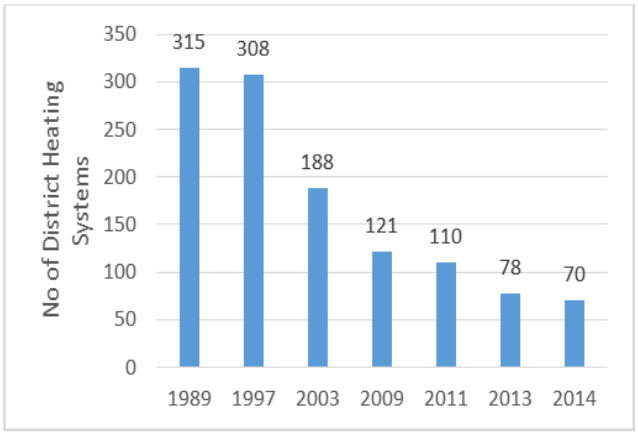



Fig.2. Evolution of the total number of DHS in Romania (1989-2014)

A set of socio-economic factors (such as the prices, the evolution of the new technologies, trends in the quality of life) have generated a process of closing of many DHSs and/or to reduce their activity.

To investigate the potential for nuclear cogeneration for DHS it is important to understand the emissions pattern and the structure by sizes. In 2015, a total number of 59 CHP was reported [14], with a total installed capacity of 1772.94 MWe. Considering the fuel type, the units' structure consisted of: 45 natural gas units (total capacity of 1067.35 MWe), 12 coal units (total capacity of 677.65 MWe), LCO and petroleum residuals units (total capacity of 27.94 MWe). The units' structure on size classes was as follows: 12 very small CHP units (< 1 MWe), 17 small units (1 to 10 MWe), 23 medium units (10 to 100 MWe), and 7 large units (> 100 MWe), respectively.

The cogeneration is considered as a strategic approach for decarbonisation in the national Energy Strategy (2016-2030) [16]. For 2030, a 20% reduction of solid fuel used for heating is estimated [16].

Under the climate changes pressure, recent EU strategic orientations for energy production, such as the Green Deal [17], create a strong determination to drastically reduce, as fast as possible, the use of fossil fuels to generate electricity and heat. In such context, most of the CHP units should be replaced by modern capacities with low or zero carbon emissions.

To explore possible solutions for the modernization of heating sector, a town with 180,000 inhabitants was considered as a good representation for the averaged county capital.

The assumptions for heating consumption in typical conditions of Romania are presented in Table 3. Based on the dominance of block of flats in the urban area, 3 types of households were used as classes of sizes and consumption. The household distribution in these three classes was based on the available national data [18]. The total heat was estimated around 525 GWh/y.

Table 3 Heating needs for a representative town

| **Size of the town** | 180,000 inhabitants | 60,000 households |
|---|---|---|
| **Heat consumption for typical households [Gcal/y]** | Type 1 | 6.1 |
| | Type 2 | 8.2 |
| | Type 3 | 10.5 |
| **Total heat [GWh/y]** | 525 | |

Based on this estimation, a SMR system is appropriate to cover the winter needs for heating in the case of the considered typical town. Some open issues that need more investigations [19] are discussed below:

- the licensing aspects such as the size of emergency preparedness zone (EPZ) and the isolation of the loops,
- the optimal back-up solution,
- the efficiency in the context of the seasonal variation of heating needs.

EPZ is one of the specific regulatory aspects to enable SMR deployment in diverse siting niches. It consists of the PAZ (precautionary action zone) and the UPZ (urgent protective actions planning zone), where arrangements are developed for protective actions in case of a nuclear or radiological emergency. One of the targets of the SMR development is the reduction of EPZ size, preferable (if possible) to the nuclear site boundary. The expectations to resize the conventional EPZ are supported by the principle ″safety by design″ (practical elimination of the paths to severe accidents) and the SMR size (smaller core means less radioactive material that could be released in a potential accident).

However, the developer has to demonstrate and convince the stakeholders (regulators, local authorities, customers, public, etc.) for the EPZ right sizing. In case of NuScale project [20], the methodology proposed to support smaller EPZs for SMRs is under discussion of NRC, the US Nuclear Regulatory Commission. A significant reduction of the EPZ is expected.

By demonstrating a smaller EPZ, the siting nearby the urban agglomeration is possible. Moreover, development of the new materials able to reduce the loss of heat during the transport opens possibility to identify an appropriate site for a SMR used in the cogeneration mode.

A back-up solution is needed to supply the heat during unplanned shutdowns. A direct solution is to use the existing CHP, by implementing a modernization programme, in order to reduce the pollution. Also, the existing CHP may be transformed in the interface between nuclear and the heat network.

The seasonal variation is important in Romania. Winters are usually cold and summers are very hot. Heating is compulsory needed usually for 5 months (from the end of October to the beginning of April) in the year. An increasing of electricity consumption during summer was generated due to the increasing of the cooling needs supported by the improvement of the life quality. Therefore, the use of SMR to produce dominantly heat in the winter and electricity in the summer seems to be practical. On the other hand, the development of SMR exclusively oriented to heating has a great market potential.

**Market potential for process heat**

The heat provided by SMR systems may be used also for the industrial process, in a large variety of applications (paper industry, oil refinery, chemical industry, soda ash, coal-to-liquid, oil sands, etc.). The application may be extended to aluminium industry, hydrogen production, synthetic fuel, or indirect liquefaction process of coal if a high temperature system is used.

Even the potential for heat process is a large one, some barriers are very effective [21]:

- the co-siting (NPP and the process heat application) aimed to produce a great efficiency,
- lifetime of the process heat application (15-20 y) and NPP lifetime (60 y),
- period for the return of investment (usually 20-30 y),
- interferences such as nuclear safety and chemical safety,
- reengineering of existing chemical plants,
- public acceptance.

Some differences between the industrial heating and DHS approach (such as the steam temperature, the spill-out strategy, the distribution network, the maximum distance) are also to be mentioned.

In the last decades the Romanian industry suffered a complex process of restructuring. A shift from large consumers grouped in industrial platforms (nearby urban agglomerations) to low intensive energy consumers more dispersed on the territory was produced.

Restructuring of the economy, stimulated by privatization and liberalization of the market, determined the closure of many large industrial platforms. A lot of abandoned sites have resulted, with large contaminated lands. Most of them have a large potential for the reconversion due to the value of lands (nearby urban areas), existing networks, roads, and buildings. The most effective barrier is connected with the large cost of the remediation (according with the national legal framework, it is in the responsibility of the owners and users). The second barrier is related on the availability of quite very cheap lands nearby the main routes of transport.

However, the reconversion of the abandoned platforms is expected in the next decade, after the exhausting of the profitable sites. The market potential for the reconversion should be higher if a strategic development of energy resources on the sites will be implemented.

In this context, an integrated solution was investigated, a simplified representation being shown in Fig.3. The integrated solution consists of:
(1) using the synergy between nuclear and renewables;
(2) start the activity by installing photovoltaic (PV) panels on a significant area, before the remediation process,;
(3) start the remediation for the nuclear site,
(4) modernization and reconversion of the buildings to host new business;
(5) install a SMR in cogeneration mode;
(6) continue the site remediation and expand the activities (new buildings, new business);
(7) finalize the remediation on the area occupied by PV panels.

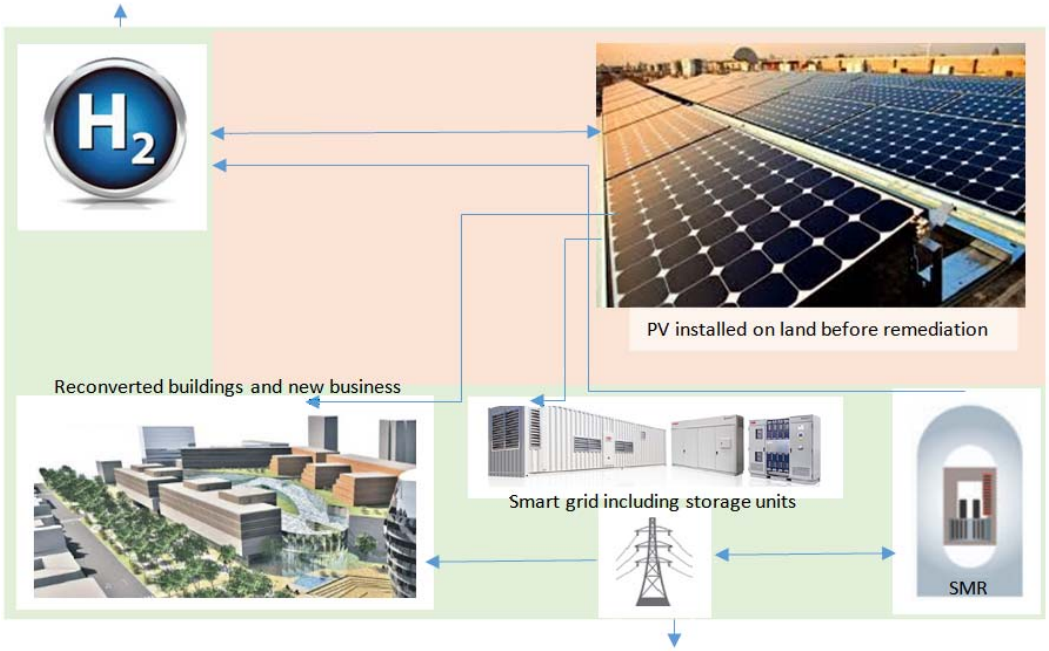



Fig.3. Integrated approach for the conversion of a brownfield

The proposed approach advantages are connected with:
- progressive investment, including the remediation,
- use a large part of the energy (electricity and heat) on the site and improve the efficiency by reducing the transport losses,
- contribute to the reduction of fluctuations generated by variability (especially day-night) of the PV production,
- create the conditions for a fast smart micro-grid implementation,
- reduce the impact of PV on the agriculture.

Two SMRs were selected as representative for Romania regarding the investigation of the integrated approach feasibility to convert a representative brownfield: NuScale SMR [22] as a representative for PWR technology and estimated to be on the market in the next decade, and ALFRED SMR [23] as representative of Generation IV systems (expected on the market after 2040), respectively. The investigation is in progress.

**Market potential for hydrogen production by nuclear energy**

The hydrogen production may be discussed in the context of needs for decarbonisation. For example, the industrial process (such as ammonia production) uses hydrogen, mainly produced by steam methane reforming method. A stream of gas is mixed with high temperature steam in presence of a catalyst (nickel): $CH_4 + 2H_2O- > 4H_2+CO_2$. Today 95% of the global $H_2$ production is generated by this method. The amount of carbon dioxide released into atmosphere is around 500 million tons per year and represents over 1% of the global GHGs. On the other hand, the method is based on the consuming of gas, a limited natural resource and, consequently, the production cost is quite unpredictable due to the possible variation of the gas price. A green hydrogen production is expected to decarbonize the ammonia industry.

The hydrogen may be used on a larger scale for the decarbonisation of the transport. Clean mobility may be obtained by massive electrification of transport and/or by the hydrogen-based engines using. Generally, hydrogen is seen as a sustainable energy carrier for fuel cell electric vehicles and some experts advanced the method as a good approach for the storage of variable electricity production.

Another potential utilization of hydrogen is to replace a part of the fossil fuels consumption in order to reduce the emissions. The hydrogen may be added in the natural gas [24] directly in the gas pipeline networks, forming a mixture of methane and hydrogen able to be transported according present safety standards and it can be used for heating and cooking. A relatively low concentration (5%-10%) is in agreement with the target of low risks associated with the utilization of the gas blend in end-use devices (such as household appliances). However, any changing of the natural gas composition has to be tested and the integrity management systems should be developed, which involve additional costs. At the same time, the gas pipeline system could be used as transport system to deliver pure hydrogen to markets, by using separation and purification systems to extract hydrogen from the blend close to the end users.

The hydrogen may be produced by common electrolysis approach (referred as normal temperature electrolysis, NTE) or by high temperature electrolysis (HTE), a more efficient process. NTE needs only electricity and water, whereas HTE needs electricity, water and an important amount of heat to reach 800 to 900 ºC [25].

A high-temperature advanced nuclear reactor (HTR) satisfies the requests of HTE and could achieve a competitive thermal-to-hydrogen conversion efficiency of 45 to 55% [25]. Most of the current fleet of reactors are designed to operate at lower temperatures (200-300 ºC) and only NTE is technically appropriate. Low temperature electrolysis using cheap off-peak electricity from actually operating NPPs may be economically approached, but in current market conditions, nuclear hydrogen produced by NTE method is not competitive, according to [26].

An important window of opportunities is open by the new context of the systems with large penetration of variable renewable (especially dominated by wind and PV) where the fluctuations have introduced variability of the electricity price on the intraday market [27], even in some cases negative prices [28]. In Fig. 4, the nuclear power generated by a load-base (100%) NPP and the demand for a typical consumption are shown. Valleys and peaks characterize the demand, and both of them introduce challenges for a nuclear plant.

To follow the valley, NPP should reduce the power to adapt to the demand profile. Generally, there is a flexibility of the plant, but there are also some constraints [29], mainly in relation with: the poisoning of the core and oscillations, the behaviour of materials under thermal cycles, and the reactivity effects. The flexibility is dependent on the type of the reactor; for example, the poisoning effect present in thermal reactors is greater than in fast reactors.

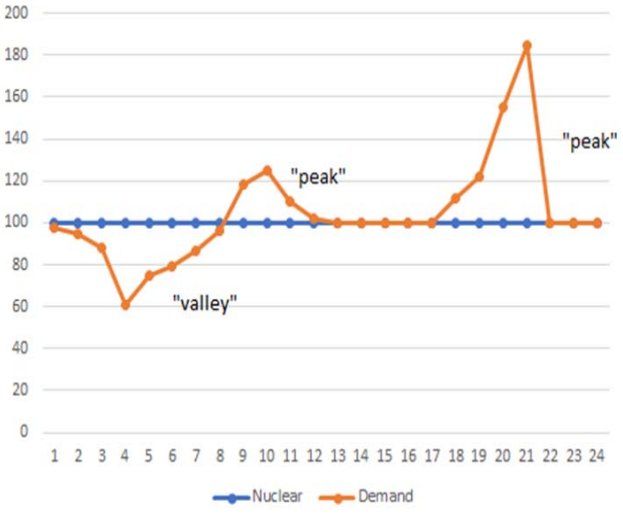



Fig.4. Typical load base production (NPP) compared with the demand of the electricity network

The European Utilities' Requirements, applicable to LWR design, formulates the restrictions as:

- range of load following [50%, 100%],
- special units designed to ensure a low power operation, ~20%,
- maximum no of changes: 2/day, 5/week, 200/year,
- rate for the change, 3% of nominal power per minute,
- special units (participating in emergency load variations) with a rate of 20% Pr/min.

Based on the economics it is preferable to operate the NPP at full power. In such context, the valley profile may be followed by using the supplementary electricity for hydrogen production [27]. The area for a valley profile:

$$A_i^- = \int_{t_1}^{t_2} (P_{nom} - P(t))dt = P_{nom} N_{h,i}^-$$

represents the amount of energy to be used for $H_2$ production.

Taking into consideration the efficiency of electricity conversion into $H_2$ (noted as ε), a very simple condition between hydrogen price and averaged low spot prices of electricity can be derived: $\varepsilon p_{H_2}^{ave} \geq p_{low}^{ave}$.

On the other hand, the costs for the investment, operation and maintenance (for production unit of $H_2$) are to be considered: $C_{add} = I + O\&M + Other$.

Therefore, a second condition should be satisfied:

$$P_{nom} \sum_{i \in Life} N_{n,i}^i (\varepsilon p_{H_2,i} - p_{low,i}) > C_{add}$$

where *Life* means the lifetime of the electrolysis unit.

A typical value for the lifetime is 20 years, a typical investment cost is 0.8 - 1.0 mil Euro/MW, and the running costs are estimated at 5 Euro/MWh. Considering an annual discount rate of 7%, the production cost (on-site) per kg of $H_2$ is presented in the table below.

Table 4. Production cost per kg of $H_2$, NTE

| **Operation of electrolysis facility, per year [hours]** | **Production cost of $H_2$ [€/kg]** |
|---|---|
| 4000 | 2.9 |
| 2000 | 3.5 |
| 1000 | 4.9 |
| 500 | 7.5 |

The current price of hydrogen on the market is in the range [2.5, 8.5] €/kg, including the transport costs, thus the production cost should be less than 2 €/kg.

In the previous estimations, the electricity price is included and considered as the average price of electricity in Romania. However, if the variable renewables share will introduce large periods with low prices (or even negative) of electricity, the condition will be dramatically changed. In such conditions, it is more advantageous to keep the reactor at full power and produce hydrogen instead to sell the electricity at a very low or negative price. Therefore, a larger penetration of variable renewable will be favourable to the nuclear production of hydrogen.

Moreover, the electrolysis units may use the excess (compared with the demand) electricity produced from both NPP and renewables units. In such way a synergy between nuclear and renewable may be produced.

**Conclusions**

The non-electric applications such as the heat production (for district heating or process heat) introduce important advantages in terms of decarbonisation, improvement of the overall efficiency of the plant, and reduce the thermal pollution. Production of hydrogen is very feasible by HTR system and will determine an effective decarbonisation of the transport and of the ammonia industry. Even if in current market conditions, the normal temperature electrolysis is not economically, for the electricity systems with large fluctuations generated by a deep penetration of renewables it become advantageous.

District heating in Romania may be relaunched based on the favourable context (existing networks, concentration of households in blocks of flats/quartiers). On the other hand, the experience in nuclear cogeneration for DHS shows excellent performance of the system (stability, reliability, prices, and public acceptance) and may be extended, in principle by the using of SMR systems.

The reconversion of the abandoned industrial sites into new industrial platforms may benefit of an integrated approach, where the supply of energy based on the synergy between nuclear and renewable will be a great advantage for smart grid achievement and competitive business environment.

In Romania, the implementation process is stimulated by some driving forces such as: the implementation efficiency of national strategic documents oriented to the climate changes prevention, the influence of EU policies targeting the climate-neutrality by 2050, and the energy efficiency and operational competitiveness of future nuclear technologies.

Some barriers and obstacles are acting against the implementation of non-nuclear applications, as follows:

- difficulties generated by the retrofitting approach (when no space was designed for future non-electric coupling),
- difficulties generated by local policy-making,
- perception on the incentives and their sharing, including pessimistic expectations,
- volatility of the prices of energy, including electricity,
- perception on the business model, including the reduced feedback from practice,
- regulatory frameworks,
- magnitude of the investment and its structural complexity (nuclear, networks, interface),
- polarized interests of stakeholders, especially NPP owner versus heating infrastructure owners.

Policy makers should recognize NPPs alongside other utilities generating large amounts of wasted heat and have to find realistic solutions to use it. The real implementation may be achieved only after a large process of consultation with the participation of all stakeholders (national authorities, local authorities, NPP owners, NPP operator, interface owners, network owners, householders, and public).

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