Sustainability of Nuclear Energy as a Source of the Future

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Abstract: *Nuclear power is one of the most profitable, reliable, and low-carbon energies, so it can be seen as a source of the future. The article makes a comparative study between renewable technologies (photovoltaic, wind and nuclear) addressing both classical high-power (LR) and small-scale systems (SMRs) located in electrical energy consumption centres. The study highlights the advantages of nuclear energy in terms of land use, agricultural production, impact on wildlife and finally the possibility of cogeneration. In addition to these advantages, SMRs can provide charging stations for electric vehicles, which are also a solution of the near future.*

Keywords: *RES, nuclear, thermal island, low carbon emissions, low footprint*

1. Introduction

Nuclear energy is relatively one of the most cost-effective and reliable energies compared to other sources. Apart from the initial cost of construction, the cost of generating electrical energy is cheaper and more sustainable than other forms of energy such as oil, coal and gas. One of the additional benefits of nuclear power is that it involves minimal risk of cost inflation compared to traditional energy sources that fluctuate regularly over periods. [1]
Nuclear fission generates much more energy than fossil fuels such as coal, oil or gas. The process produces nearly 8,000 times more energy than regular fossil fuels, resulting in fewer materials used and causing less waste [1].
Nuclear energy is the lowest carbon source of energy with a lower carbon footprint than other sources such as fossil fuels [1, 2].
A typical 1,000 MW nuclear plant has an average need of 34 ha to operate, while for the same installed power wind systems occupy 24 ha and solar systems 92 ha, according to the Nuclear Energy Institute (NEI) [3].

2. Comparative study between renewable energy sources (photovoltaic, wind and nuclear)

Analysing the share of electrical energy consumption in Romania (Fig. 1) as a result of efficiency measures, there is a slight decrease in electrical energy consumption in the residential sector, services and industry, as well as a slight increase in agriculture and transport [4].

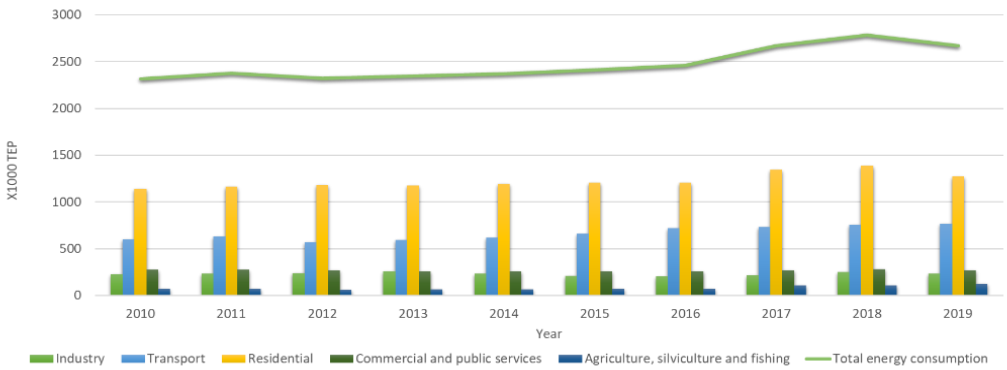

Fig. 1. Share of electrical energy consumption in Romania by sectors of activity [4]

On the other hand, the directive of the European Court of Auditors provides for the installation of 1,000,000 charging stations for electric vehicles by 2025 [5], which will put immense pressure on the Energy System (ES) of the European Union, forcing Member States to rethink their own ES.
Analysing the share of energy sources participating in electrical energy production in Romania, 33.35% are fossil fuels, 66.62% renewable energy sources (RES) (Fig. 2) [6].

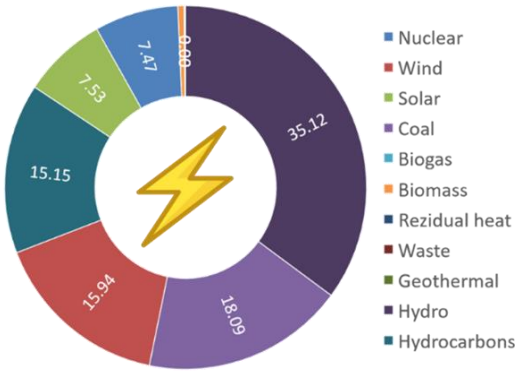

Fig. 2. Electrical energy production in Romania [6]

Romania's proposed targets for reducing greenhouse gas emissions consider three scenarios (Fig. 3) [7].

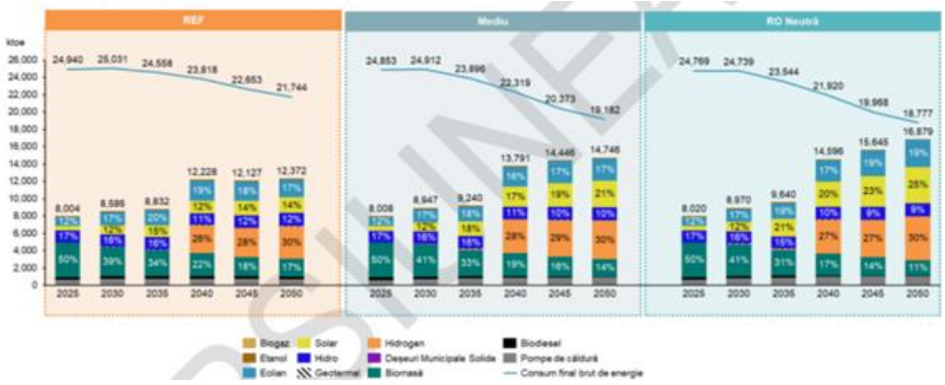

Fig. 3. Romania's targets for the share of RES in gross final energy consumption [7]

The baseline scenario for moving away from fossil fuels by 2050 calls for increasing solar and wind capacity to around 20% of the energy mix, with 27% hydrogen deployment by 2040, with a target of 30% by 2050.
These commitments involve occupying large areas of agricultural land (Fig. 4, 5, 6) [7].

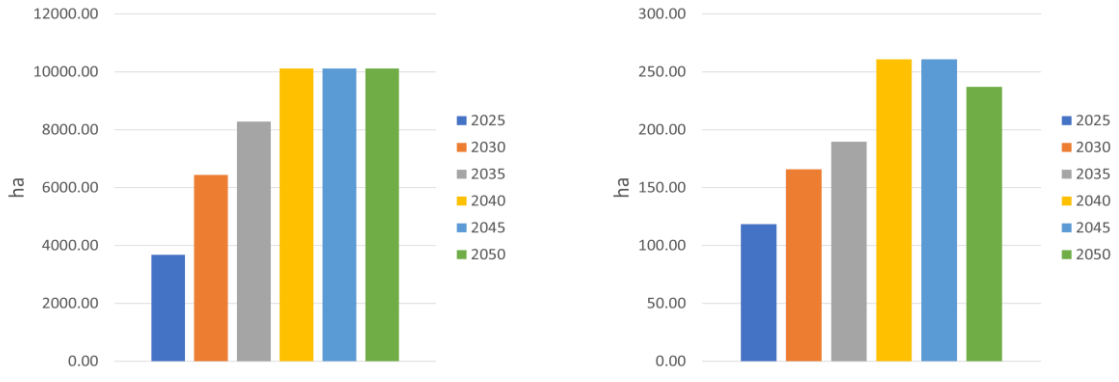

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Fig. 4. Land areas occupied by RES in the Baseline scenario. a) Solar, b) Wind [7]

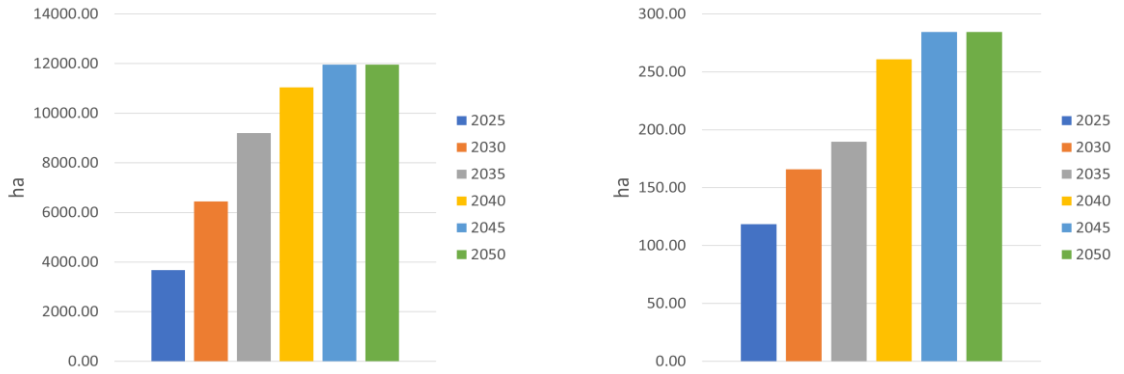

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Fig. 5. Land areas occupied by RES in the Medium scenario. a) Solar, b) Wind [7]

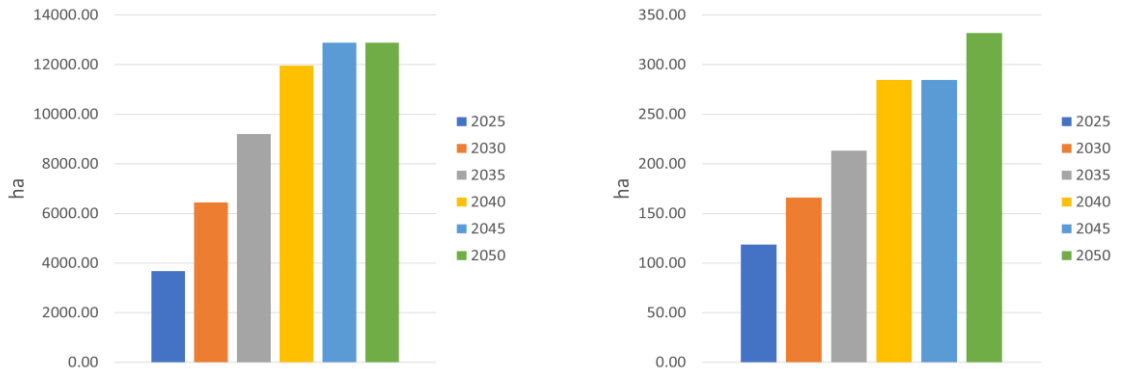

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Fig. 6. Land areas occupied by RES in the RO Neutral scenario. a) Solar, b) Wind [7]

On the other hand, the fluctuating nature of solar and wind energy forces us to consider a possible alternative to them (Fig. 7) [8].
According to data recorded in 2022, nuclear energy is found to be a source capable of ensuring the stable operation of the National Energy System (NES) (Fig. 7).

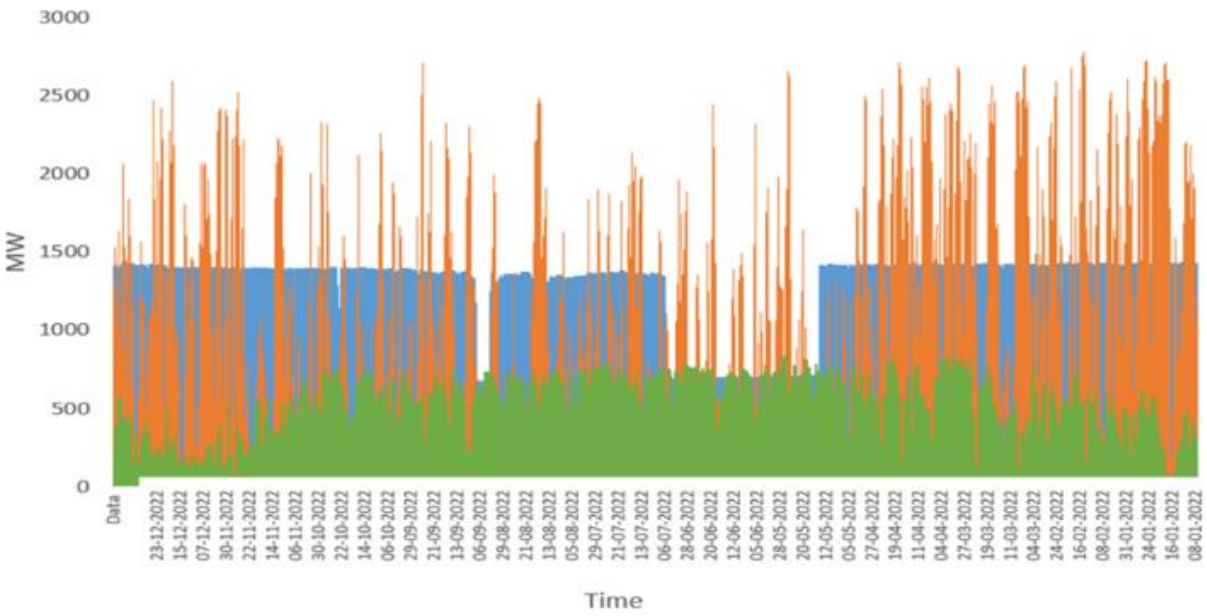

Fig. 7. Renewable energy sources (Wind, Photovoltaics, Nuclear) [8]

In the current context of the policies of some European states regarding the reconsideration of RES, the Swedish Parliament returns to the 2010 decision (by which it closed 4,000 MW of nuclear capacity) approving "Changing the target from 100% green energy to 100% energy without fossil fuels". Increasing energy production from 163 TWh to 300 TWh by 2040 is not possible without commissioning new nuclear power capacities (Fig. 8) [9, 10, 11].

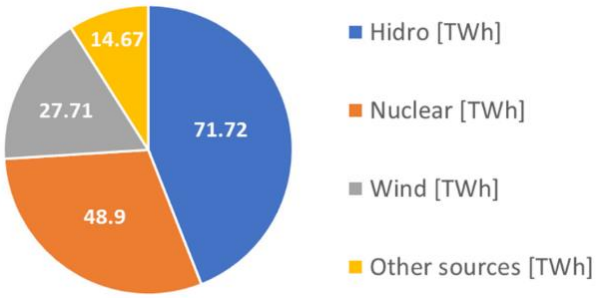

Fig. 8. Sweden's energy production in 2021 [9, 10, 11]

Analysing the variable character of RES, photovoltaic and wind (Fig. 7), the land areas occupied in Romania (Table 1) can assess the negative impact that these constructions have on the environment.

Table 1: Installed power and occupied area of RES

Capacity Type production	Installed power [MW]	Occupied area [ha]
Nuclear	1413	47.62
Wind	3014.91	71.45
Solar	1425.13	1311.12

It is known that during migration birds do not notice the rotational movement of the blades, producing a real carnage, and supporting photovoltaic panels requires special constructions [12].
Another aspect that should not be neglected is the thermal island effect due both to the high temperature under photovoltaic panels and to the fact that solar radiation is largely reflected from their surface (Fig. 9) [12].

Fig. 9. Resistance structures of photovoltaic panels [12]

Ensuring energy needs and achieving the targets assumed by the strategy can be achieved using nuclear energy.
The principle of electrical energy generation (Fig. 10) in NPP nuclear power plants is like that in TPP thermal power plants. The large amount of electrical energy and heat produced by NPP, no

greenhouse gas emissions, low footprint and low operating cost, recommends these systems in the energy mix.

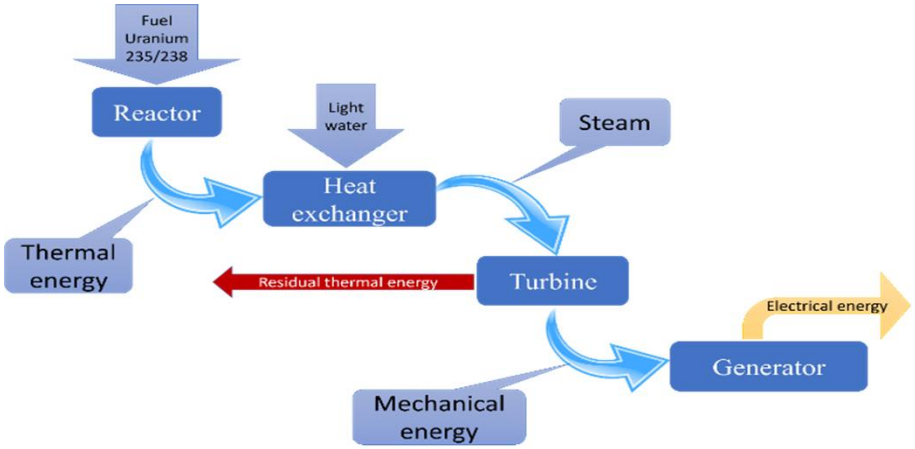

Fig. 10. Block diagram of NPP

There are 32 countries in the world that have NPP, and in France, Slovakia, Ukraine and Belgium this source is the basic source for electrical energy production [13]. The installed power in Romania is very small compared to other states, representing 0.59% (Table 2) of the installed power in the world [13].

Table 2: Technical characteristics of Cernavodă NPP [13]

Thermal power	Electrical power	Number of fuel channels	Feed water temperature
MWt	MWe	-	°C
2062	706.5	380	187.2

Even though there have been a few major accidents (Fukushima in Japan in 2011, Chernobyl in Ukraine in 1986, and Three Mile Island in the US in 1979), nuclear technology is increasingly mature.
Despite the known advantages, NPP has the disadvantage of disposable radioactive waste and the imposition of safety and vulnerability restrictions to terrorist attacks.
By analysing the targets in the strategy and the estimated production per hectare for different agricultural crops, the quantity not realized due to land occupation by dispatchable photovoltaic and wind systems was calculated (Fig. 11, 12, 13, 14, 15, 16) [7].

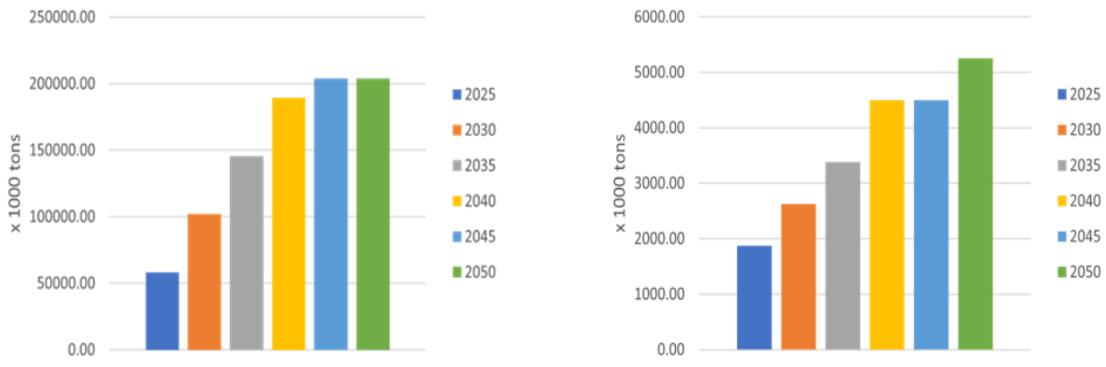

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Fig. 11. Quantities of agricultural products (potatoes) not realized as a result of land occupation by RES systems in the Baseline scenario. a) Solar, b) Wind [7]

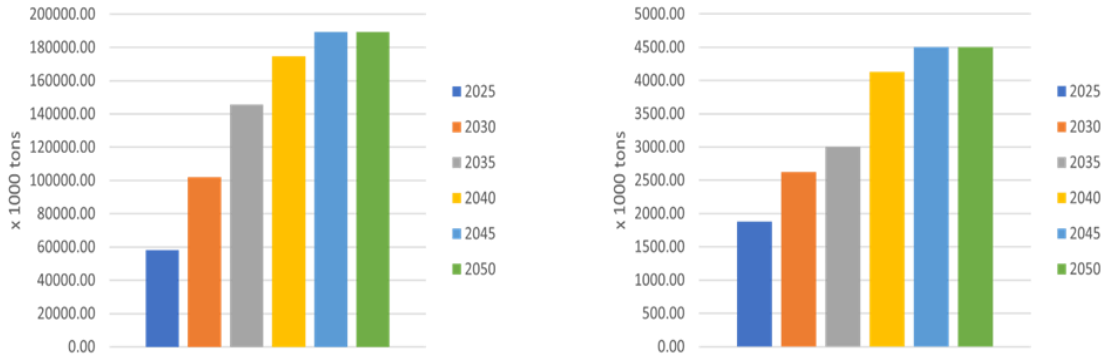

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Fig. 12. Quantities of agricultural products (potatoes) not realized as a result of land occupation by RES systems in the Medium scenario. a) Solar, b) Wind [7]

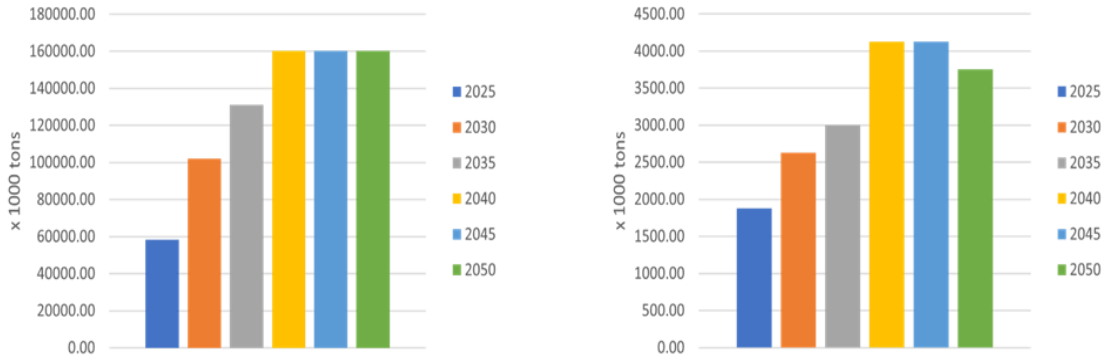

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Fig. 13. Quantities of agricultural products (potatoes) not realized as a result of land occupation by RES systems in the RO Neutral scenario. a) Solar, b) Wind [7]

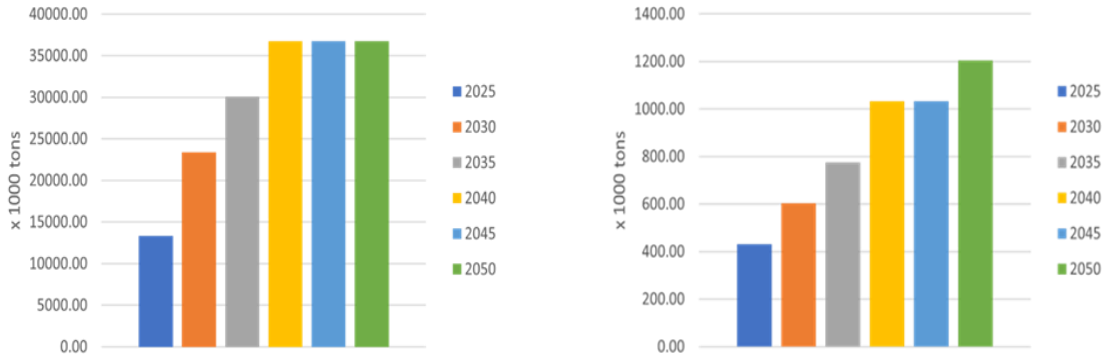

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Fig. 14. Quantities of agricultural products (cereals) not realized as a result of land occupation by RES systems in the Baseline scenario. a) Solar, b) Wind [7]

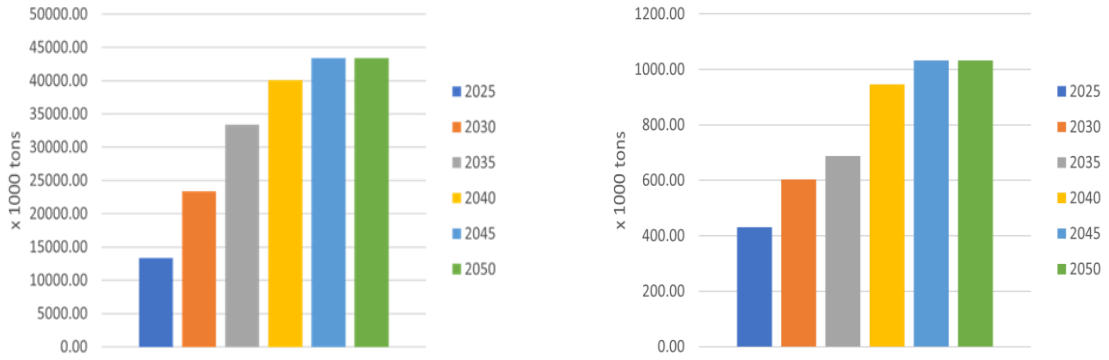

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Fig. 15. Quantities of agricultural products (cereals) not realized as a result of land occupation by RES systems in the Medium scenario. a) Solar, b) Wind [7]

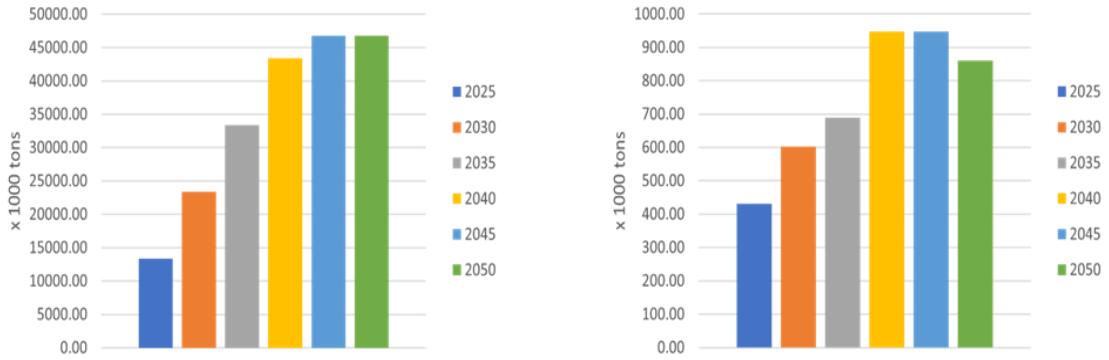

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Fig. 16. Quantities of agricultural products (cereals) not realized as a result of land occupation by RES systems in the RO Neutral scenario. a) Solar, b) Wind [7]

An emerging energy technology is small modular nuclear reactors (SMRs) suitable for areas with limited capacities and dispersed populations.
Small and medium-sized reactors, as defined by the International Atomic Energy Agency (IAEA), have installed capacities of up to 300 MWe compared to classical NPPs which have installed capacities bigger than 700 MWe.
SMRs differ from NPPs both by size and modularity in terms of design, installation, low fuel requirements [14] and storage of radioactive waste, the possibility of underground installation and finally the way of recovering waste thermal energy (cogeneration).
SMRs can be said to be a solution to eradicating energy poverty [12], as the technology is known and used in transport, medical, district heating and desalination [14].
SMRs can be appreciated as a solution for developing economies [12].

3. Conclusions

The growing need for electrical energy, but especially the achievement of the targets assumed by European countries, is not possible without the development of stable sources capable of generating large amounts of energy.
The "unloading" of transmission networks and the decentralization of electrical energy generation sources without increasing CO_2 emissions, the provision of thermal energy from reactor cooling water (technological residue) recommends SMRs as an alternative source to fossil fuels.
Even if the benefits obtained are firm, the need to ensure an emergency planning zone (EPZ) determines the implementation of specific preparation procedures and implicitly leads to increased production costs.

Although operational safety is enhanced by underground installation of this equipment in areas with low population density, public opinion is still sceptical about these systems.
The comparative study between RES (f, w, n) presents a possible solution in the future for increasing electrical energy production capacities to a low degree of land occupancy and with low CO_2 emissions, proposes even the notion of "prosumer" of electrical energy and heat.

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