SUSTAINABLE ENERGY TRANSITION ROADMAP TO 2050 FOR REPUBLIC OF MOLDOVA

FOAIE DE PARCURS PENTRU TRANZIȚIA ENERGETICĂ DURABILĂ CATRE 2050 ÎN REPUBLICA MOLDOVA

Cristina EFREMOV[1], Mihai CERNEI[2], Vasile LEU[3]

Abstract: *The present paper is entirely devoted to the conceptual elements of a roadmap for the energy transition in the Republic of Moldova that can be developed exclusively in the elaboration of the Energy Strategy toward 2050. At the national level, Republic of Moldova has already taken a number of important steps in this direction, steps that will foreshadow the basis of the national energy long-term strategy in this field. The Republic of Moldova has a satisfactory and sufficient energy potential. The Republic of Moldova has a good enough position to cope with the energy transition. The country has all the necessary things to take advantage of the inevitable evolution in the energy sector and to transform them into opportunities for the entire economy.*

Keywords: energy transition, roadmap, energy strategy.

Rezumat: *Prezenta lucrare este destinată în totalitate elementelor conceptuale ale unei foi de parcurs pentru tranziția energetică în Republica Moldova ce pot fi dezvoltate în exclusivitate la elaborarea Strategiei Energetice în perspectiva anului 2050. La nivel național, Republica Moldova trebuie să facă, deja, o serie de pași importanți în această direcție, pași ce vor prefigura baza strategiei naționale pe termen lung în acest domeniu. Republica Moldova are un potențial energetic satisfăcător și suficient. Republica Moldova se află într-o poziție destul de bună pentru a face față tranziției energetice. Tara are mijloacele necesare pentru a beneficia de pe urma inevitabilelor evoluții ale sectorului energetic şi a le transforma în oportunități pentru întreaga economie.*

Cuvinte cheie: tranziție energetică, foaie de parcurs, strategie energetică.

[1] DSc., Univ. lect., Technical University of Moldova, cristina.efremov@adm.utm.md
[2] Assoc. Prof., DSc., State University of Moldova, mihailcernei55@gmail.com
[3] DSc., Univ. lect., Director general S.A. „Termoelectrica”, vasileleumd@gmail.com

1. Introduction

The energy sector, both at European level and in the Republic of Moldova, is in the process of transition to "clean green energy", reaching a crossroad in 2030: on the one hand, there is the challenge of decarbonation of energy system, to reduce greenhouse gas emissions and to promote renewable sources, and on the other hand to ensure the security of electricity supply at a level, quality and cost which are accessible to the end consumer. The role that the Republic of Moldova (RM) will assume in addressing the energy transition will determine the degree in which RM will be able to benefit from this change and if it will bear its costs.

The supply of energy from renewable sources increased after 2010 in Republic of Moldova. Consequently, the share of energy from renewable sources in the supply of primary energy and in the final volume of energy also increased, reducing to 7.68 TWh (660 thousand tons of oil equivalent). Following these developments, the supply of energy from renewable sources increased by 27.2% in 2019 compared to 2010. Following of these developments, the share of energy from renewable sources in the supply of primary energy and in the final volume of energy supplied also increased (Figure 1).

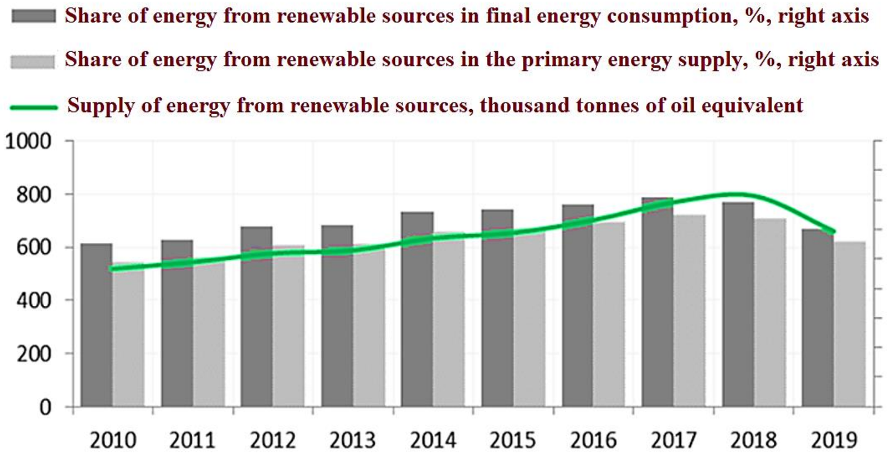

Figure 1. The supply of energy from renewable sources, thousands of tonnes of oil equivalent and the share of energy from renewable sources in the supply of primary energy and in the final energy consumption, % [1]

Although in 2010, the energy from renewable sources represented 19.7% of the energy supply, that share, in 2019, constituted 22.5%. In the same period, the share of energy from renewable sources in the final volume of energy increased from 22% to 24.1%. Compared to other European states, the Republic of Moldova has a fairly good position in terms of the supply of energy from renewable sources.

Last but not least, according to the gradual process of decarbonation, Republic of Moldova can contribute not only to global efforts to combat climate change, but also to improve the health and quality of life of its citizens. More efficient use of cheaper and abundant renewable energy sources, with the help of digital technologies, will transform cities, transport, industry and agriculture, reducing greenhouse gas emissions and improving air quality. Thus, decarbonation is not just an abstract goal of the European Union or the United Nations, but a policy with immediate and tangible benefits for everyone. The decisive factors that will generate these benefits will be the digitization and valorisation of the usable potential.

In this context, the opportunities of the Republic of Moldova in the energy sector are taken into consideration in the long-term development. In a special way, it should be mentioned that the electricity will have to become a strategic tool in the future for transport, air conditioning of houses and household needs, and the promotion of smart networks - including microgrids, will be proved to be the best way to make these things possible. Decarbonation and air quality are also on the priority list and ensuring an adequate access to the energy for the most vulnerable members of the society continues to be a topic of maximum importance.

2. Towards a clean, sustainable, competitive, and accessible energy

The roadmap for the development of the electrical energy system in the perspective of the 2050s must have a holistic vision to be able to ensure the harmonization of the electrical energy system with the other energy flows, some of which will also be converted into electricity.

Any analysis starts from the current situation of the power system, having *the volume of energy used at the country level* as an essential input.

Figure 2 presents characteristics of the energy used volume in the Republic of Moldova in 2020, based on data from [2], considered as a reference year.

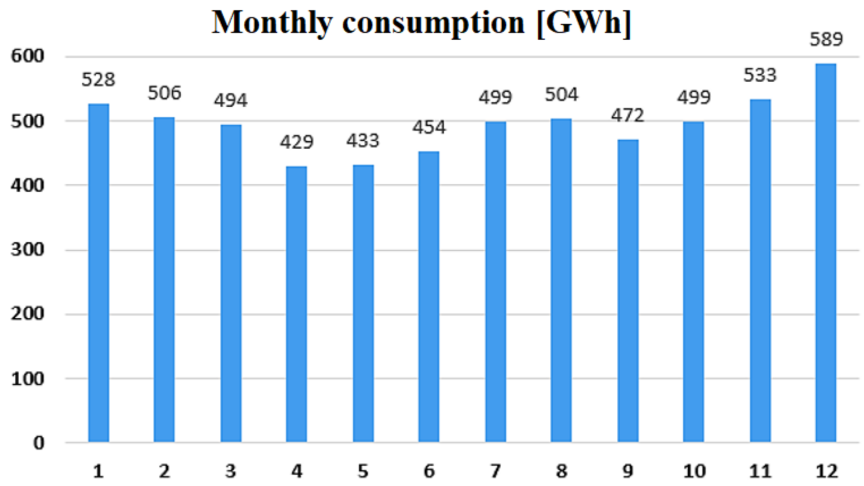

Figure 2. The monthly volume of electricity used in the Republic of Moldova in 2020.

The total energy used in 2020 was 5940 GWh, while the annual power average was 677 MW. Based on this data, the energy intensity per inhabitant is, for the Republic of Moldova, 5,940,000/4,000,000 = 1,485 kWh/year/inhabitant of electricity, where the number of inhabitants is taken as a rough estimation.

While main renewable energy sources (RES) are hydro, wind and solar, the paper is particularly focusing on the *need for photovoltaic power plants (PVPPs) in the Republic of Moldova*. PVPPs have the advantage of being able to be deployed all over the country and the technological advancements make them more and more competitive against other solutions, while potentially also adding resilience.

The necessary of PVPPs in the Republic of Moldova can be deducted, in a simplified manner, based on the calculations made in [3]. Compared to the analysis for 30% and 50% PVPP coverage, an extended coverage between 30% and 100% of the country's annual demand is shown in figure 3, where the annual energy produced by 1 kW of PV is used as an input data in two variants:

a) as a minimum value (obtained from real data, corresponding to 1,034 kWh/year/1kW), resulting as a total annual PVPP energy produced E_{MIN} and

b) as an average value at the RM level (1,182 kWh/year/kW) [4], resulting as an average annual volume of total energy produced, E_{MED}.

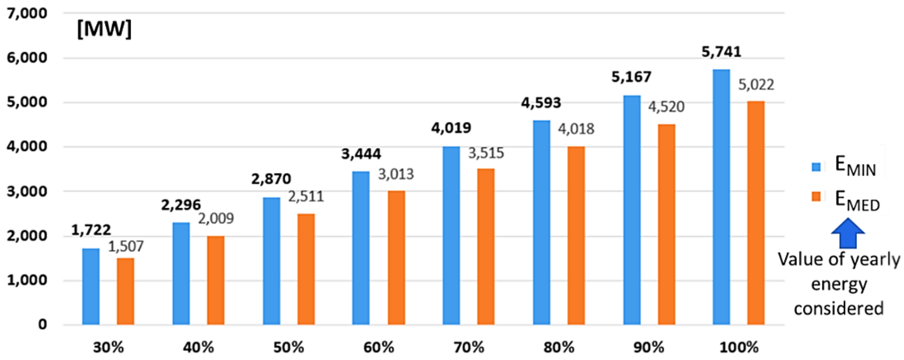

Figure 3. The need of PVPP installed power for various levels of coverage of the consumption on yearly basis in Republic of Moldova

Figure 4. Places in the Republic of Moldova used for the calculation of annual energy average with PVPPs [5].

It can be observed that for 100% of the country's necessary volume covered by PVPPs, the installed power is 5.74 GW for the minimum value of the annual production for 1 kW PV installed, which would require only 0.8% of the agricultural area of the Republic of Moldova, respectively 5.02 GW for an average annual energy value that could be obtained from the average of 11 places in RM (Figure 4).

Therefore, the value of 5.74 GW can be considered as a covering dimensioning value, which also considers additional factors, such as periods of unavailability and possible climate changes with a negative impact.

The calculation model used can also be utilized with other input data, respectively for the development of various future scenarios. In this sense, a new field of sustainable development can be approached, that of the harmonious interweaving of agriculture with PVPPs, i.e. an "agri-photovoltaic" development at the country level [5]. Such a concept would be extremely suitable for a country like Republic of Moldova, characterized by important activities related to the use of agricultural land, which can learn new valences of their potential in supporting a society that can keep in a sustainable way the traditional activities. In [6] agri-photovoltaic and floating PVPPs solutions are explicitly analyzed.

The necessary of 5.74 GW in PVPPs installations, using only 0.8% of the countries' agricultural land to cover the entire volume annually, is consistent with similar results for other countries ([7, 8]). A conclusion of the Greenpeace Organization is that, at this moment, only the political will is needed to achieve such an objective [9]. A "World Wildlife Fund" study shows that in Germany, 2% of the country's surface is sufficient to produce all the energy used annually from renewable sources alone [10]. The potential to provide electricity from RES alone is also highlighted in [11], showing that 1% of the EU area can provide the entire usable electricity requirement of the EU.

3. Conceptual elements in the vision of 2050 in Republic of Moldova

In order to draw a comprehensive vision of 2050 energy domain several important technological tendencies are presented in this section, as being conceptual elements to sustain a feasible roadmap to achieve carbon neutrality.

Power to Gas (P2G) and hydrogen-based energy solutions

In a scenario with high-RES penetration, there is a need for new energy vectors to bridge between seasons considering the RES energy variability over the entire year. Green hydrogen is an emerging direction to address this challenge.

An application with major effects in the use of H_2 in power plants was developed by General Electric through realization of modified turbines for the use of a mixture of 20% H_2 and 80% natural gas. The developed solution has been validated in over 10 million operating hours. The DOE (American Department of Energy) has invested huge sums in developing turbines capable of operating safely at higher concentrations of H_2. It is expected the appearance of a new generation of turbines that are able to use fuel up to 50% H_2 by volume. The NO_x emissions that occur in the combustion process are dramatically reduced. H_2 is used, in many cases, from furnaces or coke ovens of steel plants or from "waste" gases from oil refineries. The turbines developed today by GE, SIEMENS, Japanese, South Korean, French, etc. can save millions of dollars that should be paid for carbon emission rights.

The data from the specialized literature shows, in a typical example, that at a mixture of 50% H_2, NO_x emissions are reduced by 281,000 tons of CO_2 emissions annually. If the mixture would reach 95% H_2, the annual reduction equals to $70,000.

The ongoing multiple technological revolutions

Nowadays there are multiple technologies that allow the needed energy transition to take place. As usual, technologies that have a high rate of improvement in a short time are usually called “disruptive” (which destroy the current paradigm).

Below it will be presented some of technologies that have known or are evolving in the form of real “technological revolutions”.

a) PVs with the new technology based on perovskite

Perovskite is a chemical structure for which it was recently discovered (2010 year) that it presents the property of producing electricity, as is already widely used the technology based on poly or mono-crystalline silicon. The notable difference is the fact that the maximum theoretical yield is higher (43% instead of 34%) and that due to the different quantum phenomenon from that of silicon, it is a technology that complements the classical one. This means that is expected that a silicon + perovskite tandem to exceed a yield of 30%, but the standalone perovskite is in a position to reach the current silicon zone, ie at yields of 15-20% independently, in the conditions that the price of the installed kW is expected to reach half of silicon price. This means that the already low price of silicon PVs could be reduced with a half for future variants based on perovskite.

b) Storage (multiple technologies in competition)

Storage is a field that has known a real technological revolution. Although less important 10-15 years ago, storage field turnover has exploded in recent years, mainly due to electromobility and stationary energy applications. This caused the storage price to fall sharply, in the face of performance improvements, such as the number of the cycles and the maximum loading / unloading power. Due to the increase in the global turnover, additional advances in the storage field are expected, which will bring the price below 100 USD / kWh installed in the period of 2023-2027, making storage a widely usable tool.

c) ***Power electronics (SiC, GaN)***

Power electronics know special advances of the last hour. Thus, traditional components such as thyristors and IGBT transistors are beginning to be replaced by new technologies based on “large gap semiconductors”, with major advantages in terms of reducing losses, size, as increases switching frequency. Thus, Silicon-Carbide (SiC) technology allows switching frequencies in inverters and converters usually up to 100 kHz, while the latest Gallium-Sodium (GaN) technology can raise the frequencies to over 1 MHz.

This situation allows higher powers, smaller dimensions, high efficiency for inverters, converters and power electronics solutions used in electrical vehicles and their charging stations.

d) ***Informatics (digitization)***

Digitization has known significant advances in the recent times, enabling the democratization of many energy activities and awareness of important aspects of the energy sector (for example, through the widespread introduction of smart metering, which are enablers for many new functionalities).

e) ***Electrical vehicles (EVs)***

The ongoing revolution in switching to electrical vehicles plays a key role in its effect of the energy field. Due to a growing market and a smaller effect of business-as-usual inertia and the monopolies associated with maintaining this situation, electromobility is the main driver of the innovation through batteries, power electronics, artificial intelligence and associated ITC components, having a beneficial effect in the energy field, much more related to natural and historical monopolies and the fear of changes.

f) ***Power to Gas and Green gas***

An important aspect, represented by the need to have green energy for the periods of time in which RES have a lower contribution, is represented by the economy of green hydrogen and its derivatives such as methane gas – obtained as “green” gases, but also ethanol or “green” ammonia. It is a field for which huge efforts are expected by 2030, in order to bring these energy carriers at competitive prices with today’s situation, when its are obtained mainly from sources based on hydrocarbons. A reduction of 3 to 5 time in the price of green hydrogen, which is a goal of efforts by 2030, would help to almost solve the problem of carbon neutrality completely through economic solutions, with the time period 2030-2050 for being fully implemented.

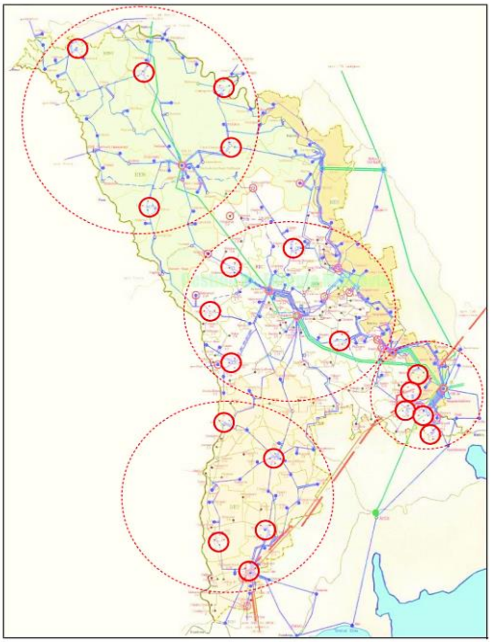

Figure 5. WPP places proposed for the Republic of Moldova RM [12]

Large wind and solar power plants

Wind and solar parks, made as large unit investments are attractive mainly due to the lower cost of the specific investment.

Figure 5 [12] shows the areas of the Republic of Moldova with wind potential, for wind powerplants (WPPs) while the study deals extensively with their integration into the national energy system of the Republic of Moldova.

The solar power plants potential, including the large-scale PVs (e.g., bigger than 1 MW installations) has been already presented in the above section, and it should have an important share of “bulk”/big PV installations.

The approach of an agri-photovoltaic (agri-PV) solution

In the study researched extensively in [3], it was shown that a small part of the agricultural area of the Republic of Moldova is needed to provide 30% or 50% of the annual volume of electricity used in the country. Even so, recent studies show that such areas can be found in the form of uncultivated land, but the areas where agricultural activities take place have a very high potential, through the application of the technologies that are particularly promising, namely agricultural activity. Photovoltaics.

Shortly, pilot projects in several parts of the world show that there are synergies between agriculture and the production of RES with PV, which may, in fact, change the perception that PV is in competition with agriculture.

Floating PVs

Another field of interest is the promotion of floating PVs. There are several reasons why they may become attractive:

a) does not occupy land usable for ordinary human activities (agriculture, urban areas, etc.);

b) ensures a higher conversion yield during the summer, because the panels, whose efficiency decreases with increasing temperature, are better cooled by the surface of water on which they float;

c) often such water surfaces (e.g., lakes) are located near urban areas, for which it can provide energy in an area close to the place where it can be used.

An exercise on lakes Ghidighici and Kongaz in the Republic of Moldova show their potential of 95 MW respectively 41 MW of floating PVs [6].

The potential of these lakes is not negligible and they also have the advantage of being close to the cities (Chișinău and Kongaz). Such lakes also exist in other zones of the Republic of Moldova; however a wider analysis is needed and is subject of other studies.

Active small, medium users and energy communities

Another particularly important direction is represented by encouraging production at the local level:

- local production to traditional users, who thus become active users (prosumers); this type of distributed production is generally achieved through PV mounted on roofs, especially in rural areas and in urban neighbourhoods that predominantly have own houses. The power installed on these roofs, usually are directed to south, this is in the range of 3 to 10 kW;

- local production for the active medium users, which refers to state institutions such as schools, hospitals and other public buildings, to industrial buildings and for commercial use. The installed power of these installations can be in the range between 50 kW and hundreds of kW. If the parking lots of the shopping complexes are added, using special awnings, the powers can also reach the MW range; it is expected a lower specific price of such RES investments compared to the production at the level of habitual end-user acting as prosumer.

- a third important category represents the energy community. Usually, the users of a community do not have a functional space to invest individually in a RES installation, however many of them are willing to organize themselves in energy “cooperatives” and to participate in a common RES investment, which may be implemented in collaboration with the mayor’s office or other public or private entity from their area.

4. Considerations for the roadmap to 2050 in the Republic of Moldova

In continuation it is proposed the roadmap to 2050 in the Republic of Moldova with essential elements that can be the basis of the national policies.

1) The development of **renewable electricity sources** distributed in all regions of the country where there is high consumption in the neighbourhood (cities, industry, etc.) should represent a high general priority. These must be especially based on photovoltaic powerplants (PVPPs) and wind powerplants (WPPs), in a proportion that corresponds to the environmental conditions of the Republic of Moldova, following in-depth, multi-criteria studies. A contribution of at least 50% to the solar has been proved to be possible [6]. A suitable solar-wind combination requires further study. It will also be analyzed whether there is still hydropower potential that can be attracted in the energy mix.

2) It will be supported **the increase the flexibility of the electrical power system**, especially through important projects, such has the construction of at least one Pumped Hydro Plant (PHP, with favourite locations being on Dniester River), combined with Battery Energy Storage Systems (BESS), these one being projected to hold the biggest amount of the necessity [13].

3) It will be taking into consideration **flexibility measures which will reduce the dependence on technological services system provided by neighbouring countries** (especially Ukraine).

4**) The household heating** needs to be electrified in steps. Various methods need to be considered: direct heating through Joule effect, heating with increased efficiency – by using heat pumps, use of existing thermal power plants combined with heating (combined heat and power – CHP), adapted for green H_2 and CH_4 and so on, These solutions need to be complemented with measures to increase the efficiency of heat consumption through retrofitting (modernization of existing installations) implemented at the heating installations level (at source), on the heat transportation segment and at the buildings level (at the end customer).

5) **It will be electrified** in stages the "**light vehicles" park** and then the "Heavy vehicles" park, meaning trucks and busses; moreover, electrical vehicles (EVs) with vehicle-to-grid (V2G) functionality will be encouraged, in order to obtain more synergies between EVs and the electrical network, especially by supplying flexibility services to the grid; this process will be accompanied by information and telecommunication technologies (ICT) charging coordination solutions (solutions equivalent to demand response) and the promotion of EVs with V2G facilities, whose potential to provide flexibility through the use of energy in batteries, is extremely high.

6) The introduction of renewable energy sources will be accompanied as much as possible by **agri-photovoltaic (agri-PV) solutions** which will bring synergistic benefits to both areas, including accelerated electrification of agriculture. The change mentality, from keeping land for agriculture only, to a beneficial combination with local PV production for local needs is a raising phenomenon [14, 15] and need further studies; where feasible, floating PVPPs on lakes close to large consumers such as cities and energy communities should be also encouraged.

7) It will be encouraged the **digitalisation of the energy activity, including through smart metering systems**, of the participation and operation of energy and flexibility services markets, including local markets to serve local communities. SCADA systems and functionalities related to Smart Grid paradigm will be also sustained by advanced ICT solutions. Digitalisation will allow more real-time decisions and operations, while also contributing to a higher efficiency on the value chain of the energy production, transport, distribution and use.

8) An important target should be **the creation of resilient energy communities** which will reduce the risk of losing the energy local supply in the situation of outages in the public network (e.g., due to extreme climatic situations). As resilient energy communities ask usually for a substantial share of local energy production, such entities can be as well resilient against large price fluctuations in the energy field because the local energy has usually its own price related to the already made investment. These energy communities will also bring an incremental experience in the perspective of building future smart cities, where resilience and sustainability play key roles. In the same context, small RES producers will be encouraged to become active users, which can have also a certain energy resilience at the end-user level.

9) It will be encouraged **the realisation of various pilots to prove and to gain experience regarding emerging technologies**. Domains such as Power-to-Gas transformation, especially for obtaining H_2, appropriate

solutions for transporting green hydrogen, inclusively in mixture with methane gas (CH_4) can be subject of such small and medium size pilots. As it is needed a huge international effort for the gradual maturation of such technologies, this field has to be stepwise developed in RM until 2030 horizon and then, solutions which will gain meanwhile a higher technological readiness level (TRL) should be embraced and should be prepared towards generalisation.

10) It will be encouraged **new business models**, such as Power Purchase Agreements (PPAs) – which have the potential of keeping low energy prices over specified periods of time (thus helping predictably and sustainably of other activities of the community, especially those which are more energy dependent), but also appropriate approaches for new technologies, such as financial models such as Storage as a Service (SaaS) or RES production coupling models with local storage, as unitary solutions for better RES integration in the grid.

11) H**igh-level education and scientific research** need to be encouraged in order to support the implementation of the incoming energy revolution, by providing qualified personnel and new solutions for achieving the goal of carbon neutrality.

12) **Energy policies should be implemented** in such a way that they can stimulate efficiently the objectives, through government, through the energy regulation agency and through other bodies which is necessary to be involved.

5. Discussions and conclusions

The Republic of Moldova future in the energy field has a good potential in the long-term for a carbon neutrality perspective. In order to ensure that this potential is exploited, the Republic of Moldova must take courageous decisions to attract investments, as there is a fierce global competition between countries in the world to attract capital, especially between developing and emerging countries. The Republic of Moldova can be a good participant in this race, if it presents a solid business plan in the medium- and long-term development.

But all these will happen if the energy strategy planned for decades, state policies and regulations will be put into practice based on the projects carried out in the energy sector in order to take advantages through the inevitable energy transition. The Republic of Moldova will face with a lot of challenges in the energy sector in the next ten years, but it is still in the process that can be prepared.

The paper presents conceptual elements which can support a credible energy strategy for the future, which include technological trends which are meaningful for the purpose of energy filed decarbonation. Multiple technological revolutions are presented as key enablers for the energy field transformation. A roadmap towards 2050 horizon is presented through twelve essential elements that can be the basis of the national policies of Republic of Moldova. It is important to highlight that these elements are of various types, from pointing technologies to be promoted up to new business model and societal changes, supported also by appropriate measures in high education and political will through laws, energy policies and practices to pushed by different bodies of the society, such as government and energy regulation agency.

The paper is intended to propose directions and possible solutions for preparing Republic of Moldova to advance towards carbon neutrality in 2050, while also keeping an open door for deeper analysis and future studies related to various aspects of this complex and highly inter-disciplinary subject.

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