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CONTRIBUTIONS TO INCREASE THE FLEXIBILITY OF THE ENERGY SYSTEM IN ORDER TO INTEGRATE RENEWABLE ENERGY SOURCES

221.01. ENERGY SYSTEMS AND TECHNOLOGIES

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I. CONCEPTUAL GUIDELINES OF RESEARCH

The topicality and importance of the issue addressed. In the modern society *Energy* is an essential product for economic and social well-being. It is indispensable for the economic development of the country, respectively according to the industry, transport, agriculture, etc. The energy is a symbol of socio-economic development and civilization. But at the same time, the energy presents the cause of serious damages to the environment and human health.

Climate change, triggered and sustained by the human activity, is currently ***the greatest global challenge and threat to humanity.***

Mitigation of the phenomenon is possible in the long term perspective and with increasing efforts to reduce greenhouse gas emissions, which is a major concern of the world's states. The world understands that the danger of its existence is so great that urgent action is needed. In the absence of emission reduction policies, is expected during this century an average global temperature increasing between 1.1 ° C and 6.4 ° C.

This problem suppose a responsible approach, with concrete action taken at local, national, European and global levels. In this context, the UN Framework Convention on Climate Change (UNFCCC) was adopted in 1992 and is the main instrument for resolving this major problem.

Extreme meteorological phenomena, such as forest fires, heat and flood, the increasing number of storms and associated phenomena, etc. are becoming more and more common both on the European continent and in other parts of the world. The European Union (EU) is the leader in the fight against global climate change. EU climate and energy policies are evolving, implementing with the 1980s. At the beginning it came with multiple initiatives related to the common market of electricity and natural gas, environmental issues, and then to energy efficiency in the building sector, energy efficiency in the energy sector and other areas, so that, finally, it promotes renewable energy sources. In the present is currently a well-developed Energy and Climate policy and legislative framework in the EU that has been implemented and revised over time to increase the volume and effectiveness of climate change mitigation and prevention measures. The EU and its Member States are engaged in a long-term, multi-step process to reduce greenhouse gas emissions.

It should be mentioned that, since 2010, the Republic of Moldova is a Contracting Part to the Energy Community of the Balkans. In this context, national energy policy is fully in line with the policy of the Energy Community and the European Union on energy and climate, respectively.

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 2020: on the one hand, there is the challenge of decarbonization 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, accessible to the end consumer. The role that the Republic of Moldova will assume in addressing the energy transition will determine whether our country will be able to benefit from this change or whether, rather, it will bear its costs.

The potential benefits are not limited to clean energy production, the energy transition can have a positive effect on construction, transportation, energy services, industrial production and the automotive industry. But these benefits can not be materialized without a well-defined strategy at both national and European level.

The Von der Leyen Commission officially announced the Green Deal at the end of 2019, in which the EU aims to become a world leader in mitigation the effects of climate change and to be the first continent with “net zero” greenhouse gas emissions to 2050.

Consequently, it is needed a sustainable transformation of the economy, by removing fossil fuels, promoting clean energy from renewable sources and developing a circular economy based on changes in the behavior and attitude of society as a whole. However, making these changes requires significant need for investment, also the European Commission intends to mobilize € 1 trillion over the next decade. But in order to truly feel the benefits of such a change and to put the EU's ambitions into practice, it will be necessary for a significant part of the investment to move towards the creation of a strong and independent European industry that can deliver solutions to the challenges, generating added value in the economy. Otherwise, Europe risks failing to meet its proposed targets, which are particularly ambitious.

At the national level, the Republic of Moldova have to do a number of important steps in this direction, steps that will foreshadow the basis of long-term national strategies in this field. The Republic of Moldova has a satisfactory and sufficient energy potential. The Republic of Moldova is in a good enough position to cope with the energy transition. The country has the means to take advantage of the inevitable developments in the energy sector and turn them into opportunities for the whole economy.

First of all, digitalisation is already having a huge impact on many sectors of the economy, and the effects are beginning to be visible in energy sector as well. With an essential contribution to the GDP of the IT&C sector - a modern infrastructure and a well-qualified workforce, the Republic of Moldova can fully benefit from the advantages of digitalisation. For the energy sector, this means integrating new technologies, lowering production costs, improving the quality of distribution service, encouraging energy efficiency and much more other things.

By implementing smart metering and other digital technologies, consumers will gain more control over energy consumption, they will be able to become "prosumers", but also to provide energy storage services. At the same time, the technologies will lead to the creation of many highly qualified jobs, supporting economic growth. In other words, the digitalisation of the energy market is a solution that becomes indispensable for the Republic of Moldova as well.

Secondly, as innovations begin to produce results in this area, it becomes imperative to encourage the widespread use of electricity. Whether we are considering energy security, improving energy efficiency or air quality, the use of electricity will have to increase in the medium and long term perspective. The Republic of Moldova has sufficient resources, especially in the field of renewable energy sources, to cope with this advance in the use of electricity. As less developed localities continue to narrow the gap with the rest of the country, there is an accelerated rate of adoption of household appliances and other equipment that increase the quality of life. In addition, due to technological advances, in the near future heating and cooling of buildings will be possible with the help of electricity, especially through the use of heat pumps.

At the same time, electric mobility is no longer just a prospect for the future, but a concrete reality of our day. All this will materialize in a larger volume of electricity, mostly from renewable sources, given the significant improvement in their efficiency and lower technology costs to record lows.

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

Overall, the opportunities of the Republic of Moldova in the energy sector are taken into account, during this thesis, long-term development. In particular, electricity will have to become a strategic tool for the future of transport, air conditioning and household needs, and the promotion of smart grids will prove to be the best way to make this possible. Decarbonisation and air quality are also on the list of priorities, and ensuring adequate access to energy for the most vulnerable members of society continues to be a top issue.

In conclusion, the country's future in the energy field looks pretty good in the long term perspective. But in order to ensure that this potential is realized, the Republic of Moldova have to take courageous decisions to attract investment. There is fierce global competition between countries in the world to attract capital, especially between developing and emerging countries. Republic of Moldova can be a good participant in this race, if it presents a solid business plan in the medium and long term perspective.

But all this will happen if the energy strategy planned for decades, state policies and regulations will be transposed in practice based on projects in the energy sector in order to take advantage of the inevitable energy transition. Republic of Moldova will face many challenges in the energy sector in the next ten years, but we are still in the process of preparing.

The aim of the thesis is to identify and analyze a package of measures / actions to increase the long-term flexibility of the national electricity and thermal energy systems in order to ensure the transition to 100% energy from renewable sources.

Research objectives

The main objective of this thesis is to study a series of innovative technologies whose contribution becomes significant to increase the flexibility of the energy system, with the evaluation of the potential to increase RES capacities, applied both in the national power system and in the national thermal energy system, storage of both thermal and electrical energy.

Specific objectives include:

- Study on the development of the global energy transition and the integration of the Republic of Moldova in the perspective of long-term development;
- Achieving the main directions to increase the flexibility of SEN in order to increase the share of renewable energy sources;
- Elaboration of the conceptual elements of a roadmap for the energy transition in the Republic of Moldova;
- Study on the coverage of 30% to 50% of the annual consumption of Moldova with renewable energy obtained from photovoltaic power plants (CEF), in addition to other studies that focused on the potential of wind power plants (EEC);
- Study on the flexibility potential of electric vehicles on the national power system;
- Determining the heat consumption in the Republic of Moldova in the territorial profile, the potential of energy cogeneration and electrification of the heating sector;
- Study on building up hydro pumped storage plants on the territory of the Republic of Moldova as a large-scale energy storage;
- Carrying out the study on the need for short-term storage in the conditions of large-scale introduction of photovoltaic power plants in the Republic of Moldova;
- Elaboration of the case study for the Republic of Moldova on the flexibility of energy networks through a combination of storage facilities: pumped hydro power plants

(CHEAP) and battery energy storage systems (BESS).

Research hypothesis

With the development of energy systems in the transition from the use of fossil fuels to 100% renewable resources, concerns are growing about the possible operation of the national energy system with sufficient flexibility. As a result, there are signs of limiting the addition of new intermittent renewable sources (solar, wind) in the system. Making energy demand, on the one side, and supply, on the other side, more flexible, becomes an essential precondition for the integration into the system of high levels of energy from renewable sources.

An efficient transition to decarbonised energy systems requires the search for innovative solutions to increase SEN's flexibility. In this context, various solutions have been studied to increase the flexibility of the national energy system as a key factor in ensuring the proper functioning of SEN based on 100% renewable energy sources, as a whole, focusing on changing the future energy system by promoting and evaluating innovative prospects increasing the flexibility with a share of electricity based on SRE-V, with the analysis of the possibilities of storing both thermal energy and electricity.

Synthesis of the research methodology and justification of the chosen research methods

When was calculated the impact of EV on the national energy consumption of the Republic of Moldova, the percentage of increase in electricity consumption was determined as a result of the gradual introduction of EV from 10% to 100%.

When was determined the heat consumption in the Republic of Moldova in territorial profile, the potential of energy cogeneration and the electrification of the heating sector, it was started from the modeling of household consumption. Respectively, the methodology for assessing the cogeneration potential included the determination of the total thermal energy consumption in territorial and residential areas (urban, rural) for the accepted reference year, the determination of the optimal economic share of cogeneration and the determination of cogeneration potential at the level of consumption of the reference year (2018), as well as the time horizon - the year 2025.

Through modeling and analysis, with verification and correction of the total based on data available at the national level (Energy Balance), a satisfactory solution for assessing heat consumption has been reached - by districts, municipalities and geographical areas of development (climate zones).

Calculations were made for a possible CHEAP built on the territory of the Republic of Moldova, as well as its economic-financial feasibility determined based on the assessment of the updated net income (VNA). In order to determine the VNA income, the calculation of the total updated expenses (CTA) related to the construction and operation of CHEAP during the 30-year study period, as well as the total updated income (VTA) obtained from the electricity produced on the balancing market during the top hours of the system.

In order to analyze the specific situation of a wide penetration of photovoltaic power plants in the energy system of the Republic of Moldova, two scenarios were chosen and evaluated: covering 30% and 50% of the country's annual consumption with CEF production, by reporting their annual energy to the country's annual consumption. The need for short-term, one-day storage, respectively, was analyzed in order to compatibilize the RES production curve with the national consumption curve, in terms of a limitation of cross-border exchange power (Net Transfer Capacity - NTC). This was the main part of the study, as storage capacity was seen as an essential element in increasing flexibility in power systems. The field requirements for the implementation of PV production scenarios were analyzed. This analysis complements other studies that have focused on the production of wind power plants (CEF).

The analysis of the strengths of the two competitive storage technologies (pumped storage hydropower plants (CHEAP) and the latest battery-powered energy storage systems (BESS)) investigated appropriate models and business opportunities for BESS . These options are capable of complementarity, bringing synergies and providing appropriate storage solutions in a decarbonised energy paradigm.

Summary of thesis chapters

The thesis includes the introduction, 4 chapters, annotation in Romanian, English and Russian, the list of abbreviations used, the list of tables, the list of figures, the compartment containing the final conclusions of the thesis, the bibliographic list of 291 titles, 7 annexes. The total number of pages of the paper is 151 (up to bibliography), with 52 figures and 19 tables.

II. THESIS CONTENT

The **Introduction** presents the current trends in the field of renewable energy and climate change, the topicality of the research topic, the argumentation of the chosen research topic, the purpose and objectives of the thesis, the scientific problem solved, the synthesis of the research methodology and the justification of the chosen research methods.

Chapter 1 "Study on the development of the global energy transition and the place of the Republic of Moldova in this process" is a synthesis of the current stage of development on the development of the global energy transition and the place of the Republic of Moldova in this process, and the perspective of promoting RES-V at global, European and national level. Also here are described the new trends and innovations of the fundamental attributes for a reliable operation of the future energy system that has a high share of RES. Chapter I concludes with the priority topics addressed and solved in the thesis with the formulation of research problems.

Adopting ambitious global measures in addition to mitigation climate change will bring benefits, such as lower fossil fuel imports and improved air quality and public health.

At national level, the launch of the energy transition calls for the development of a special program, which would pursue a strategy with concrete medium- and long-term objectives. The launch of TE requires wide public acceptance for a better future. There is an obvious paradigm shift in the energy sector towards renewable energy sources. Consequently, a sustainable and sustainable transformation of the economy is needed, by removing fossil fuels, promoting clean energy from renewable sources and developing a circular economy. The results of the research study show that the energy transition will have an undeniable impact on the energy economy and security of the Republic of Moldova.

In the case of the Republic of Moldova, the TIMES modeling program was used, which allows the discretization of the study duration analyzed in several periods and respectively the assignment of different growth rates and elasticity for the factors that determine the future energy demand. The elaborated scenarios will serve for the elaboration of the Integrated National Plan in the field of energy and climate change 2021-2030, as well as the updating of the Energy Strategy of the Republic of Moldova until 2030.

Complete electrification of energy consumption sectors and massive integration of electricity storage systems to balance the system and by integrating storage technologies contribute to the elimination of greenhouse gas emissions. Digitization can help integrate variable renewable resources, allowing networks to act at different times of energy demand when the sun is shining and the wind is blowing. Following a documentary study, it is noted that there are several concrete ways of digitization, which can be developed and applied. These actions must be accompanied by promotional campaigns, through which consumers can properly assimilate the benefits they can benefit from, as well as the extremely low risks, through the transition to smart systems.

Energy storage, in turn, is one of the most important components in ensuring flexibility and supporting the integration of renewable energy sources into energy systems. In conclusion, it can balance the generation of electricity both centrally and distributed, while contributing to increasing energy security.

In Republic of Moldova, with all the successes achieved in the development of the use of renewable energy sources, there are new possibilities to increase their share, especially through the development of microgrids and prosumers. Based on the analysis of the current situation regarding the capitalization of the potential of RES in Republic of Moldova, it would be possible based on a path focused on the gradual implementation of appropriate policies and measures to increase the benefits of increased integration of RES in SEN, time associated costs.

By the time 2050, the country's electricity system will need capacity to balance intermittent production.

Chapter 2 "Increasing SEN flexibility in energy supply and demand in order to integrate RES-V" focuses on the key term of the thesis "Energy system flexibility". All measures and flexibility solutions are proposed and presented to ensure a significant contribution with a high level of SRE-V penetration. The main directions for increasing flexibility are established by promoting storage technologies, modern technologies in the future of district heating systems and the development of hydrogen as a flexible vector in the energy sector.

An important contribution to ensuring a high level penetration of RES-V is the measures and flexibility solutions. Increasing the share of intermittent renewable energy sources determines the necessity of the interconnections development, energy storage systems, flexible generation sources, the promotion of demand response, as well as advanced tools for operating the system. In this context, there should be a roadmap for increasing the flexibility of the energy system, which will ultimately accommodate very high penetration levels of variable SRE-V generation into networks.

Flexibility issues are on the agenda of European agencies and decision-makers. The 2020 Flexibility Agenda aims to accelerate the introduction of flexibility measures, given the recent developments in energy policy at European level. The solutions implemented for the integration of renewable sources are not unique, but arise from the synergies of different innovations that combine technologies, market design, business models and the operation of systems.

Energy storage is a necessary option for future carbon-free systems, complementary to other solutions for flexibility and energy security. Energy storage is one of the most important components in ensuring flexibility and supporting the integration of renewable energy sources into energy systems. In conclusion, energy storage is rational for the global energy transition to a low-carbon system, mainly based on renewable energy sources, as well as for achieving the EU's climate and energy goals.

The centralized power supply system is not a new concept, but it has a new relevance in a world that is looking for practical solutions for decarbonization. The latest generation of infrastructure for centralized (4G) power systems allows urban planners to increase energy efficiency, while creating a viable channel for access to renewable energy sources. Safe, durable, scalable - the centralized structure is an essential component for reducing carbon levels today.

Hydrogen is, in turn, a flexible energy "vector" with potential applications between the various energy sectors. The transition toward economy based on the hydrogen - began, and the Republic of Moldova may have the potential and scientific capacity to make an original contribution in this multidisciplinary field. The transition toward economy based on the hydrogen could take several decades, so the Republic of Moldova will have to become an active participant in this process in the future.

Chapter 3 „**Conceptual elements of a roadmap for an energy transition in Republic of Moldova ”** is fully dedicated to a first time presentation of 12 conceptual elements of a roadmap for an energy transition in Republic of Moldova, which can be further developed for elaborating the Energy Strategy towards year 2050. It targets a conceptual approach of the thermofication problem, as being a key sector towards the deacrbonation of the supplied thermal energy. Challenges have been identified regarding the development and operation of electroenergetic system. For this purpose it has been presented the impact and the potential of flexibility of the electrical vehicles (EV) on consumption of electrical energy at the national level and on the electrical power system (EPS), as well as the potential of flexibility given by EVs with V2G (Vehicle to Grid) characteristics.

The roadmap for developing EPS in the perspective of years 2030 and 2050 need to consider several essential elements. It is needed a holistic vision to harmonise EPS with other energy fluxes, considering also that some of them will be converted sa well into electrical energy. To the new trends one can add the fact that the process of out sourcing intensive energy domains towards other countries, after the ‘90^{th} ask for reevaluation due to new policies for economic resilience. Covid19 crysis shown the fact that key industrial sectors is advisable to “come back home”, such that in case for force majeure to prevail the national or European interest. It means that the degree of consumption increase has not only the component of economic growth based on traditional sectors and the complete electrification of the rural zones, but also sectors which have been outsourced from the country in the past and now need to be reintegrated in national economy, and new domains such as PV panels or batteries production, all making it more credible an increase of energy need in the future.

The ful power system need a rightful level of flexibility, defined for equilibrating at any time the production and consumption. .The variability and the incertitude are not new for the power system, as loads change in time, sometime not predictable, while classic resources can suddenly fail as well.

It has been calculated for the first time the need of photovoltaic plants in the Republic of Moldova (RM), based on a simplified method presented in the thesis. The initial annalysis made for 30% respectivelly 50% coverage of consumption on a yearly basis, has been extended in order to cover 30 to 100% from this consumption. It has been shown that if ipotetically it is chosen to cover 100% of national consumption, the installed power is as much as 5.74 GW (by using coverage factors), which represent only 0.8% of the agricultural area of RM.

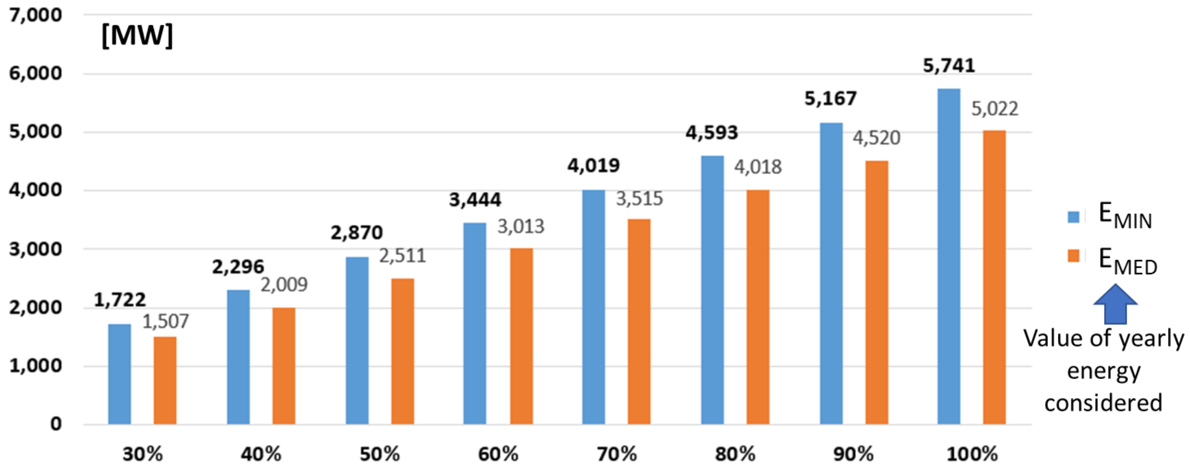

Figure 1. The need of PV power for various levels coverage of the consumption on yearly basis in Republic of Moldova

For the first time it has been proposed a new domain of sustainable development, by combining in harmony the agriculture with photovoltaic plants at national level. Such a concept is extremly adequate for a country like RM, having important agricultural activities, which can see new valences through the potential of supporting a society which can keep in a sustainable and durable manner traditional activities. Another aspect of interest is to promote floting PVs. The work made an exercise to show the potential of floting PVs has been made for two lakes in RM. The potential of these lakes is not negligible, while having the advantage as being nearby cities (Chișinău, Kongaz). Between the main objectives to be promoted in RM, the agro-photovoltaic and floting PVs are explicitely listed.

The roadmap for the development of the electrical power system in the perspective of years 2030 and 2050 need a holistic vision to ensure harmonisation between electrical power system and other energy fluxes, while some of these other fluxes will be converted in electrical energy as well. There have been propsed 12 conceptual elements which can be at the basis of the national policies of Republic of Moldova:

1) It will be facilitated the development of renewable electricity sources to be placed in a distributed manner in all country regions which have nearby consumers (photovoltaic and wind based renewables);
2) It will be supported the increase the flexibility of the electrical power system, especially through important projects, such has the edification of at least one Pumped Hydro Plant (PHP, with favorite locations being on Nistru river), combined with Battery Energy Stprage Systems (BESS);
3) Measures of flexibility should be considered to reduce the dependency of ancillary services supplied by neighborhood contries, while Net Transport Capacity (NTC) need also to be increased, to have more available fexibility;
4) It will be electrified in stages the household heating, through various methods (direct heating through Joul effect, heating with increased efficiency – by using heat pumps, use of existing thermal power plants combined with heating, adaped for green H_2 și CH_4 etc.);
5) It will be electrified in stages the small vehicles park and then the one with trucks and busses and it will be promoted EVs with V2G characteristics;
6) The introduction fo renewable energy sources will be accompanied as much as possible by agro-photovoltaic solutions;
7) It will be encouraged the digitalisation of the energy activity, including through smart metering, energy and flexibility services markets, SCADA systems and promotion of initiatives which contain Smart Grid functionalities;
8) It will be encouraged the creation of resilient energy communities;
9) It will be encouraged the realisation of pilots for the emerging technologies, such as Power-to-Gas;
10) It will be encouraged the new business models (PPA, SaaS etc.);
11) It will be encouraged the high-level education and scientific research;
12) Energy policies should be achived such that they stimulate in an efficient manner these objectives, through lawmakers, government and regulation agency in the energy domain.

An important tendency for the future is the raise of electrification in the economy activities.

In this aspect, there aer at least two major domains which will be electrified in the next period: the domain of transport, especially related to small and medium-size cars, through the use of electrical vehicles, and the domain of heating based on electrci energy.

Different heating units can balance the power system and can contribute to the sustainability of future power systems.

As an asnwer in different challenges of SACET, this is heading towards the implementation of a more intelligent thermal system – centralised central system of the 4th generation (4G). This system implies the interraction between smart thermal system and the smart grid.

Electrical vehicles are important in the future power system. Each of the mentioned aspects ask for a deeper analysis, which can be made, in the perspective of gradual introduction of EVs in the auto park of the Republic of Moldova, combined with gradual increase of the intelligence in managing this aspects, including through V2G technologies.

Table 1. Posible evolution of accesible energy in the batteries of EVs for V2G applications

1	**2**	**3**	**4**	**5**	**6**	**7**
Percent of EV	**Number of EVs**	**E_{VE} [kWh]**	**E_total [MWh]**	**V2G Share**	**Proportion Bat. V2G**	**E_Tot_V2G [MWh]**
10%	100,000	30	3,000	1%	20%	6
30%	300,000	40	12,000	5%	25%	150
50%	500,000	50	25,000	10%	30%	750
70%	700,000	70	49,000	12%	35%	2,058
90%	900,000	80	72,000	15%	40%	4,320
100%	1,000,000	100	100,000	20%	40%	8,000

It can be observed that at the highest percentages of VEs (70-100%) it can be used for the power system between 2 and 8 GWh of energy stored in batteries, as instrument of flexibility, the latest value being in the range of storage needed on daily basis for 50% of yearly national electrical energy consumption through PV production. It can be seen that electromobility doesn’t bring only challeges, but it can substantially help to the flexibility need in a scenario with a large penetration of RES. Preliminary results show that EVs with V2G can cover up to 50% from the need of flexibility (in subchapter 4.4 it is estimated the need for storage on a daily basis to be approximate 10 GWh for 50% RES).

Moreover it has been observed that if for a low penetration of EVs the effect in energy consumption at national level is rather small (only 7.6% for 30% EVs), for a karge addoption of EVs, for example $\geq$ 70%, the national consumption raises at 25%. This extra energy need to come from renewable resources, asking for additional RES at national level.

In **Chapter 4 "Determining the heat consumption in the Republic of Moldova in territorial profile, the potential of energy cogeneration and electrification of the heating**

sector" was determined for the first time the heat consumption in the Republic of Moldova in territorial profile, the potential of energy cogeneration and electrification of the heating sector. Thus, the calculation of the heat consumption in the country in territorial profile at the level of 2020 and 2030 was performed with the evaluation of the national potential (2025) for the implementation of high efficiency cogeneration. The optimal economic share of cogeneration was determined for the three development zones of the country: North, Center and South and the generalized characteristic of the cogeneration installations park that could be promoted in the country with the determination of the average cogeneration index.

In conclusion, the cogeneration potential at the level of consumption of the reference year (2018) was determined, as well as the existing potential for additional cogeneration by 2025: the nominal electrical power of the cogeneration plants, MWe, which constitute 647 MW.

Table 2. Existing potential for additional cogeneration by 2025: rated power of cogeneration plants, MWe

	Districts / Municipalities	**Urban household**	**Services+ Commerce**	**Industry +other sectors**	**Total 2018**	**Total 2025**
	North Zone					
1	m. Bălți	17,73	3,62	5,34	**26,7**	**27,3**
2	Briceni	4,48	1,28	1,89	**7,7**	**7,9**
3	Dondușeni	2,87	2,88	4,25	**10,0**	**10,5**
4	Drochia	4,74	8,74	12,90	**26,4**	**27,8**
5	Edineți	7,08	7,35	10,84	**25,3**	**26,5**
6	Fălești	4,07	1,21	1,78	**7,1**	**7,2**
7	Florești	5,42	2,27	3,36	**11,1**	**11,4**
8	Glodeni	3,13	0,83	1,22	**5,2**	**5,3**
9	Ocnița	4,90	0,77	1,13	**6,8**	**6,9**
10	Râșcani	3,78	1,24	1,83	**6,9**	**7,1**
11	Sângerei	4,86	2,17	3,21	**10,2**	**10,6**
12	Soroca	8,00	2,80	4,13	**14,9**	**15,4**
	Subtotal Nord	**71,1**	**35,2**	**51,9**	**158,1**	**163,8**
	Center Zone					
1	mun. Chișinău	71,00	54,86	80,94	**206,8**	**215,7**
2	Anenii Noi	2,77	4,68	6,90	**14,3**	**15,1**
3	Călărași	3,66	1,54	2,27	**7,5**	**7,7**
4	Criuleni	1,87	1,51	2,23	**5,6**	**5,9**
5	Dubăsari (Cocieri)	0,00	0,59	0,87	**1,5**	**1,6**
6	Hăncești	3,98	4,18	6,16	**14,3**	**15,0**
7	Ialoveni	3,74	3,12	4,61	**11,5**	**12,0**
8	Nisporeni	4,81	1,04	1,53	**7,4**	**7,5**
9	Orhei	6,95	4,51	6,66	**18,1**	**18,9**
10	Rezina	2,87	20,63	30,43	**53,9**	**57,3**
11	Strășeni	5,66	1,90	2,80	**10,4**	**10,7**
12	Șoldănești	1,88	0,68	1,01	**3,6**	**3,7**
13	Telenești	2,00	0,97	1,43	**4,4**	**4,5**
14	Ungheni	10,83	2,59	3,83	**17,2**	**17,7**
	Subtotal Centru	**122,0**	**102,8**	**151,7**	**376,5**	**393,1**
	South Zone					
1	Basarab	2,93	0,62	0,91	**4,5**	**4,6**

2	Cahul	9,61	3,05	4,51	**17,2**	**17,7**
3	Cantemir	1,11	0,64	0,94	**2,7**	**2,8**
4	Căușeni	6,08	1,50	2,22	**9,8**	**10,0**
5	Cimişlia	3,16	1,25	1,84	**6,3**	**6,5**
6	Leova	3,66	0,53	0,78	**5,0**	**5,1**
7	St Voda	2,28	1,02	1,50	**4,8**	**5,0**
8	Taraclia	5,04	1,55	2,29	**8,9**	**9,1**
9	Găgăuzia	14,68	5,46	8,05	**28,2**	**29,1**
	Subtotal Sud	**48,5**	**15,6**	**23,0**	**87,2**	**89,7**
	TOTAL Moldova	**241,6**	**153,6**	**226,6**	**622**	**647**

One of the main measures to increase the flexibility of the power system, based on the use of variable renewable sources is the electrification of rural household consumption. Thus, the rural domestic consumption of heat (useful energy) in the country (2018) for electrification was calculated and presents P_{ins} = 862 MW.

Table 3. Potential for electrification of rural domestic heat consumption

	Useful rural heat consumption (30%)		
	Necessary, tep	**Electrified, MWh**	**Sarcina el., MWe**
North	71 914	836 357	300
Center	85 769	997 494	378
South	40 941	476 141	184
Total	**198 624**	**2 309 992**	**862**

Subsequently, the thesis presents a series of in-depth and detailed studies on the implementation of concrete measures to increase the flexibility of the energy system: construction of hydro power plants with pumped storage, assessment of the need for PV in the Republic of Moldova photovoltaic) and case study for the Republic of Moldova - flexibility of energy networks through a combination of storage facilities and competitive technologies - pumped storage hydropower plants (CHEAP) and the latest battery-powered energy storage systems (BESS).

Accumulation by pumping is the only commercially proven technology available for the large-scale storage of electricity in an energy system, from which the Republic of Moldova could benefit fully. This type of plant was and remains imperative for the future energy system of the Republic of Moldova. The possibilities of the "Google Earth" software were used to determine the altitude of the slopes near the river. Following the study, possible locations of some CHEAP-MDs along the Nistru and Prut rivers and near some lakes were identified.

Table 4. Possible locations for Pumped-Storage Hydro Power Plant in Moldova

No	Locality, district		Altitude of the upper reservoir surface, m	Altitude of the river water surface, m	Net fall height, m
	Locations on the NISTRU river				
1	Verejeni,	Ocnița	196	63	133
2	Ungari,	Ocnița	242	60	182
3	Tatarăuca Veche,	Soroca	160	55	105
4	Șeptelici,	Soroca	202	58	144
	Inundeni	Soroca	196	40	156
	Vărăncău	Soroca	180	40	140
5	Vasilcău,	Soroca	105	35	70
6	Sănătăuca ,	Florești	145	30	115
	Poina,	Șoldănești	220	28	192
7	Rezina,	Rezina	185	25	160
8	Saharna,	Rezina	227	25	202
9	Țipova,	Rezina	204	25	179
10	Lalova,	Rezina	200	24	176
12	Oxentea,	Dubăsari	122	24	98
	Locations on the PRUT river				
	Cuconeștii Vechi,	Edineți	180	82	98
	Costești,	Ungheni	82	60	22
	Lucăceni,	Fălești	160	48	112
	Ungheni		48	37	11
	Cotul Morii		23	27	-4
	LEOVA		120	16	104
	Locations near lakes				
	Lacul Dănceni		250	78	172
	Lacul Ghidighici		175	53	122

The results of the calculations for a possible CHEAP, built in the Republic of Moldova, are presented in the table 5.

Table 5. The main characteristics of the 100 MW Hydro Pumped Storage Power Plant

No	Indicator	Notation	Unit	Capacity, MW					
				25			**100** (4 x 25)		
1	Water flow	Q_{apa}	m^3/s	32			127		
2	Operation time (generation)	T_{zi}	h/zi	4	8	10	4	8	10
		T_{an}	h/an	1 440	2 880	3 600	1 440	2 880	3 600
3	Electricity produced over a day, year and 30 yrs period	W_{zi}	MWh/zi	100	200	250	400	800	1 000
		W_{an}	GWh/an	36,50	73,00	91,30	146,00	292,00	365,00
		WTA	GWh	410,9	821,8	1027,8	1643,6	3287,3	4109,1
4		Wzi	MWh/zi	130	260	325	520	1040	1300

	Electricity consumed (for water pumping)	Wan	GWh/an	47,45	94,9	118,625	189,8	379,6	474,5
		WTA	GWh	534,2	1068,4	1335,5	2136,7	4273,5	5341,8
	Waterfall's height			H = 100 m					
5	Water volume	V_{zi}	mil. m^3/zi	0,46	0,92	1,15	1,83	3,67*	4,59
		V_{an}	mil. m^3/an	165	330	413	661	1321	1651
6	Surface of the upper reservoir	S_{apa}	mii m^2	18 349	36 697	45 872	73 394	146 789	183 486
		S_{apa}	ha	1,8	3,7	4,6	7,3	14,7	18,3
7	Diameter of upper reservoir	D	m	153	216	242	306	432	483
8	Diameter of pipe thread	d	m	3,19					
	Waterfall's height			H = 150 m					
9	Water volume	V_{zi}	mil. m^3/zi	0,46	0,92	1,15	1,83	3,67	4,59
		V_{an}	mil. m^3/an	165	330	413	661	1321	1651
10	Surface of the upper reservoir	S_{apa}	mii m^2	18 349	36 697	45 872	73 394	146 789	183 486
		S_{apa}	ha	1,8	3,7	4,6	7,3	14,7	18,3
11	Diameter of upper reservoir	D	m	153	216	242	306	432	483
12	Diameter of pipe thread	d	m	3,19					

* Lake Danceni, Ialoveni district, volume- 22 mil. m^3 , surface - 420 ha; surface of the upper reservoir – 14,7 ha.

Subsequently, the economic-financial feasibility of a project to build a new CHEAP-MD was determined, which was based on the assessment of the updated net income (VNA). In order to determine the VNA income, the calculation of the total updated expenses (CTA), related to the construction and operation of CHEAP during the 30-year study period (Figure 2), as well as the gross revenue (VTA) obtained from the realization of electricity produced on the balancing market during peak system hours.

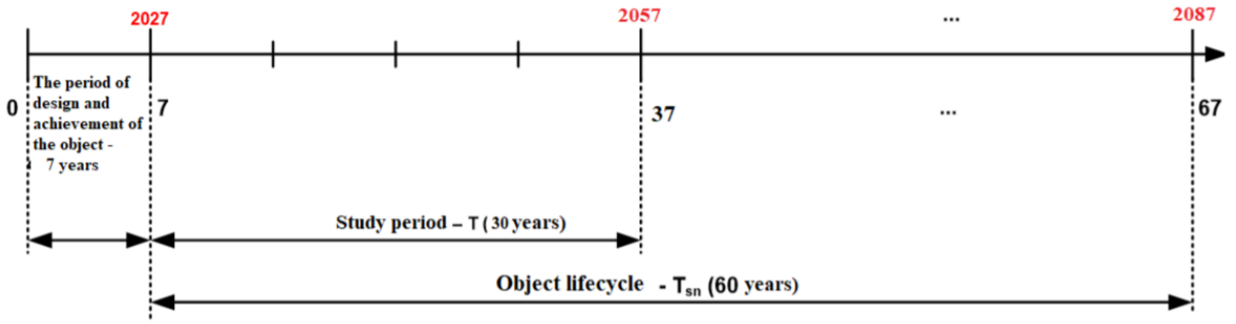

Figure 2. Time axis with the appropriate the time periods

In this context it is to be noted that the above presented economic evaluation was carried out for a study period of 30 calendar years, and it demonstrates that the investment effort is recovered from the annual gains. In the case when annual revenues could have been accounted for the entire CHEAP lifetime – the economic attractiveness of the project would only increase.

Building of a pumped-storage hydro power plant (HPSPP), as the main infrastructure for large-scale energy storage, represents a measure to increase the flexibility of the power system.

The present study demonstrates the economic attractiveness of the CHEAP - project implementation.

Another first made study “***Short Term Daily Storage Need Assessment for a Large PV Deployment Scenario - Preliminary Case Study for Republic of Moldova***” dealt with a diffcult take in order to make projection in the future by usig today known data.

For analysing the specifc situation of a large penetration photovoltaic power plants in RM, it has been chosen a simplified method which has that advantage of providing an order of magnitude for the capacities of production in PVs and the need of storage in the conditions of two scenarios: coverage of 30% respectivelly 50% of yearly national electrical energy consumption with PVs, by comparing the yearly PV production with the anuall consumption of the country. The obtained results show that the necessary targets can be fulfilled even with existing technologies, becoming even more economically viable for high level objectives in the period 2025-2030.

The sudy went through the following stages, in specific chapters.

- The evaluation of the need of production capacities with PVs in Republic of Moldova, respectivelly obtaining the installed power for 30% and 50% coverage of the yearly consumption;
- Analysis of the short term storage need, respectivelly on a daily basis, in order to ensure compatibility with the production profile with RES, in the conditions of a limited power on the interconnection line (Net Transfer Capacity - NTC).

These are the main parts of the study, the storage capacities being seen as essential elements for increasing the flexibility in electrical power systems.

- An analysis of the necessary land for implementing the PV production scenarios.

In Table 6 are presented synthetical figures for all the studied cases. The internal topology constraints of the country have been not detailed, as it has been considered that most of the PV plans are distributed over the country, and have electrical energy storage systems, as a possible change of paradigm comparing with Pumped Storage Plants, which usually ask for additional transport lines. Some network reinforcement might be still necessary. Each scenario has been separatelly analysed, in order to give a first image of the potential of production and on the need of associated storage. Aditional details may be obtained in the future, with new cases and for other time periods. The synthesis of the 4 scenarios is presented in the Table 6.

Table 6. Studied Scenarios (daily basis)

Scenario	**S0**	**S1-Summer**	**S2-Summer**	**S3-Summer**	**S4-Winter**	
Line identifier (line ID)	**A**	**B**	**C**	**D**	**E**	
Description	Actual status	30% PV / year	50% PV / year	50% PV/ year +Wind	Winter, S3	Col. Id
E_{Cons} [MWh]	16,035	16,035	16,035	16,035	21,485	1
E_{Prod} [MWh]	15,197	16,038	23,365	23,276	21,557	2
K_{TTP} [%]	100	12.3	0	0	82.0	3
$P_{PV_{INST}}$ [MW]	0	1,722	2,870	2,650	2,650	4
$P_{Wnd_{MAX}}$ [MW]	0	0	0	200	200	5
E_{Prod}/E_{Cons} [%]	94.8%	100.0%	145.7%	145.2%	100.3%	6
E_{RES}/E_{Cons} [%]	0.3%	82.4%	138.8%	138.3%	19.3%	7
$E_{P_{TTP}}$ [MWh]	14,038	1,727	0	0	16,623	8
$E_{P_{RES}}$ [MWh]	54	13,208	22,262	22,173	4,143	9
$E_{P_{PV}}$ [MWh]	0	13,155	22,209	20,506	2,475	10
$E_{P_{Wnd}}$ [MWh]	0	0	0	1,614	1,614	11
$E_{P_{HPP}}$ [MWh]	1,103	1,103	1,103	1,103	792	12
$E_{Ex} + H_2$ [MWh]	837	-3	-7,230	-7,241	-73	13
$E_{Exch_{Imprt}}$ [MWh]	945.5	1,785	0	0	784	14
$E_{Exch_{Exprt}}$ [MWh]	109	1,788	7,230	7,241	856	15
$P_{Exch_{Import}}$ [MW]	117	176	0	0	136	16
$P_{Exch_{Export}}$ [MW]	114	225	426	426	201	17
$\boldsymbol{E_{Stor}}$ [MWh]	**0**	**4,260**	**10,700**	**9,550**	**800**	18
$\boldsymbol{P_{Max_{Stor}}}$ **[MW]**	**0**	**820**	**1,730**	**1,570**	**220**	19

The last two lines in the table present the need of storage for each scenario (lines with I_d=18 and 19). It has been observed that it is needed a capacity of **4260 MWh** (**4.26 GWh**) in storage systems for the *30%* PV secnario and of **10.7 GWh** for the *50%* PV scenario. These storage capacity values represent credible goals for the time horison of years 2027-2030, respectivelly 2035-2040, if we take into consideration that storage projects of 2.5 GWh or even more are already planified for years 2021-2030.

The analysis regarding the land need for these ambitious scenarios concludes that it is needed less than 1% of the agricultural area for a complete coverage of the yearly consumption in RM with PV plants.

As a synthesis of the obtained data from this study, in the conditions of a large penetration of RES, by covering 30% respectivelly 50% of the yearly consumption, the following important aspects can be highlighted:

- For a coverage of 30% of yearly consumption with PVs, it is necessay to install 1722 MW of PVs, asking for 4.26 GWh of electrical storage, with an installed power $\boldsymbol{P_{Max_{Stor}}}$ = 820 MW. In the studied day, 83% of the consumed energy can be covered by RES.

- For a coverage of 50% of yearly consumtion with PVs, it is necessary to install 2870 MW of PV, asking for 10.7 GWh of electrical storage and for $P_{Max_{Stor}}$= 1730 MW, while the maximum exchange power with the neighbours is NTC=450 MW, considering future developments related to interconnection lines. The power needed to be installed in PVs uses only 0.37% of the agricultural land in RM. During such a summer day, there is an excess of produced energy of 45%, in the case of investment only in PVs as well as un the case of a moderate share of wind power plants, energy which can be exported and/or consumed for the production of green hydrogen through electrolysis. In the case of 50% PVs scenario, it is still necessary in a typical winter day that 81% of the energy is provided by classic power plants, which can use as fuel a mix of green CH_4 + H_2 or only green H_2.

Other daily simulations, not presented here, show that the most sunny summer days are the most indicated days for estimation the storage need for the 30% and 50% anual production with PVs. These results show the fact that these goals can be attended even with today technologies, then more economic viability for big scale objectives will come in next years, probably in the 2025-2030 period. This shows that the political ambitions for a decarbonated energy domain can be feasible through a roadmap towards CO_2 neutrality, as it is requested by the „European Green Deal" project.

For implementing these requests, the design of future power systems ask for several measures: a massive introduction of PV power plants which are geographically distributed, a moderated introduction of wind power plants in specific places where there are propoer environmental conditions, am enforcement of the electrical network, the introduction of local electrical microgrids and the proliferation of prosumers, all these measures being sustained by a large support from storage systems.

The elements of a roadmap towards an electrical power system with large penetration of RES, which are presented in Chapter III, ask for a high flexibility of the electric power system, by using various storage technologies. Traditional Pumped Storage Systems, as well as new BESS are competitive technologies, which need to co-participate in the context of integration of RES in the electrical power system. For the first time it has been studied a combination of these resources, by combining Pumped Storage Systems and BESS, having as case study for Republic of Moldova entitled „***Increasing System Flexibility through a Combination of Pumped-Hydro and Battery-Storage Systems***".

As a synthesis, several solutions of combined Pumped Storage Systems and BESS, have been analysed:

a) A first section made a comparison based analysis of Pumped Hydro Plants and BESS, as the most relevant technologies from the next period;

b) Options to build business models specific for BESS (investigated in the second section), with focus on new business models;

c) A third section analysed the BESS role in sustaining the energy „grid parity" at the point of common coupling (PCC) between the user and the electrical network;

d) A forth section made a preliminary analysis of the mix between Pumped Storage Systems (PSS) and BESS, and the opportunity to use BESS in the specific case of Republic of Moldova.

While the analysis took into consideration the high value of PSS, which can cover an acceptable share of the flexibility package of the electrical power system, the study explored the most appropriate business models and the opportunitis of emerging BESS technologies, which can be complemented with long term storage systems, based on power to gas (P2G) conversion and on the energy based on green hydrogen.

Figure 3 shows the evolution of specific price of a MWh of BESS (as main part of BESS capital costs – CAPEX) for a specific producer and the yearly cost of maintenance (operational costs – OPEX). It has been observed that in the range between 50 and 3000 MWh, the specific cost of the investment is relativelly constant, being around 290 thousand USD/MWh instaled, such that the specific operational costs for a lifetime of 10 years is only 4,1% from the CAPEX. These values haev been used to obtain an estimation of storage services (Storage as a Service - SaaS).

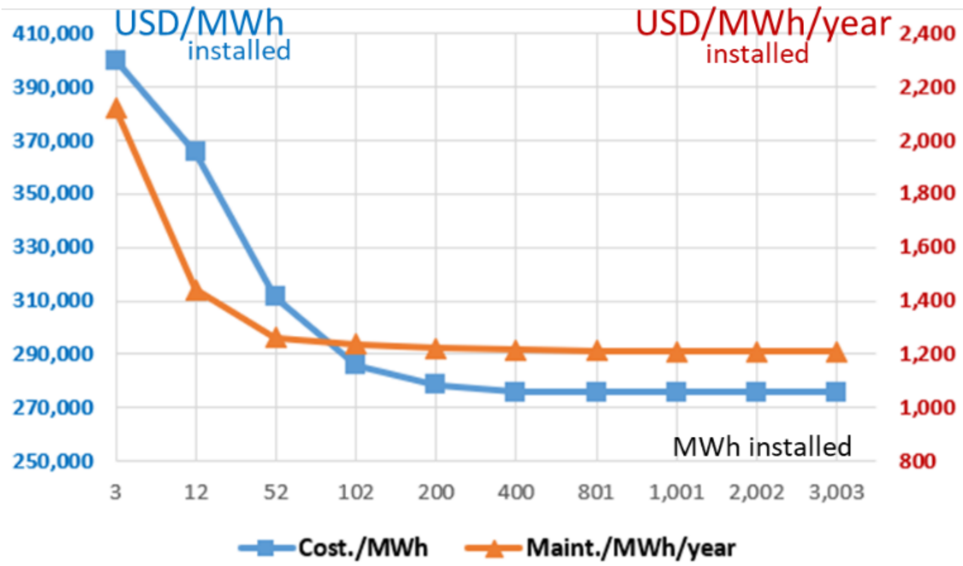

Figure 3. Specific CAPEX and OPEX for BESS

It has been observed that due to multiple advantages of BESS, these can serve multiple domains and can be addressed through various business models. The systematisation from Figure 4 considers two domains:

a) BESS which are sustained by new business models, based on PPA, SaaS and new services, having in the same time the possibility to perform services such as balancing and frequency-power control;

b) BESS to support self-consumption for future situations in which network parity is achieved and to allow the operation of networks in an *insular regime*, where these are strictly necessary devices.

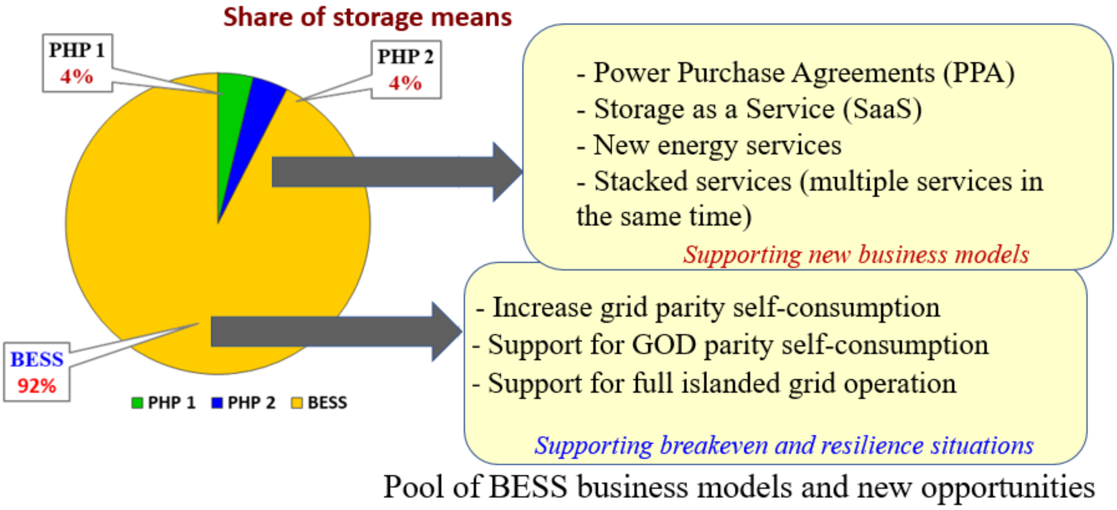

Figure 4. Combining various means of storage

It should also be mentioned that the latter categories aim to address an important value promoted recently in energy - the resilience of consumers and sustainable energy communities, both in urban areas (smart city concepts) and in rural areas.

In the thesis were investigated appropriate business models, presenting some elements to assess the specific situations of PPA and SaaS. Particular situations were analyzed, such as grid parity, GOD parity (the cost of locally produced energy equal to the cost of transporting that produced remotely) and insularized operation. In addition, a simplified general analysis was made regarding the need for BESS, by using input data specific to the Republic of Moldova.

In conclusion, it was pointed out that a high quota of BESS is needed to cover the storage needs of the Republic of Moldova, taking into account the fact that CHEAP have both geographical limitations and a difficulty in complying with time restrictions given by the targets of the year. 2030. Looking ahead to the long-term future, green hydrogen and new storage discoveries can make the roadmap to carbon neutrality even more feasible in a timely manner.

Each chapter of the thesis ends with the presentation of the basic conclusions and highlights the main results obtained. The thesis ends with the presentation of general conclusions and recommendations for future development.

III. OVERALL CONCLUSIONS AND RECOMMENDATIONS

1. The adoption of ambitious global measures to combat climate change will have the benefit of reducing fossil fuel imports and improving air quality and public health.

2. The evolution of the RES quota is a topic of major importance not only for the Republic of Moldova, but also a commitment to external partners and, in particular, a responsibility to future generations. The results of the research study show that the energy transition will have an incontestable impact on the energy economy and security of the Republic of Moldova.

3. In the case of the Republic of Moldova was used the TIMES modeling program, which allows the discretization of the study duration analyzed in several periods and respectively the assignment of different growth rates and elasticity for the factors that determine the future energy demand. The elaborated scenarios will serve for the elaboration of the Integrated National Plan in the field of energy and climate change 2021-2030, as well as the updating of the Energy Strategy of the Republic of Moldova until 2030.

4. An important contribution to ensuring a high level of penetration of RES-V is the measures and flexibility solutions. Increasing the share of intermittent renewable energy sources needs the development of interconnections, energy storage systems, flexible generation sources, the promotion of demand response, as well as advanced tools for operating the system.

5. In this context, a roadmap has been proposed for the Republic of Moldova with 12 conceptual elements that can form the basis of the national policies in the Republic of Moldova with a long-term development in the Energy Strategy toward 2050.

6. Electric vehicles are important in the future energy system. Each of the aspects mentioned in the paper requires a more detailed analysis, which was carried out, in general, in the perspective of a gradual introduction of EV in the car parc of the Republic of Moldova. Thus, for a low penetration of EV the effect on energy consumption at the country level is in turn small (only 7.6% for a share of 30% in EV), in situations of a wide adoption of the new type of vehicle, situations characterized by high penetration rates (≥ 70%), national consumption increases by 17 to 25%.

7. The need for photovoltaic power plants in the Republic of Moldova was determined in a simplified way based on the simplified calculations. The initial analysis made for 30% and 50% coverage, respectively, was extended, with values of the necessary capacities in photovoltaic power plants (CEF) covering between 30% and 100% of the country's annual consumption. It has been shown that if it is hypothetically covered even 100% of the country's energy consumption by CEF, the power that needs to be installed is 5.74 GW, which has only 0.8% of the surface of the

Republic of Moldova.

8. In this sense, it was proposed a new field of sustainable development, that of the harmonious interweaving of agriculture with photovoltaic power plants, ie the achievement of an "agro-photovoltaic" development at the country level. Such a concept is extremely conducive to a country like the Republic of Moldova, characterized by important activities related to the use of agricultural land, which may know new values of their potential to support a society that can sustainably and sustainably maintain traditional activities. In one of the subchapters, dedicated to the main objectives of promotion in the Republic of Moldova, agro-photovoltaic solutions and floating CEF are explicitly listed.

9. The problem of determining the total heat consumption in the country is addressed for the first time. The total consumption of thermal energy was determined in territorial profile and by areas of residence (urban, rural) for the reference year. It was deduced from the total consumption - heat consumption, related to the rural residential sector - as an unfeasible sector for the promotion of cogeneration; existing useful heat consumption, already covered by cogeneration sources.

10. The optimal economic share of cogeneration was determined for the three development zones of the country - North, Center and South and the generalized characteristic of the park of cogeneration installations that could be promoted in the country with the determination of the average cogeneration index. Finally, the cogeneration potential at the level of the consumption of the reference year (2018) was determined, as well as the existing potential for additional cogeneration by 2025: the nominal electrical power of the cogeneration plants, MWe, which constitutes 647 MW.

11. One of the main measures to increase the flexibility of the power system, based on the use of variable renewable sources is the electrification of rural household consumption. Thus, the rural domestic consumption of heat (useful energy) in the country at the level of the reference year (2018), intended for electrification was calculated and represents Pins = 862 MW.

12. For the first time, was realized a study on the construction of hydro pumped power plants with pumped storage on the territory of the Republic of Moldova as a large-scale energy storage. Following the study, possible locations of CHEAP-MD along the Nistru River in the Republic of Moldova were identified and the economic-financial feasibility of a project to build a new CHEAP was calculated based on the assessment of updated net revenue. . The study demonstrates the attractiveness of the implementation of CHEAP projects.

13. Elements of a roadmap presented to a power system with a wide penetration of renewable sources require a high flexibility in the power system, by using different storage

technologies. Previous CHEAP studies have been used as a starting point, which is compared and combined with BESS technologies.

14. Several solutions for the combined use of CHEAP and BESS were presented. It was found that the most attractive aspects of CHEAPs are the specific price of installation of the average value, the long period of operation, favoring, consequently, the low price of storage services. On the other hand, BESS has many advantages in terms of flexibility, which allow them to be used for multiple purposes, including emerging services.

15. Appropriate business models were investigated, as well as some elements needed to assess the specific PPA and SaaS situations. Particular situations were analyzed, such as network parity and GOD parity, as well as insularized operation, seen from the perspective of BESS. In addition, a simplified general analysis was made in relation to the need for BESS, by using input data specific to the Republic of Moldova.

16. A variety of possible developments have been considered to meet the need for flexibility for a wide penetration of RES. There is therefore no single model for the introduction of BESS, but a range of various business models and opportunities to be investigated in future work.

17. At the same time, green hydrogen and new storage discoveries will make the roadmap to carbon neutrality even more feasible to support the overall decarbonisation effort in a timely manner.

Research directions and objectives for the future. A detailed roadmap is needed to achieve the ambitious goals of a decarbonate energy field. Future study directions are to analyze in detail the various challenges related to these goals and add more concrete elements related to the need for flexibility. Flexibility will need to be assessed in the light of various risks, such as those related to the inability of the market to ensure the required level of flexibility, or those related to the evolution of extreme weather conditions with all associated forecast errors. It is also necessary to carry out an analysis on ensuring and maintaining the energy security of the Republic of Moldova, as well as a detailed analysis of the widespread introduction of CEE (including through agro-photovoltaic solutions) - as RES on which the work focused in particular, the optimal mix of CEE and CEF - to complement existing studies related to CEF. It is also considered in the future to detail the most appropriate electricity storage technologies, in terms of appropriate business models, combined with obtaining and using green hydrogen in the carbon neutral paradigm.

IV. LIST OF PAPERS PUBLISHED ON THE THESIS THEME

Articles in scientific journals of international circulation:

1. **Cristina EFREMOV** „*PROVIDING GREATER FLEXIBILITY FOR HIGH PENETRATION RENEWABLE INTEGRATION*", Quarterly publication of Romanian National Committee of World Energy Council (WEC/RNC) and The General Association of Engineers in Romania **(AGIR) – EMERG 2** (Energy, Environment, Efficiency, Resources, Globalization, Volume 7) – ISSN 2668-7003, ISSN 2457-L5011; An V / 2021 – p.p. 109-128. DOI: 10.37410/EMERG.2021.2.1. https://emerg.ro/files/providing-greater-flexibility-for-high-penetration-renewable-integration/
2. **Cristina EFREMOV** *„CHALLENGES OF THE ENERGY TRANSITION IN MAINTAINING THE ENERGY SYSTEM SECURITY AND CONTINUITY".* Quarterly publication of Romanian National Committee of World Energy Council (WEC/RNC) and The General Association of Engineers in Romania **(AGIR) – EMERG 10** (Energy, Environment, Efficiency, Resources, Globalization, Volume 10) – ISSN 2457-5011; An V / 2019 – p.p. 43-55. https://cnr-cme.ro/wp-content/uploads/2019/11/EMERG-10-corectat-13.11_compressed.pdf
3. **EFREMOV C.**, ARION V., SĂNDULEAC M. „*SHORT TERM DAILY STORAGE NEED ASSESSMENT FOR A LARGE PV DEPLOYMENT SCENARIO - PRELIMINARY CASE STUDY FOR REPUBLIC OF MOLDOVA*". 2021 10th International Conference on ENERGY and ENVIRONMENT (CIEM), 2021, pp. 1-5, doi: 10.1109/CIEM52821.2021.9614898. https://ieeexplore.ieee.org/document/9614898
4. **EFREMOV C.**, LEU V., SĂNDULEAC M., „*INCREASING SYSTEM FLEXIBILITY THROUGH A COMBINATION OF PUMPED-HYDRO AND BATTERY-STORAGE SYSTEMS. PRELIMINARY CASE STUDY FOR REPUBLIC OF MOLDOVA*". 2021 International Conference on Electromechanical and Energy Systems (SIELMEN), 2021, pp. 237-242, doi: 10.1109/SIELMEN53755.2021.9600386. https://ieeexplore.ieee.org/document/9600386
5. ARION V., **EFREMOV C.** „*PUMPED-STORAGE HYDRO POWER PLANTS IN MOLDOVA: BENEFITS FOR GRID RELIABILITY AND INTEGRATION OF VARIABLE RENEWABLES*". In: Journal of Engineering Science. 2020, Vol. 27(3), pp. 76-89. ISSN 2587-3474. ISSN 2587-3482. (Categoria B+). https://ibn.idsi.md/sites/default/files/imag_file/JES-2020-3_76-89.pdf

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9. ERMURATSCHII V., EREMENCOV N., **EFREMOV C**., *CALCULATION OF ECONOMICALLY OPTIMAL HEAT TRANSFER COEFFICIENT FOR FENCING ELEMENTS OF BUILDINGS WITH RENEWABLE ENERGY (RE) HEAT SUPPLY,* International Conference “Energetica Moldovei- 2016”, 29 sept. 2016, IE AȘM, Chisinau, p.524-532. ISBN 978-9975-4123-5-3, 0.85 c.t.

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10. **Cristina EFREMOV** „ *ENERGY TRANSITION AND MAIN CHALLENGES FOR THE REPUBLIC OF MOLDOVA*”, Technical Scientific Conference of Undergraduate, Master and PhD Students UTM, 2019, p.79-82. ISBN 978-9975-45-588-6. http://cris.utm.md/bitstream/5014/237/1/79-82_13.pdf
11. **Cristina EFREMOV**, „ *DEVELOPMENT OF CENTRALIZED STRUCTURES FOR A SUSTAINABLE ENERGY TRANSITION*”. Technical Scientific Conference of Undergraduate,

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Participation with reports in national and international scientific forums:

12. Constantin BOROSAN, **Cristina EFREMOV**, *„MODELLING OF THE NATIONAL ENERGY SYSTEM DEVELOPMENT SCENARIOS IN THE GLOBAL ENERGY TRANSITION CONTEXT”*, WEC Central & Eastern Europe Regional Energy Forum – FOREN 2020, Romania, 15 p. ID65.
13. ERMURATSCHII V., EREMENCOV N., **EFREMOV C.**, *PARAMETRIC STUDY ON THE CHARACTERISTICS OF A SEISMIC BASE ISOLATED BUILDING WITH AIR SOLAR HEATING SYSTEM*, International Conference “Energetica Moldovei- 2016”, 29 sept. 2016, IE AȘM, Chisinau, p.516-523. ISBN 978-9975-4123-5-3, 0.85 c.t.

ADNOTARE

Autor – EFREMOV Cristina. **Titlul** – *Contribuții la majorarea flexibilității sistemului energetic în vederea integrării surselor de energie regenerabilă.* Teză de doctor în vederea conferirii titlului științific de doctor în științe tehnice la specialitatea 221.01. *Sisteme și tehnologii energetice*. Chișinău 2021.

Structura lucrării: Lucrarea conține o introducere, patru capitole, concluzii generale și recomandări, bibliografie din 291 titluri și include 7 anexe, 151 pagini, 52 figuri, 19 tabele. Rezultatele obținute sunt publicate în 13 lucrări. **Cuvinte cheie:** flexibilitate, surse regenerabile de energie, tranziția energetică, stocarea energiei, foaie de parcurs, cogenerare, intermitență, consum de energie termică în profil teritorial. **Domeniul de studiu** – științe tehnice.

Scopul tezei constă în identificarea și analiza unui pachet de măsuri/acțiuni de creștere pe termen lung a flexibilității sistemelor electroenergetic și termoenergetic naționale în vederea asigurării tranziției către 100% energie din surse regenerabile. **Obiectivele lucrării:** Studierea unui șir de tehnologii inovative cu aport la creșterea flexibilității sistemului, cu evaluarea potențialului de creștere a capacităților SER aplicată atât în sistemul electroenergetic, cât și în sistemul termoenergetic național, cu analiza posibilităților de stocare, atât a energiei termice, cât și a energiei electrice.

Noutatea și originalitatea științifică a lucrării. Dezvoltarea elementelor teoretico-metodologice de implementare a măsurilor de creștere a flexibilității adaptate la nivelulși specificul Republicii Moldova. **Rezultatul obținut** care aduce o contribuție cu caracter științifico-practic la soluționarea problemei intermitenței SER prin majorarea flexibililității sistemului energetic. **Importanța teoretică.** Teza aduce contribuții științifice în identificarea celor mai eficiente soluții distribuite de creștere a flexibilității principalelor elemente ale sistemului energetic național în vederea integrării unor capacități de producție cât mai înalte ale surselor regenerabile. **Valoarea aplicativă a lucrării.** În lucrare a fost elaborată o foaie de parcurs cu 12 elemente conceptuale ce pot sta la baza politicilor naționale în Republica Moldova cu dezvoltare pe termen lung în Strategia Energetică, în perspectiva anului 2050; a fost abordată pentru prima dată problema determinării consumului total de căldură în profil teritorial în țară; a fost analizată situația specifică unei largi penetrări a centralelor fotovoltaice în sistemul energetic al RM; au fost edificate centrale hidroelectrice cu acumulare prin pompare (CHEAP), precum și investigate soluții de utilizare combinată a CHEAP și BESS.

Implementarea rezultatelor științifice. În cadrul Ministerului Infrastructurii și Dezvoltării Regionale a fost elaborat studiul cu privire la potențialul de cogenerare a energiei și de electrificare a sectorului încălzire. Rezultatele importante din lucrare vor fi utilizate în procesul didactic la Facultatea Energetică și Inginerie Electrică, precum și în acțiunile de proiectare-dezvoltare în domeniu.

SUMMARY

Author – EFREMOV Cristina. **Title** – *Contributions to increase the flexibility of the energy system in order to integrate renewable energy sources.* Doctoral thesis for PhD qualification in technical sciences, 221.01. *Energy systems and technologies* specialty. 2021Chisinau.

Thesis structure: The paper comprises an introduction, four chapters, general conclusions and recommendations, 291 references, 7 annexes, 151 pages, 52 figures, 19 tables. The results are published in 13 scientific papers.

Keywords: flexibility, renewable energy sources, energy transition, energy storage, roadmap, cogeneration, variability, thermal energy consumption in territorial profile. Field of study – technical sciences.

The purpose of the thesis is to identify and analyze a package of measures / actions to increase the flexibility of the national electricity system and the thermal energy systems in the long-term perspective in order to ensure the transition to 100% energy from renewable sources.

Objectives of the paper: Studying a series of innovative technologies with the contribution to increase the system flexibility, with the evaluation of the potential for increasing RES capacities, the analysis of storage possibilities applied in the both systems: electrical and thermal,

The novelty and scientific originality. Development of theoretical-methodological elements for implementing measures to increase flexibility adapted to the level and specificity of the Republic of Moldova.

The result obtained that brings a scientific-practical contribution in solving the problem of the variability RES by increasing the flexibility of the energy system.

Theoretical value. The thesis brings scientific contributions in identifying the most efficient distributed solutions to increase the flexibility of the main elements of the national energy system in order to integrate the highest possible production capacities of the renewable energy sources.

The applicative value of the thesis. The paper developed a roadmap with 12 conceptual elements that can form the basis of the national policies in the Republic of Moldova with long-term development in the Energy Strategy, in the perspective of 2050; was addressed for the first time the issue of determining the total territorial heat consumption in the country; was analyzed the specific situation according to a wide penetration of photovoltaic power plants in the energy system of the Republic of Moldova; building of pumped storage hydro power plants (CHEAP), as well as investigattion of the solutions for the combined use of CHEAP and BESS.

Implementation of research results. The study on the potential of energy cogeneration and electrification of the heating sector was developed within the Ministry of Infrastructure and Regional Development. The important results of the paper will be used in the teaching process at the Faculty of Energy and Electrical Engineering, as well as in the design-development actions in the field.

АННОТАЦИЯ

Автор - ЕФРЕМОВ Кристина. **Название** – „*Вклад в повышение гибкости энергетической системы с целью интеграции возобновляемых источников энергии”*. Диссертация на соискание ученой степени доктора технических наук по специальности 221.01. *Энергетические системы и технологии*. Кишинев 2021.

Структура работы: Работа содержит введение, четыре главы, общие выводы и рекомендации, библиографию из 291 наименований и включает 7 приложений, 151 страницы, 52 рисунков, 19 таблиц. Результаты опубликованы в 13 работах. **Ключевые слова:** гибкость, возобновляемые источники энергии, энергетический переход, хранение энергии, дорожная карта, когенерация, прерывистость, потребление тепла в территориальном профиле. **Область изучения** - технические науки.

Целью диссертации является определение и анализ пакета мер/действий по повышению долгосрочной гибкости национальных систем электро- и теплоэнергетики для обеспечения перехода на 100% возобновляемую энергию. **Цели работы:** изучить ряд инновационных технологий, способствующих повышению гибкости системы, с оценкой потенциала увеличения мощностей ВИЭ, применяемых как в национальной электроэнергетической системе, так и в теплоэнергетической системе, с анализом возможностей хранения как тепловой, так и электрической энергии.

Новизна и научная оригинальность работы. Разработка теоретических и методологических элементов для внедрения мер по повышению гибкости, адаптированных к уровню и специфике Республики Молдова.

Полученный результат вносит научно-практический вклад в решение проблемы прерывистости ВИЭ путем повышения гибкости энергосистемы.

Теоретическая значимость. Диссертация вносит научный вклад в определение наиболее эффективных распределенных решений для повышения гибкости основных элементов национальной энергетической системы с целью интеграции максимально возможных производственных мощностей возобновляемых источников.

Прикладная ценность работы. В диссертации разработана дорожная карта с 12 концептуальными элементами, которые могут лечь в основу национальной политики Республики Молдова с долгосрочным развитием в Энергетической стратегии в перспективе до 2050 года; впервые рассмотрена проблема определения общего потребления тепла в территориальном разрезе в стране; проанализирована конкретная ситуация широкого проникновения фотоэлектрических станций в энергетическую систему Республики Молдова; построены Гидроаккумули́рующие электроста́нции (CHEAP), а также исследованы решения комбинированного использования CHEAP и BESS.

Implementarea rezultatelor științifice. În cadrul Ministerului Infrastructurii și Dezvoltării Regionale a fost elaborat studiul cu privire la potențialul de cogenerare a energiei și de electrificare a sectorului încălzire. Rezultatele importante din lucrare vor fi utilizate în procesul didactic la Facultatea Energetică și Inginerie Electrică.

Внедрение научных результатов. В Министерстве инфраструктуры и регионального развития было разработано исследование потенциала когенерации энергии и электрификации сектора отопления. Важные результаты работы будут использованы в учебном процессе на факультете энергетики и электротехники, а также в проектно-конструкторских работах в данной области.

EFREMOV CRISTINA

CONTRIBUTIONS TO INCREASE THE FLEXIBILITY OF THE ENERGY SYSTEM IN ORDER TO INTEGRATE RENEWABLE ENERGY SOURCES

221.01. ENERGY SYSTEMS AND TECHNOLOGIES

PhD Thesis Summary

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