Deploying Renewable Energy Sources and Energy Storage Systems to Achieve Energy Security in the R. of Moldova

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***Abstract* - 100% RES scenario to improve energy security of R. Moldova is analyzed. Economic simulations are used. The paper shows that only about 70% of the demand could be covered directly from wind farms (WF) and photovoltaic (PV) energy sources (WPES). The remained 30% of energy (RE) - by energy storage system (ESS) with a capacity (kWh) of 32% from RE and a power (MW) of 87% from maximum power demand. As country doesn't have its own hydro reserves, Li-ion batteries are considered for ESS. The investment in such SSE would exceed 3-52 times national GDP and that makes unrealistic 100% RES scenario for R. Moldova. As analysis showed, there are more than 1400 episodes within the year when energy to cover daily demand cannot be accumulated during 1 to 4 days. By reducing SSE capacity to a value equal to the daily energy demand and maintaining ESS power, it was found that the levelised tariff of WPES+ESS scenario exceeds, however, those of traditional scenarios. Only 5% of energy produced by WPES can be accumulated in such ESS, the remaining 25% - by importing night electricity, at negligible price in the calculations.**

Cuvinte cheie: *SRE, stocarea energiei, 100% SER, securitatea energetică.*

Keywords: *RES; energy storage; 100% RES; energy security.*

I. INTRODUCTION

Energy security (ES) can be described as "the uninterrupted physical availability of energy sources at a price which is affordable, while respecting environment concerns" (ES) [1]. The measures to achieve energy security are well known, and mainly include diversification of fuel and energy sources, diversification of energy carriers, creation of reserves, and use of renewable energy sources. To achieve ES, adequate cooperation among energy market participants, and international cooperation are also important.

From the perspective of energy security, the power system of the Republic of Moldova is characterized by the following peculiarities:

a) Due to the Transnistrian secessionism, the national power system is divided between the right and left banks of river Nistru.

b) Only approximatively 15 % of the electricity needs on the right bank of Nistru river are met by the power plants located on this bank of the river. The residual demand is covered by energy imports from Ukraine, or by the condensing Thermal power plant from Transnistria (TPP).

c) The fuel used by power plants located on the right bank of the river is natural gas, imported from a single country (Russia), and the main pipelines cross only one country–Ukraine.

d) The country's natural sources of wind and solar energy are more than sufficient to cover its energy demand for years in the future. R. of Moldova's technical reserves of wind energy are in the range of 23 billion kWh and 9GW power [2], with PV reserves of around 12 billion kWh and 8.7GW [3] power. By comparison, gross demand of electricity in 2017 was around 4.2 billion kWh, and the power consumed was circa 0.8GW. I.e., by promoting 100%RES concept country energy security challenge would be resolved.

Besides overcoming the problem of energy security, R. of Moldova has committed to reducing greenhouse gas emissions, as set out in its National Determined Contribution (NDC). Country NDC sets an unconditional target of achieving 64%-67% below 1990 GHG emissions by 2030, and a conditional target of achieving 78% reduction. Low-Emissions Development Strategy through 2030 (LEDS) sets out 44 measures to reduce the country's GHG emissions, which include the building of at least 400MW of renewable sources of electric energy (RES) to meet the NDC's unconditional objective, and another 400MW to meet the conditional objective. The focus on RES is not accidental. On the one hand, electric and thermal energy generation in R. Moldova accounts for 37% of the country's CO_2 emissions [4]. On the other hand, as it was mentioned above, R. Moldova imports circa 85% of its needed electricity.

Notwithstanding, given that wind and solar energy generation is intermittent, the development of these sources of energy in R. Moldova depends on the feasible options for meeting energy demand when these sources are unavailable. In contrast to other countries, R. Moldova does not have conventional power plants that could fill in this gap. Therefore, the options available to overcome the intermittency issue are:

1. to build conventional power plants;
2. to import energy;
3. to store WPES energy when it is generated in excess so that it can be used when WPES energy is unavailable.

The first option requires important investments that will result in a significant increase in the electricity tariff. Bearing in mind that energy affordability in R. Moldova is low [5], this option is not feasible at this stage. Furthermore, these power plants would be using imported fossil fuels, which would further diminish the country's already low energy security and increase GHG emissions.

The second option is affected by significant geopolitical risks outside of R. Moldova. This means that although imported energy could potentially be secured over the short term, the availability of this option over the medium and longer terms is highly uncertain.

The third option is gaining more and more attraction given the recent advances in battery storage [6], with further improvements in storage systems expected in the near future.

On these bases, investigating option three is of relevance for the case of R. Moldova too.

The idea on whether energy demand could be fully covered with RES generation (the "100% RES" strategy) is not new. Many other countries [7,8,9] and authors [10,11,12] have examined various aspects of this opportunity. Nevertheless, the fundamental issue remains as to the feasibility of storing excess RES energy for use in periods of low RES generation when it is insufficient to meet full demand. Several studies have been published assessing options for reducing the costs of a deeper integration between WPES and ESS for the purpose of meeting energy demand. Of note are [13] and [14], which demonstrate that the ESS economic parameters can be significantly improved if not all of the WFPS energy produced at maximum power is stored. Efforts aimed at determining the optimal solutions for developing a national power system that is low in GHG emissions and high in energy security must take such findings into account.

This study aims to answer the following question: given that wind and solar PV energy in R. Moldova is sufficient to cover the country's energy needs, to what extent can storage solutions help advance the development of these RES in the country and thus help overcome the energye security issue? To the best our knowledge, this question has not been addressed in the existing literature.

PROBLEM DEFINITION

The development of sources of electricity generation through the conversion of wind and solar energy has been on the rise in R. Moldova. In 2017, for example, a total of 343 of guarantees of origins were issued to cover 30.19 GWh of electricity generated from RES. Compared to 2016, this generation represented an increase of around 69.4%. This trend continued in 2018, when 14.9MW of wind and 120kW of solar PV generation were installed, which together are able to produce 23.4GWh of electricity [15]. The Government has also drafted a Decision to introduce capacity limits, maximum quotas and capacity categories for electricity generation from renewable sources until 2020, in order to apply the support schemes provided by art. 34 of Law no.10 of February 26, 2016 on promoting the use of energy from renewable sources. It prescribes to install 100MW of WF and 40MW of PV [16]. Notwithstanding these trends, future RES growth will be constrained by the lack of standby generation that could be brought into the grid when RES energy output is low. As mentioned previously, energy storage could help overcome this problem. There is currently a wide range of battery storage options, and the economics of these options have a promising outlook. The feasibility of these options in R. Moldova's context has not yet been studied; yet this would help identify decisions concerning the country's ability to reach a level of energy security that R. Moldova has aimed for since its independence. In an aim to further the analysis of these options, the following themes should be explored and developed:

- Identifying the technical and economic parameters of large-scale energy storage systems (ESS), and of the advantages and disadvantages of using ESS in the national power system;
- Battery life can depend on the number of charge-discharge cycles, which in turn can significantly affect the cost of energy storage and the price of energy produced by a WPES+ESS system. Given this, the following must be determined: the required number of ESS charge-discharge cycles, ESS capacity, other performance parameters associated with the load curves of wind and PV solar energy generation required to meet annual RES energy demand;
- Determining the ESS parameters needed to ensure that R. Moldova's energy demand can be met through a WPES+ESS system, and providing the necessary recommendations.

ESS OUTLOOK

Over the last years, stationary energy storage systems have expanded at a rapid pace, and this trend is expected to continue in the near future too. Whereas in 2017 the total global capacity of ESS was 1.9GW, total global production of energy storage batteries reached a record 10.4GW in 2018 Q1 alone [17,18] provides a list of electricity storage projects currently underway globally.

IRENA [6] provides an overview of these technologies in its 2017 report. Given that R. Moldova does not have hydro storage resources, the most feasible energy storage solutions (out of those examined by IRENA) are those that are based on (i) electro-chemical conversion, such as lithium-ion (Li-ion) and REDOX Flow Battery (RFB), and (ii) chemical conversion, mainly for producing hydrogen through electrolysis, with hydrogen being further used to produce electricity. However, this latter form of energy storage has low round-trip efficiency of around 20% (wind energy – hydrogen production through electrolysis – fuel cells – electricity generation). Subject-matter experts suggest that this technology will become mature no earlier than 40 years from now [19]. Another solution would be to pump hydrogen into national gas network. To date, discussions have largely focused on technical, safety, cost and (to some extent) funding issues, and possible "steady-state" models for a hydrogen system in the long term (for example, by 2050) [20][1].

[1]See e.g. Frontier Economics: Report for BEIS on Market and Regulatory Frameworks for a Low Carbon Gas System, March 2018; Hydrogen-in-a-low-carbon-economy November 2018, published by the Committee on Climate Change; and Hydrogen supply chain evidence base November 2018, prepared by Element Energy for BEIS.

Li-ion technology is relatively more accessible, and its supply on the market is constantly growing. The storage capacity of stationary ESS using Li-ion technology is forecast to grow from 3-4GWh in 2018 to 100GWh in 2025, i.e. by over 25 times [21]. Experts in the field forecast a 10% p.a. fall in the price of Li-ion batteries in the next five years, reaching \$144/kWh (compared to estimates of \$207/kWh in 2018); by 2030, the price is expected to reach \$73/kWh [22].

In seeking technologies with the best outlook (except pumped hydro), one may find the answer by checking the financing priorities of EU's Horizon 2020 program for science and research [23]. For the 2019-2020 period, these are mainly to support the development of RFB technology for stationary energy storage at the grid level. For 2019, around €40 million are allocated to this topic. The focus on RFB is not by accident, as this technology has the important characteristic of its capacity to produce energy being independent of the ESS power; this is in contrast to other technologies that are based on principles of electro-chemical conversion. Against the backdrop of some ambitious RFB projects such as the 200MW/800MWh currently under way in the Dalian peninsula in China, RFB technologies have the potential to become the core technology directly competing with Li-ion and Na-S – the main two stationary energy storage technologies currently on the market. RFB can cause second-generation Li-ion batteries to become obsolete, offering a stable operation of RFB in the system [24]. A lot of research currently goes into reducing the costs of increasing the life of RFB components. For example, scientists at ORNL have recently developed a membrane for a sodium-based non-aqueous RFB that could double or triple the energy density typically seen in aqueous-based RFBs; this, in turn, would contribute to the system's cost reduction [25].

THE ADEQUACY OF WPES+ESS TOMEET ENERGY DEMAND

As it is well known, both wind and solar PV energy generation is intermittent – a feature that influences much the technical and economic indicators of electricity storage systems that release the energy needed to cover demand when wind or sun radiation is unavailable. Determining these indicators requires information about the actual hourly energy generation by wind and solar PV sources. R. Moldova does not have sufficient experience with collecting such information, and data collected to date is incomplete. For this reason, we used data from a repository that can be accessed via the electronic platform provided by Romania's system operator "Transelectrica" [26]. We used the 2016 platform as basis for sourcing the data. In Romania, the share of solar PV energy generation in this year was16.4% out of the country's total WPES generation. On this basis, an algorithm was developed to process the data and estimate two critical parameters that determine the economic indicators of an ESS: the required ESS capacity for R. Moldova, and the number of charge-discharge cycles in the system. The primary condition underpinning parameter estimation was to achieve full replacement of R. Moldova's 2016 imported energy with WPES, i.e. to achieve 100% RES for imported energy.

In 2016, energy imports in R. Moldova accounted for 84.5% of gross demand, i.e. 4.2 billion kWh. We did not also model replacing the electricity generated by local CHPs, which typically use natural gas and which also supply thermal energy.

The hourly WPES power was estimated based on the equation:

$$\sum IE_x = \sum WPES_{dx} + \sum WPES_{sx} * \eta ,$$

where:

IE_x - is the energy imported in the hour x of the year 2016;

$WPES_{dx}$ - is the energy produced by WPES in the hour x of the year 2016 in Romania's power system, estimated such that it directly covers R. Moldova's energy import, i.e. WPES energy is not stored;

$WPES_{sx}$ - is the energy produced by WPES in the hour x of the year 2016 in Romania's power system, estimated such that it covers R. Moldova's energy import through storage, i.e. WPES energy is first stored, and is used subsequently to cover energy import during the hours when wind intensity and solar radiation is insufficient to fully cover the required import at hour x;

η - is the measure of ESS efficiency, which includes daily losses of stored energy.

The ESS technology was assumed to be Li-ion, with daily losses of 0.2%, and with a level of charge-discharge round-trip efficiency of 95% [6].

Below, in the Figure 1, are the results obtained from overlaying the load duration curve of imported energy and the hourly curve of energy in a WPES+ESS system that fully replaces imported energy at respective hour.

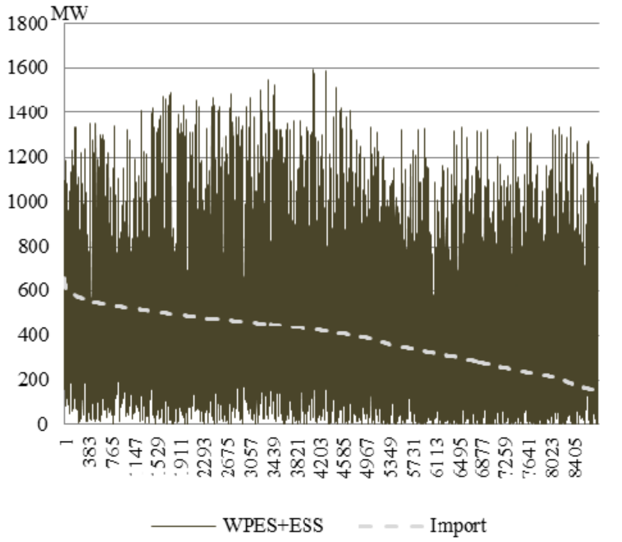


Fig.1 The annual load duration curve of imported energy, overlaying WPES power and imported energy at each hour.

In 2016, the maximum load of imported energy was of 655MW. Given the settings described above, we estimated that the maximum WPES power needed to cover the entirety of imported energy is 1596.4MW (i.e. 2.44 times more than the demand for imported power), 70% of energy demand is provided directly by WPES and 30% by the ESS. We estimate that the ESS would need to have a capacity of 332.7 million kWh, and power of no less than 1.109MW at charge and 567MW at discharge, assuming 100% discharge take place. To meet these indicators, the number of charge-discharge cycles would need to be no more than 3.1. At a specified cost of $79-1.260/kWh, such an ESS would cost $24-420 billion, while country GDP was around $8.1 billion in 2017. To better understand the factors that make the 100% RES scenario so unaffordable (except the specific costs of ESS), we examined the frequency of WPES power availability (WPES-PA) during a year, as measured by the number of episodes when the average WPES power does not exceed its pre-determined limits. The results are shown in Table I.

TABLE I.
THE NUMBER OF EPISIDES RECORDED DURING THE YEAR WITH DIFFERENT AVERAGE AVAILABLE POWERS FOR WPES CASE:

A) 82% WIND, 16.4% SOLAR; B) 100% WIND

A)

$\%Pmax_{WPES}$	1%	2%	5%	10%	15%
2 hours	251	451	1062	2094	3094
4 hours	185	372	957	2025	3066
8 hours	84	210	704	1765	2950
16 hours	**6**	**23**	287	1238	2699
24 hours	0	0	107	874	2489
2 days	0	0	**16**	349	1881
4 days	0	0	0	**58**	1176
7 days	0	0	0	0	538
10 days	0	0	0	0	296
14 days	0	0	0	0	**129**
21 days	0	0	0	0	0
1 month	0	0	0	0	0
Energy produced in limited episodes, mil kWh	0.2	0.5	3.6	14.3	74.9

B)

$\%Pmax_{WF}$	1%	2%	5%	10%	15%
2 hours	490	810	1692	2894	3861
4 hours	410	718	1613	2824	3809
8 hours	277	512	1387	2665	3726
16 hours	109	282	938	2373	3519
24 hours	**36**	143	676	2109	3281
2 days	0	**8**	301	1524	2645
4 days	0	0	71	866	1850
7 days	0	0	**23**	459	1287
10 days	0	0	0	260	995
14 days	0	0	0	**128**	938
21 days	0	0	0	0	820
1 month	0	0	0	0	**432**

As can be seen from Table I(A), six episodes are recorded, each of 16 hours, when the average WPES power is less than 1%. There are also 129 episodes, each of 14 days, when the average WPES power does not exceed 15% of the maximum annual value. The results in Table I(B) suggest that using only wind energy to cover the demand for imported energy leads to an increase in the frequency of similar episodes.

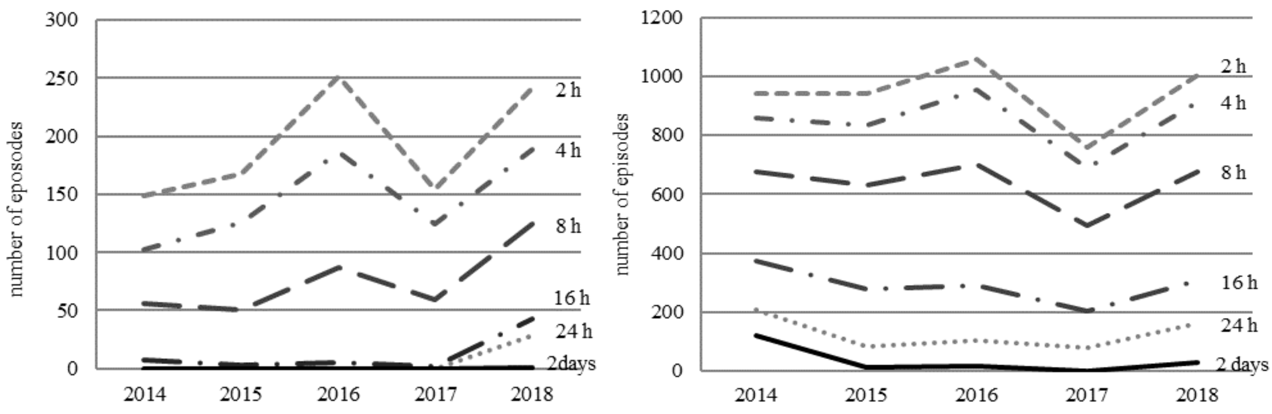
The bottom row in Table I(A) shows the energy produced during at-the-limit episodes. On the basis that the value of daily imported energy ranged between 6-9.2 million kWh in 2016, we estimate that storing this energy over a period of 1-4 days is not possible in around 1,400 episodes during the year (107+16+874+349+58). This significantly affects the feasibility of the 100% RES scenario with a WPES+ESS configuration, given that the ESS capacity required is significantly higher than that available for a single day. Nevertheless, it is worth exploring the conditions that allow the economics of a 100% RES scenario to be comparable to the economics of other feasible scenarios of electricity source development. We do so by modelling the outcomes of competition.

Before discussing the modelling, however, it would be useful to first illustrate the wind and solar power availability for a more representative number of years. For this purpose, we used 2014-2018 data provided by "Transelectrica" [26].

WPES POWER AVAILABILITY DURING 2014-2018 YEARS

Figure 2 and Figure 3 illustrate the evolution of episode numbers recorded over a period of five years at 1% and 5% available power of WPES and WF respectively.

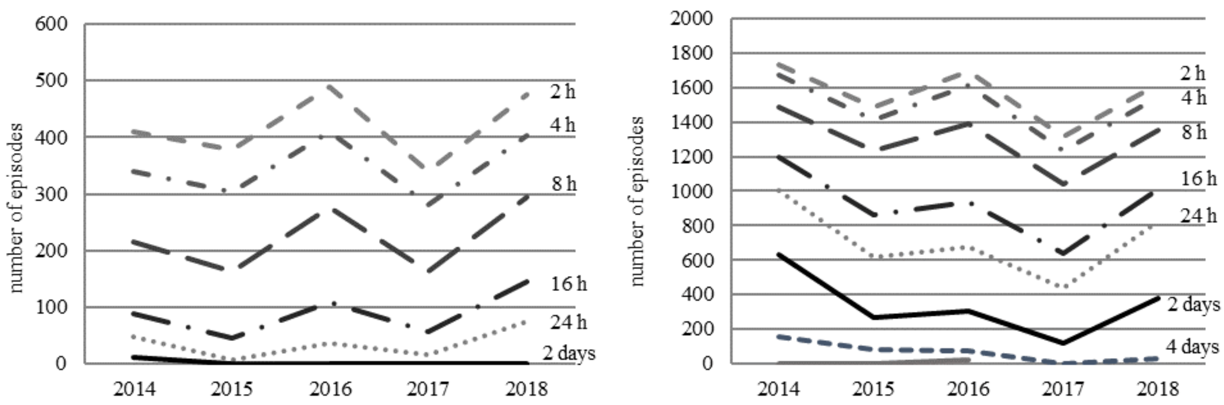
As can be seen, the general patterns identified in the Table I for 2016 are the same for all the five years considered (2014-2018), i.e. the number of episodes per each episode duration (expressed in hours or days) increases with an increase in RES power availability. For each episode duration, the number of appropriate episodes is much higher in case of WF vs WPES, which can be noted from the Table II.



a) 1% WPES available capacity

b) 5% WPES available capacity

Fig. 2. The evolution of episodes number recorded during the years2014-2018 at 1% (a) and 5% (b) available power of WPES.



a) 1% WF available capacity

b) 5% WF available capacity

Fig. 3. The evolution of episodes number recorded during the years 2014-2018 at 1% (a) and 5% (b) available power of WF.

TABLE II.
EXCEEDING THE NUMBER OF EPISODES IN WF CASE COMPARED TO WPES: A) 1% AVAILABLE CAPACITY; B) 5% AVAILABLE CAPACITY

A)

Years	2014	2015	2016	2017	2018
2 hours	2.8	2.3	2.0	2.2	2.0
4 hours	3.3	2.4	2.2	2.2	2.1
8 hours	3.9	3.2	3.2	2.8	2.4
16 hours	12.6	15.0	21.8	28.0	3.3
24 hours	>48	>6	>36	>16	2.6
2 days	>11				1

B)

Years	2014	2015	2016	2017	2018
2 hours	1.8	1.6	1.6	1.7	1.6
4 hours	1.9	1.7	1.7	1.8	1.7
8 hours	2.2	2.0	2.0	2.1	2.0
16 hours	3.2	3.1	3.3	3.2	3.3
24 hours	4.8	7.5	6.6	5.5	5.1
2 days	5.3	24.5	18.8	>117	13.6
4 days	15.8	>78	>71		>26
7 days			>23		

The findings above imply that, for the same RES available pc ... duced has a energy produced by WF and PV installation over 2014-2018, ar ... s generated

This well-known weather characteristic enables to both to increase the share of demand covered directly from WPES and to improve available WPES power indicator, by increasing the share of PV capacity in total capacity of WPES. At present, PV penetration in the power system is dictated mainly by market mechanisms. If the target is to improve technical and economical parameters of ESS in order to make WPES+ESS more feasible, the share of PV in total renewable energy production should be increased either through regulations or by promoting respective incentives. What the appropriate level would be for an increase in PV capacity is the subject for a separate study.

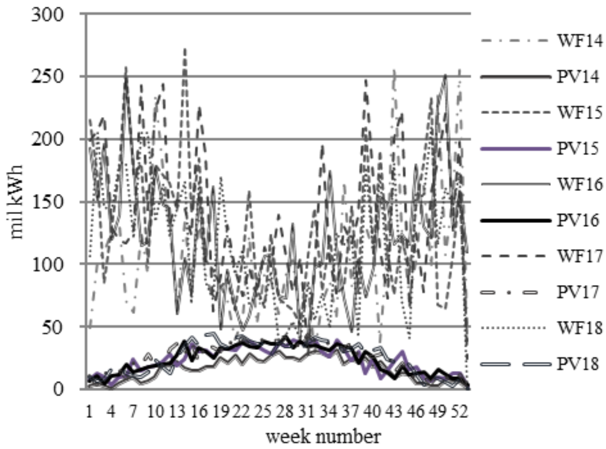


Fig. 4. The weekly WF and PV electricity production in 2014-2018 years.

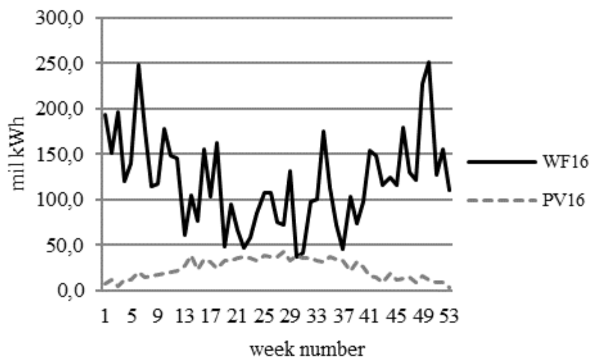


Fig. 5. The weekly WF and PV electricity production in 2016 year.

In Figure 2 and Figure 3, data for 2016 show a different pattern when compared to the other years. This is explained by the fact that 2016 is an intercalary year, with a higher probability of having more number of considered episodes for the same RES available power. Almost all the curves from Figure 2 and Figure 3 record a trend, either an increase or a decrease of episode numbers across the years considered, 2014-2018. This can be explained by several factors: weather conditions (wind and solar availability) the share of PV energy in total WPES energy production and, the capacity of WF and PV installation involvement in renewable energy generation. The indicators which characterize these aspects are presented in Table III.

TABLE III.
THE CHARACTERISTICS OF WF AND FV ENERGY GENERATION IN ROMANIA POWER SYSTEM

Indicators		2014	2015	2016	2017	2018	Average 5 years
Capacity factor, %	WF	25.3	28.5	26.1	30.2	25.8	27.2
	PV	15.0	18.2	17.7	18.3	17.8	17.4
	WPES	28.2	27.7	26.3	30.1	26.7	27.8
Share of PV energy in WPES energy production, %		13.3	15.5	16.4	15.7	17.8	15.8
Maximum capacity, GW	WF	2.57	2.70	2.81	2.78	2.78	2.7
	PV	0.66	0.78	0.81	0.86	0.88	0.8
	WPES	2.62	3.27	3.32	3.28	3.24	3.1

THE SIMULATION MODEL

The problem defined above was solved by simulating the relationship between the average electricity tariff (paid by end users) and the factors that influence the costs of both the electricity sources and electricity grid development. We chose the electricity tariff as measure of such costs instead of the electricity price in order to take account of grid-related aspects that are characteristic of a scenario of electricity source development in R. Moldova. Transport, Distribution and Supply tariffs have been modeled based on the appropriate Tariff Methodologies in effect. The model was developed in the frame of ESMAP Moldova Electric Power Market Sector Study project [27], launched and developed by the World Bank, being subsequently adapted for the needs of the present study. Each scenario element is simulated separately. It was separately modeled each type of power plant too, the energy prices of which being dependent on its annual load factor and other parameters. The efficiency of power units is linear modeled, the function being determined based on efficiencies recorded at technical minimum capacity and rated capacity. The investments are spread per years of electricity elements construction period according to "S" curve shape, i.e. time construction parameter is taken into consideration as well. For RES up to 2019 the prices for electricity are predetermined and correspond to ones approved or forecasted by ANRE as starting bidding prices. Starting with 2020 RES prices depend on specific investments, O&M costs and rate of return (8%). Balancing power come from import. The annual energy produced is calculated based on RES capacity and load factor of electricity generated during the year. The following three scenarios have been examined:

1. WPES+ESS, alongside existing power plants that have their lives extended to 2033 at their current capacity. WPES+ESS replaces imported energy in increasing proportion as follows: 2020-15%, 2021-30%, 2022-45%, 2023-60%, 2024-80%, 2025-2033 – 100%;

2. The Baseline scenario corresponding to (1), where WPES+ESS are replaced with energy imported from East;

3. Asynchronous connection to ENTSO-E, where the baseline imported energy is replaced with energy imported from the free "East-West" market. Connection to the ENTSO-E system takes place through the respective inter-connectors, the core element being the Back-to-Back installation which enables the concomitant operation of electricity networks that have different standards for current frequency or for current frequency maintenance. Technical and economical parameters of grid development correspond to the best Asynchronous scenario 3 from the study [5]. In this scenario, 2/3 of the capacity of the Back-to-Back installation is put in operation in 2020, and the rest in 2027. In the absence of own sources of energy, and given a yearly GDP growth of 3.26%, the power deficit by 2033 is estimated to be 870MW. The energy price in 2018 is 5.28UScent/kWh in real terms, which increases annually by 1%. It is also assumed that when the connection is made to the Romanian power grid in 2020, the price for imported electricity may fall up to 0.6UScent/kWh, which represents the maximum difference recorded in the last eight years between the electricity imported from the East and the electricity from the Romanian power market. Below this price drop is shown as "Asynchronous, 0.6UScent/kWh difference".

ESTIMATIONS AND REZULTS

Without modifying the ESS power specified above (567.5MW), in the WPES+ESS scenario we modelled a variation of the ESS capacity and the related cost so that the average electricity tariff stays around those of Baseline and Asynchronous scenarios. We found that only the limit values of (i) $77/kWh for ESS investment (the lowest value in Annex 1 of [6]) and (ii) of ESS capacity required to store energy enough to meet demand in a single day (ESS-24h) can result in an average electricity tariff that is relatively close to (although exceeding) that in the Baseline and Asynchronous scenarios. Nevertheless, ESS-24h does not allow the entirety of the demand for imported energy to be covered, but only 5% out of the 30% mentioned in section IV above. These 5% are achieved through storing only a portion of the energy produced by WPES, which are disconnected from the grid when their power exceeds the storage capacity (also discussed in [15,17]).

As a result, in the scenario examined the combination of WPES+ESS can only cover 75% of imported energy. This means that the 100% RES objective is unachievable for R. Moldova if ESS specific investments are within the minimum limits through to 2030 as per [6]. The respective results are presented in Figure 6, which illustrates the evolution of electricity tariffs in all four scenarios examined (two are Asynchronous scenarios, of 0.6 UScent/kWh difference and of 0.0 UScent/kWh difference), and in Figure7 which shows the 10-year levelised tariff over the period 2020-2030. Our estimates show that the number of charge-discharge cycles for ESS of 10 million kWh capacity is small, i.e. 18 cycles per year. Given this, ESS life is determined not by the number of these cycles (based on [6], the life of Li-ion batteries, as measured by the number of cycles, varies between 500 and 20,000 full charge-discharge cycles), but by the limited life of 10 years. This is why the levelised tariff was calculated for a period of no longer than 10 years; otherwise the estimates would include investments in new installed ESS.

The WPES+ESS load curve in Figure6 is determined on the assumption that the source of the remainder 25% of the energy required to cover imported energy is not WPES but previously imported energy, which is stored during night-time hours at a negligible price. Clearly, if a higher price is assumed, the WPES+ESS scenario becomes even less feasible.

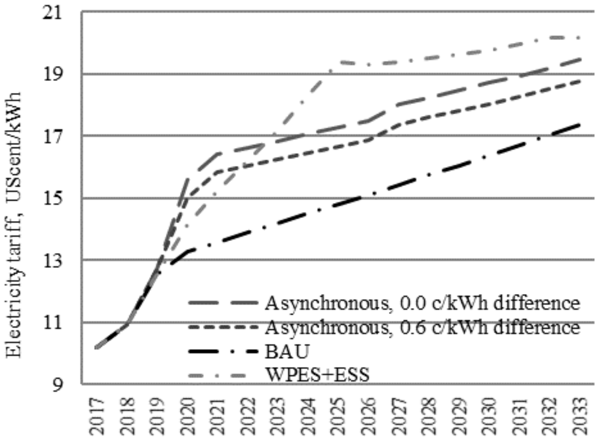


Fig. 6. The evolution of the average electricity tariff in the Baseline, Asynchronous and WPES+EES scenarios.

As can be seen in Figure7, the levelised tariff in the WPES+ESS scenario exceeds the tariffs in the Baseline and Asynchronous scenarios by 17.2% and 6.3% (2.8%) respectively. Options to improve the WPES+ESS scenario include deploying a higher share of PV component in the aggregate WPES.

CONCLUSIONS

1. The Republic of Moldova imports cca 85% of its energy needs. The scenario of 100% RES to replace imported energy would fully address the energy security issue, and would help achieve the NDC commitments in the energy sector. However, due to the intermittency of wind and solar PV energy, high RES penetration cannot be achieved without energy balancing solutions, either by using conventional power plants (but this eliminates 100% RES), or by using energy storage systems (ESS) to store WPES energy when WPES power exceeds energy demand. R. Moldova does not have the former, nor does it has traditional technical reserves for storing energy such as hydro storage. Building new fossil-fuel-based power plants would lead to a significant increase in the electricity tariff, which the end users may not afford. At the same time, the recent trend of falling ESS costs is encouraging. This paper shows the extent to which ESS can be integrated given R. Moldova's context, the focus being on electro-chemical technologies, i.e. Li-ion and REDOX which are most widely promoted globally.
2. The hypothetical implementation of WPES in 2016 (where solar accounts for 16.4% of total) at capacity that would allow annual energy to be generated at levels sufficient to cover R. Moldova's imported energy needs (plus the energy needed to cover over 7% of ESS losses), i.e. sufficient to meet the 100% RES objective, shows that:

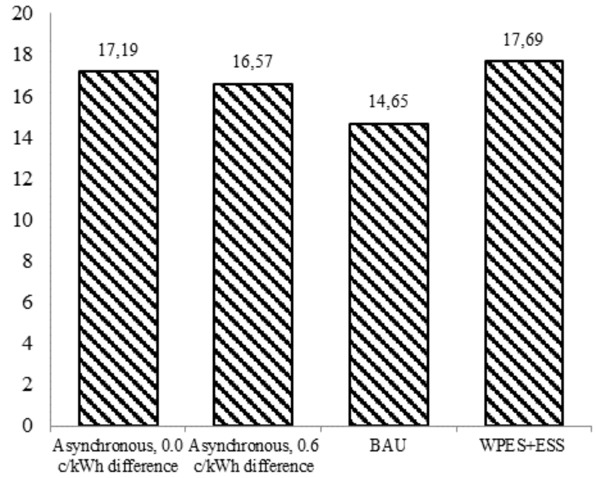


Fig. 7. The levelised electricity tariff for 2020-2030 in the Baseline, Asynchronous and WPES+EES scenarios, UScent/kWh.

   a) The maximum WPES capacity needed to cover the entirety of imported energy is around 2.27 times higher than the maximum load demand for imported power;
   b) 70% of the imported energy is directly covered by WPES, and the remainder 30% (RE) are to be covered through other sources, including through feasible ESS options;
   c) The ESS capacity required to fully cover the 30% mentioned above for the WPES+ESS scenario equals 32% of the RE capacity (kWh), whereas the discharge power (MW) – 87% of the maximum power demanded (655 MW). At a specific lowest cost of \$77–1.260/kWh by 2030 [6], the total ESS cost would exceed national GDP by 3-52 times, making the 100% RES scenario unrealistic for R. Moldova.
3. Based on the fact that during 2016 the value of the daily imported energy ranged between 6-9.2 million kWh, we find that storing this energy over a period of 1-4 days is not possible in 1,400 episodes during the year. This significantly affects the feasibility of the 100% RES scenario;
4. Only the limit values of \$77/kWh for ESS investment (the lowest value specified by IRENA [6]) and (ii) of ESS capacity required to store energy at levels sufficient to meet demand in a single day can result in an average electricity tariff that is relatively close to (although exceeding) that in the Baseline and Asynchronous scenarios. Nevertheless, only 5% of the WPES energy can be stored in such an ESS. The levelised tariff for the WPES+ESS scenario exceeds that in the Baseline and Asynchronous scenarios by 17.2% and 2.8%-6.3% respectively (depending on the rate of energy price decline on the market following the ENTSO-E connection).
5. The share of energy demand that can be covered either directly from WPES, or by storing WPES

energy in the SEE can be increased by increasing the share of PV energy produced out of the total WPES energy generation. The detailed assessment of this opportunity is the subject for a separate study.

6. The feasibility of the WPES+ESS scenario may be improved by modifying the ESS power, storing energy during night-time hours, using gas turbines, deploying a higher share of PV component in WPES, using ESS for meeting system service requirements, application of DSM, etc. This aspect is subject for exploring in future work.

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