Moldova Energy Independence and Resilience (MEIR)

Support in modelling and analysis of Moldova's power system for the integration of renewables and energy storage solutions

Modelling and Analysis of Moldova's Power System for the Integration of Renewables and Energy Storage Solutions

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Modelling and Analysis of Moldova’s Power System for the Integration of Renewables and Energy Storage Solutions

Task 4: Defining minimum parameters for BESS that the Government could include in future tenders

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Deliverable 4: RES and BESS integration report

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ACE	Area Control Error
BESS	Battery Energy Storage System
CHP	Combined Heat and Power
ENTSO-E	European Network of Transmission System Operators for Electricity
FRR	Frequency Restoration Reserve
GWh	Gigawatt-Hour
HPP	Hydro Power Plant
MW	Megawatt
MWh	Megawatt-Hour
P2G	Power to Gas
PV	Photovoltaic
RES	Renewable Energy Source
RoR	Run of River

1.0 INTRODUCTION

This report is the fourth deliverable of the PN07-2025 service agreement to support the Moldovan government in fulfilling certain commitments, stemming from the letter of intent signed on 4 February 2025 between the Government of Moldova and the European Commission.[1] The agreement underscores Moldova's determination to fast-track renewable energy deployment and the integration of energy storage solutions. This initiative is supported by the Energy Community Secretariat, an international organization dedicated to harmonizing the European Union internal energy market with its neighbouring regions, thereby extending European energy market rules and principles to the Energy Community Contracting Parties.

The letter of intent foresees the development of an action plan aimed at organizing a series of new renewable energy and energy storage auctions throughout 2025, specifying the allocated capacities for each auction, with a view to fast-track renewable energy deployment by the end of 2026. With the European Commission providing technical support, the Government of Moldova has been tasked with defining the capacity allocations for each auction. As part of this effort and in continuation of the work Tetra Tech carried out under the U.S. Agency for International Development (USAID) Moldova Energy Security Activity (MESA), this assignment has leveraged an exhaustive review of existing studies and analyses, including the latest version of the Moldovan National Energy and Climate Plan and the draft Ten-Year Network Development Plan, to thoroughly capture the current policy environment and strategic priorities for enhancing energy security and sustainability.

Task 4 builds upon the findings and groundwork established in the previous phases of the study—specifically Tasks 1 through 3—which collectively aimed to support Moldova's transition toward a more renewable, secure and integrated power system.

Task 1 ensured that modelling and analysis activities were grounded in accurate and up-to-date data, reflecting Moldova's internal conditions and the influence of its regional neighbours, such as Romania and Ukraine. This regional lens is essential for understanding Moldova's evolving role within the broader European energy landscape.

Building on this foundation, Task 2 refined the PLEXOS model by updating operational constraints and integrating cross-border interdependencies. This step was crucial to simulate system behaviour under increased shares of renewable energy, laying the groundwork for evaluating future deployment scenarios.

Task 3 identified the optimal mix and scale of new renewable energy projects—particularly solar, wind and biomass—through iterative modelling, in line with the spillage threshold established by the Moldovan authorities. These results directly inform the 2025 auction strategy, aligning technical planning with policy objectives and market readiness.

With this background, Task 4 defines the minimum required parameters for battery energy storage systems (BESS) that the government could reference in future tenders. Specifically, this report assesses the role of BESS in enabling the integration of additional renewable energy capacities, improving system flexibility, reducing spillage and maintaining grid stability. While the analysis does not directly address grid stability in a dynamic

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[1] Letter of Intent between the Government of the Republic of Moldova and the European Commission - European Commission

sense, it provides insights into how storage can support operational flexibility and reduce spillage and frequency regulation risks in Moldova's evolving power system.

By leveraging the outcomes of Task 3, Task 4 quantifies the required BESS power (MW) and energy (MWh) capacities needed to manage the variability of intermittent generation and support Moldova's renewable deployment targets.

2.0 METHODOLOGY

This section outlines the methodology employed to analyse the power and energy dimensions of BESS. It encompasses a comprehensive framework that integrates various analytical approaches, including data collection, modelling and simulation techniques. By examining the performance characteristics, operational efficiencies and integration capabilities of BESS, this methodology aims to provide insights into their role in addressing renewable energy source (RES) imbalances, enhancing energy management, supporting the power system's flexibility and facilitating the energy transition of the power system as a whole.

Task 3 showed that the Moldovan power system can easily accommodate an additional 310 MW of wind power plants and 234 MW of solar power plants with minimal impact on the cross-border electricity flows, since most of the new RES generation is absorbed by local demand. It highlighted that these values for photovoltaic (PV) and wind generation will be strong candidates for the next rounds of tendering procedures.

The proposed scope for Task 4 was to dimension BESS to serve multiple purposes, namely:

- Balancing RES and the system,
- Providing arbitrage, and
- Reducing RES spillage.

To respond to the proposed scope, a four-step methodology was developed:

1. Set preliminary BESS characteristics using the results of the flexibility study of Moldova's power system developed by Tetra Tech.
2. Check reserves (upward and downward frequency restoration reserve [FRR]) for the different BESS configurations.
3. Check whether the defined BESS capacities from step 2 decrease RES spillage.
4. Check whether it is economically justified to add more BESS capacity in the system to further decrease RES spillage.

First, the charging and discharging characteristics of BESS were dimensioned based on the results of the Tetra Tech flexibility study. This study estimated the necessary upward and downward FRR requirements based on historical area control error (ACE), RES forecast errors, demand forecast errors, and time series of thermal power plant forced outages. This estimation employed a probabilistic approach that has been developed and used as common practice by members of the European Network of Transmission System Operators for Electricity (ENTSO-E).

After dimensioning the BESS charge and discharge characteristics, BESS with a two-hour autonomy was added to the PLEXOS market model, and the reserve provision level was checked. To assess the BESS's impact on the grid, hourly ACE time series were generated by making the following assumptions:

- The average RES generation forecast error is 8 per cent for both PV and wind.
- The average load forecast error is 5 per cent.
- Thermal power plants' forced outage time series were generated in PLEXOS.
- ACE time series were calculated by summing upward and downward errors from the previously listed sources of system imbalance.

The RES forecasting error is comparable to the value considered by the Moldovan government as acceptable (margins as per the provisions of the Law on Promotion of Use of Renewable Energy) and is in line with the results of Tetra Tech's RES forecasting exercise in Moldova. In the case of solar, the forecasting error is used only for hours with actual generation (daytime). If counted for the entire day, the forecasting error would be around 4 per cent. Additionally, the imbalances for these two technologies, as well as the direction of the error, were forecasted separately for each hour, considering the capacity factors per technology and RES installed capacity.

As a validation criterion, the methodology considers that the BESS capacity is appropriate if it covers at least 98.5 per cent of the upward and downward FRR provision (upward and downward FRR needs could not be met in 131 hours during the year).

In the next step, the reduction of RES spillage resulting from BESS operation was estimated by considering FRR requirements.

The final step involved checking whether the addition of more BESS capacity would further reduce RES spillage while maintaining a reasonable equilibrium between costs and revenues.

3.0 SCENARIOS

To evaluate the requirements and potential impact of BESS in addressing the challenges posed by renewable energy integration and system imbalances, several scenarios were agreed upon with the Ministry of Energy. Each scenario focuses on the specific impact of integrated RES capacity, considering various factors such as forecasting errors to appropriately dimension BESS. The following scenarios were assessed to identify the optimal approach for dimensioning BESS, which the Moldovan government can use to ensure flexibility and enhance the overall efficiency of the power system while integrating more RES generation.

1. **Scenario 1: Dimensioning BESS to cover all imbalances in the system for 2026 and 2030**

In this scenario, the focus is on determining the optimal size and capacity of BESS required to address the overall system imbalances projected for 2026 and 2030. This includes analysing fluctuations in energy demand and supply, as well as those determined by the integration of RES generation into the grid. The methodology considers factors such as RES generation and its forecast error, thermal power plants' forced outages and the need for ancillary services to ensure the flexibility of the system. By accurately dimensioning the BESS, the system can effectively mitigate imbalances, enhance reliability and support the transition to a more sustainable energy landscape.

2. **Scenario 2: Dimensioning BESS to cover the RES forecasting error of additional RES capacities for 2030 (234 MW of solar PV and 310 MW of wind)**

This scenario dimensions BESS to specifically address the forecasting errors associated with the additional renewable energy capacities proposed to be integrated in 2030, which include 234 MW of solar PV capacity and 310 MW of wind energy capacity, if the government relies on the minimum impact of new RES capacities on the cross-border flows when deciding on the RES capacities that may be subject to the support schemes. The analysis focuses on the variability and unpredictability of these additional renewable sources, assessing how BESS can be utilized to smooth out the discrepancies between forecasted and actual energy generation and thus minimize the impact on the overall system imbalances. By calculating the necessary BESS parameters, this approach aims to ensure that the grid can effectively accommodate the increased share of renewables while maintaining a reliable supply of electricity.

3. **Scenario 3: Dimensioning BESS to cover the RES forecasting error of additional wind capacities to be auctioned for 2030 (173 MW of wind)**

In this scenario, the emphasis is on dimensioning BESS to manage the forecasting errors specifically related to the wind capacities that the Ministry of Energy is considering in the new RES auction to be launched by the end of 2025. Per the communication from the Ministry of Energy, this totals 173 MW. The analysis considers the inherent variability of wind energy generation, which can be influenced by factors such as weather conditions and seasonal changes. By determining the appropriate size and capacity of BESS, this scenario aims to provide a robust solution for mitigating the risks associated with inaccurate wind generation forecasts. This will not only enhance grid reliability but also facilitate the integration of additional wind resources into the energy mix, supporting the overall goals of energy transition and sustainability.

4.0 MODELLING RESULTS: OPERATIONAL BENEFITS OF BESS

This section presents the modelling results that highlight the operational benefits of BESS under realistic conditions. The analysis is structured into three sub-sections.

Sub-section 4.1 explores the initial capacity requirements for BESS, focusing on optimal sizing to meet anticipated FRR requirements and checking whether BESS can effectively support the integration RES and enhance overall grid reliability.

Sub-section 4.2 delves into the specific capacity needs for BESS to provide frequency regulation services. This aspect is vital for maintaining grid stability, as it addresses the rapid response capabilities required to balance supply and demand in real time. Examining these two dimensions provides a comprehensive understanding of the operational advantages that BESS can offer in a modern energy landscape.

Sub-section 4.3 presents the results of the analysis focusing on RES and BESS. The findings highlight the operational performance and benefits derived from the combined deployment of RES and BESS in addressing challenges such as supply variability and demand fluctuations.

4.1 INITIAL BESS CAPACITY DIMENSIONING

Initial BESS parameters for all scenarios were determined based on the results of the Tetra Tech flexibility study of Moldova's power system, which quantified the upward FRR required for a predetermined portfolio of RES.

To compute the BESS energy capacity, the FRR values obtained from the flexibility study were rescaled to suit the objectives and scale of this analysis. Specifically, the upward reserve volumes for the selected RES fleet were proportionally adjusted to establish a set of scenario-specific capacity requirements. To do so, the team began with the primary data from the flexibility study, 1,261 MW of variable RES capacity, which requires upward FRR of 162 MW. Estimates of the initial BESS capacity for each scenario used the same ratio of RES capacity to FRR capacity, the first step in defining the BESS parameters for each scenario. These values are presented in Table 4-1. The starting autonomy of BESS was chosen as the absolute minimum needed to provide charging and discharging power, as the useful BESS energy capacity is lower than the installed capacity. For all three scenarios, the calculations assume that BESS is freely interacting with the market, which also includes energy arbitrage.

Table 4-1 BESS capacity sizing

BESS capacity sizing					
Scenario	**RES capacity as considered in the flexibility study [MW]**	**Upward FRR [MW], as estimated in the flexibility study**	**Additional RES considered per scenario [MW]**	**Estimated initial BESS capacity [MW]**	**Autonomy [h]**
Scenario 1	1 261	162	1 138	146	2
Scenario 2	1 261	162	544	70	2
Scenario 3	1 261	162	173	22	2

4.2 DIMENSIONING BESS CAPACITY FOR FREQUENCY REGULATION SERVICES

The analysis examined the operational behaviour of several BESS configurations to reach the target FRR upward reserve provision of at least 98.5 per cent of the time within a year. To do this required first generating a one-year time series of possible system imbalances that would trigger an upward or downward reserve activation. RES generation and demand forecast errors were estimated by multiplying random time series of numbers 1 and -1 with the absolute value of the imbalance (8 per cent average error for RES generation forecast and 5 per cent average error of demand forecast). The system imbalance time series were calculated as the superposition of imbalances caused by RES generation forecast, load forecast and forced outages at thermal power plants. For each configuration, the battery was sized by assigning initial power and energy limits, estimated as described in the section above, and simulating its response—dispatching up to those limits whenever an imbalance occurred. The results of the simulations were used to calculate the number of hours when the BESS fully covered the reserve requirement, iteratively adjusting its dimensions until the 98.5 per cent target was reached. The modelling presumption is that balancing will be performed strictly within the country;

however, Moldova might participate in European balancing platforms in the future, allowing the Moldovan power system to use a BESS of lower capacity for reserves. Table 4-2 shows the results of the reserve check assessment.

Table 4-2 Reserve check assessment

Reserve check assessment									
Scenario	**Year**	**BESS capacity [MW]**	**BESS energy [MWh]**	**Unacquired upward FRR [h]**	**Max unacquired upward FRR [MW]**	**Upward reserve provision [%]**	**RES spillage [GWh]**	**RES spillage [%]**	**RES spillage decrease [GWh]**
Scenario 1	2026	**1 314**	**5 256**	104	224	98.8	0.35	0.02	3.31
Scenario 1	2030	**1 460**	**5 840**	96	194	98.9	0.17	0.01	1.74
Scenario 2	2030	**70**	**140**	22	24	99.75	1.81	0.11	0.1
Scenario 3	2030	**22**	**44**	117	13	98.66	2.16	0.14	-0.25

As expected, results for Scenario 1 show that BESS systems with large dimensions are necessary to cover all system imbalances for at least 98.5 per cent of the year. (The 98.5 per cent threshold of upward reserve provision was chosen based on the consultant's expert opinion and the fact that upward reserve provision is harder than downward.) To cover all system imbalances using only BESS, the Moldovan power system will require 1,314 MW of four-hour BESS in 2026, increasing to 1,460 MW by 2030. This result is largely influenced by the prolonged periods of imbalances in the same direction, as well as the need to ensure sufficient reserves in case of forced outages of thermal power plants. Both require the rapid use of stored energy and, therefore, exponentially growing BESS capacity. Considering the high capital costs of installing enough BESS for all FRR needs, BESS may not be the most suitable solution for mFRR. Other technical solutions, such as flexible thermal power sources, may be more economical. Also, the results indicate that this much BESS capacity would be able to reduce RES spillage almost to zero.

For Scenario 2, 70 MW of BESS with a two-hour autonomy can cover most of the imbalances caused by RES forecasting errors from the additional 234 MW of PV and 310 MW of wind capacities.

Similarly, in Scenario 3, 22 MW of BESS with a two-hour autonomy is sufficient to compensate for the RES forecasting errors induced by the 173 MW wind park in the power system.

However, for both Scenarios 2 and 3, BESS has a limited impact on RES spillage. This is because most of the spillage is registered in a limited number of hours during the year and at high values, at times exceeding the proposed capacity for BESS. The possibility of increasing BESS capacity to diminish the spilled energy was assessed in the sensitivity analysis, and the results are presented below.

4.3 RESULTS

The following sub-sections analyse each scenario from the perspective of the impact on the overall operation of the power system, highlighting the operational performance and effectiveness of BESS in addressing specific challenges within the system. The findings provide insights into how the dimensioned capacities contribute to enhanced integration of RES. Since similar results for Scenarios 2 and 3 were expected in 2026, the simulations for these scenarios are conducted only for 2030. Because it takes at least three years to develop new RES projects, it makes sense to simulate Scenarios 2 and 3 for 2030 as the target year.

4.3.1 RESULTS 2026 - SCENARIO 1

Table 4-3 presents the expected annual charge and discharge of BESS for Scenario 1 in 2026, which assumes that 1,314 MW BESS with a four-hour autonomy is integrated into the system. This dimensioning is intended to cover most system imbalances (98.5 per cent).

Table 4-3 BESS operation – Scenario 1, 2026

BESS operation [GWh]	
	Moldova
Discharge	784.66
Charge	922.77

Table 4-4 presents the results for 2026, showing the generation, load, unserved energy, price and power-to-gas (P2G) values for Moldova (right and left bank of the Nistru River), Romania and Ukraine. Based on all input assumptions, the analysis of the projected state of the Moldovan electricity sector in 2026 (right bank) indicates that local generation will cover 50 per cent of the demand. Comparing these results with those without BESS for the same level of RES integration, as presented in the appendix, shows that a slight increase in the marginal price can be expected in Moldova (right bank). This is a result of the BESS charging and increased imports and production from gas-fired units.

Table 4-4 Results per country – Scenario 1, 2026

Results per country				
	Moldova (right)	**Moldova (left)**	**Romania**	**Ukraine**
Generation [GWh]	2 322	2 073	69 458	116 531
Load [GWh]	4 657	2 042	54 982	102 812
Unserved energy [GWh]	/	0.16	/	/
P2G [GWh]	/	/	861.85	/
Price [€/MWh]	80.58	102.64	93.86	75.47

The impact on the net cross-border electricity exchanges involving Moldova, Romania, Ukraine and the rest of ENTSO-E for 2026 is similar to that in the analysis of Task 3. Most electricity imports are expected to come from Ukraine, approximately 100 GWh more than in the scenario without BESS. Imports occur primarily during peak hours, when electricity demand is at its highest. Additionally, there will be transit flows of electricity from Ukraine to Romania through Moldova. The low net transfer capacity with Romania is anticipated to negatively impact commercial trade, making it difficult for Moldova to fully leverage its potential for cooperation with neighbouring markets. Electricity will also be exported from Ukraine and Romania to ENTSO-E and to Moldova.

Table 4-5 Exchanges – Scenario 1, 2026

Exchanges per border	
Border	**Exchange [GWh]**
Moldova–Ukraine	-2 570
Moldova–Romania	122
Romania–ENTSO-E	15 782
Ukraine–ENTSO-E	9 952
Ukraine–Romania	1 196

Figure 4-1 presents the total yearly electricity generation by type, illustrating the contributions of different generation sources, including combined heat and power (CHP), biomass, PV, wind and hydropower. The figure highlights the dominance of RES, particularly wind and PV, in the overall generation mix due to the high installed capacity of these sources. RES generation is increasing because of its low costs, replacing imports when RES is available.

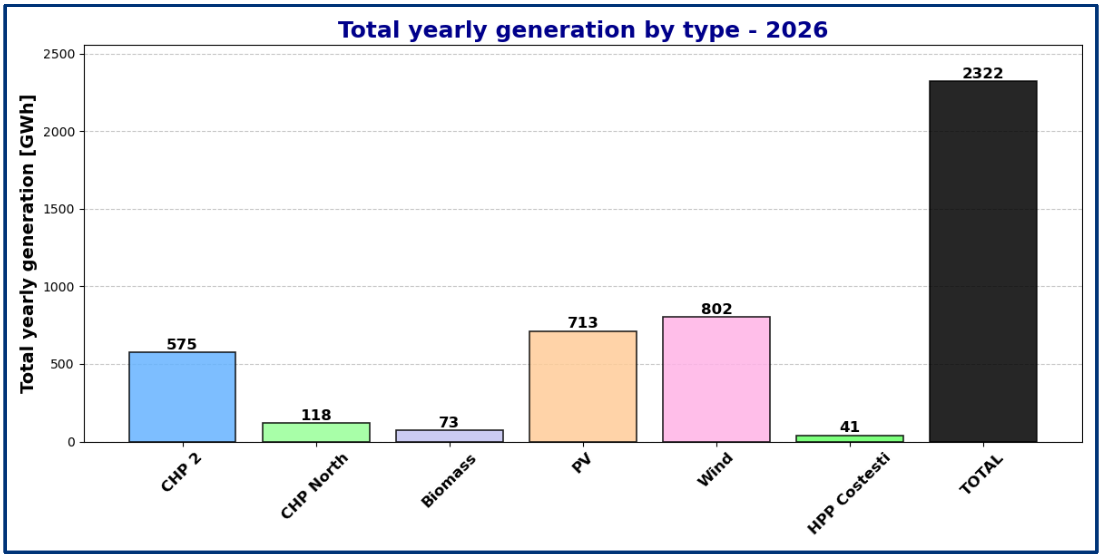

Figure 4-1 Total yearly generation for 2026 (right bank) - Scenario 1

Figure 4-2 presents the results for 2026, showing the yearly PV, wind and biomass, as well as RES spillage on an annual basis for Moldova (right bank). Comparing these results with those without BESS for the same level of RES integration, as presented in Table 4-2 and the appendix, shows that there is a 3.31 GWh decrease in RES spillage in Moldova (right bank) as a result of the integration of BESS into the system, bringing the value of the overall spillage close to zero. In this scenario, spillage occurs only for five hours throughout the entire year.

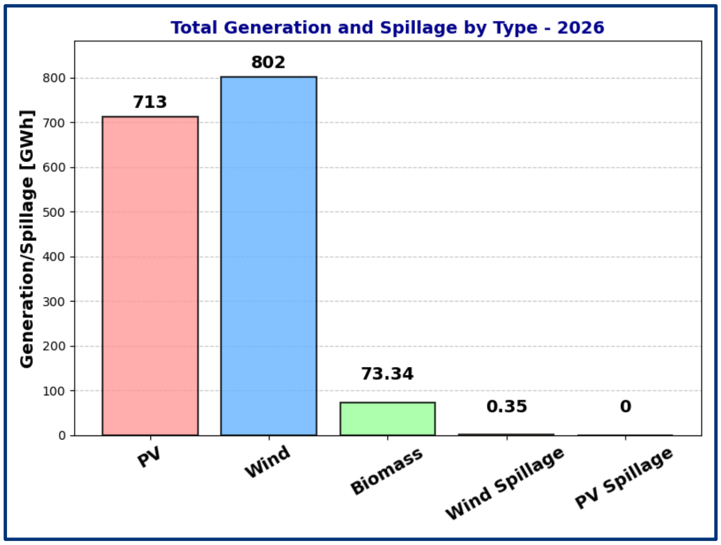

Figure 4-2 Results for 2026 (right bank) - Scenario 1

Figure 4-3 shows the load and the expected generation from all sources for 2026 in Moldova. Based on the results shown in the figure, Moldova will import electricity throughout the year, impacted by the increase in consumption, the limited amount of new RES capacities, constraints on gas units and the unavailable energy from MGRES (which will only cover consumption on the left bank). As shown in Table 4-5, the electricity will be mostly imported from Ukraine.

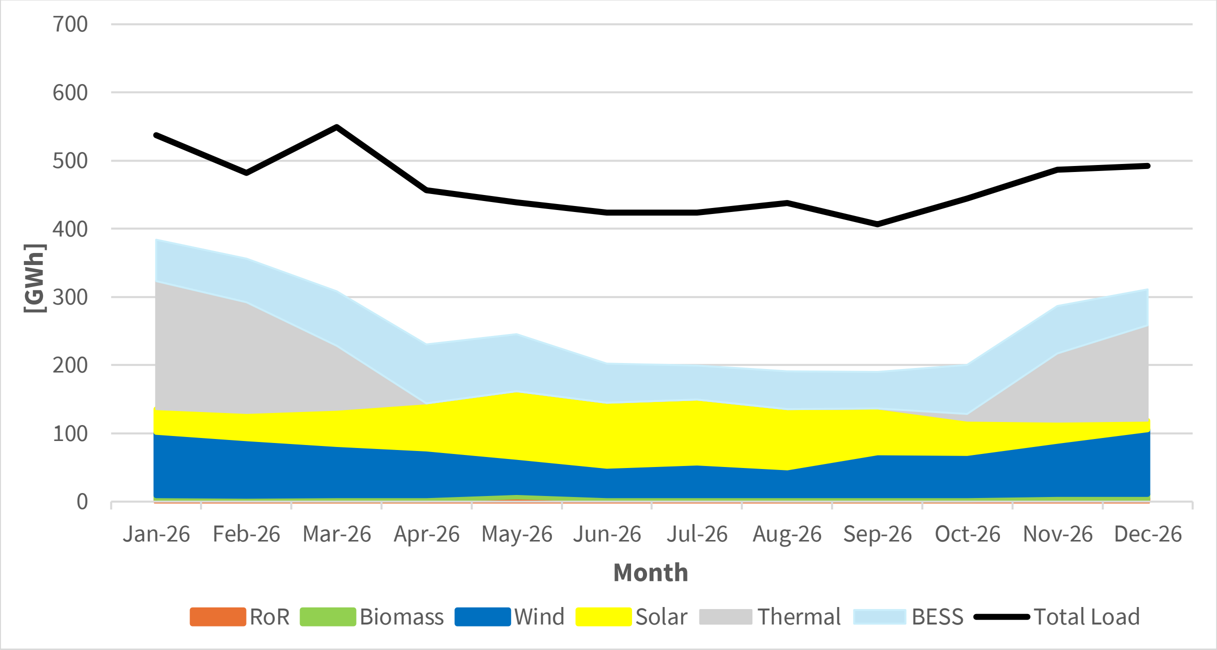

Figure 4-3 Monthly generation and load for Moldova (right bank) in 2026 with BESS – Scenario 1

4.3.2 RESULTS 2030 - SCENARIO 1

Table 4-6 presents the expected annual charge and discharge of BESS for Scenario 1 in 2030, which assumes that 1,460 MW BESS with a four-hour autonomy is integrated into the system. This dimensioning is intended to cover all system imbalances.

Table 4-6 BESS operation – Scenario 1, 2030

BESS operation [GWh]	
	Moldova
Discharge	598.94
Charge	703.36

Table 4-7 presents the results for Scenario 1 for 2030, showing the generation, load, unserved energy, price and P2G values for Moldova (right and left bank of the Nistru River), Romania and Ukraine. Based on all input assumptions, the analysis of the projected state of the Moldovan electricity sector in 2030 (right bank) indicates that local generation will cover 55 per cent of the demand. Comparing these results with those without BESS for the same level of RES integration, as presented in the appendix, shows that the marginal price is similar in Moldova (right bank).

Table 4-7 Results per country – Scenario 1, 2030

Results per country				
	Moldova (right)	**Moldova (left)**	**Romania**	**Ukraine**
Generation [GWh]	2 781	2 307	69 349	104 544
Load [GWh]	5 029	2 281	60 039	105 180
Unserved energy [GWh]	/	0.18	/	/
P2G [GWh]	/	/	94.61	/
Price [€/MWh]	82.91	146.69	81.07	80.44

The table below presents the net cross-border electricity exchanges involving Moldova, Romania, Ukraine and the rest of ENTSO-E for Scenario 1 in 2030.

Table 4-8 Exchanges – Scenario 1 2030

Exchanges per border	
Border	**Exchange [GWh]**
Moldova–Ukraine	-736
Moldova–Romania	-1 592
Romania–ENTSO-E	7 141
Ukraine–ENTSO-E	-889
Ukraine–Romania	-483

The results are similar to those in the analysis from Task 3. The majority of electricity imports are expected to come from Romania and Ukraine, especially during peak hours, which may pose challenges to ensuring the security of supply. With the expected increase in net transfer capacity with Romania due to the construction of the 400 kV interconnection between Bălți and Suceava, an increase in electricity exchange and annual net imports of electricity from Romania are anticipated.

Furthermore, due to increased consumption in Ukraine and Romania, as well as the CO_2 surcharge on the marginal production costs of conventional thermal generation units (which makes them more expensive than average market prices), by 2030 exports from Romania to ENTSO-E countries will decrease. It is expected that Ukraine will become an importer of electricity by 2030, owing to lower production levels and higher demand. This situation underscores the need for infrastructure improvements, the development of the generation system in Moldova, and strengthened regional collaboration to enhance the security of supply and reduce dependence on imports by 2030.

Figure 4-4 presents total yearly electricity generation by type, illustrating the contributions of different generation sources, including CHP, biomass, PV, wind and hydropower. The figure highlights the dominance of RES, particularly wind and PV, in the overall generation mix due to the high installed capacity of these sources. However, it is noticeable that the production from gas units has increased, considering that a rise in consumption is expected by 2026, as well as the fact that the old units in CHP 1 have been replaced with new ones, which are more efficient.

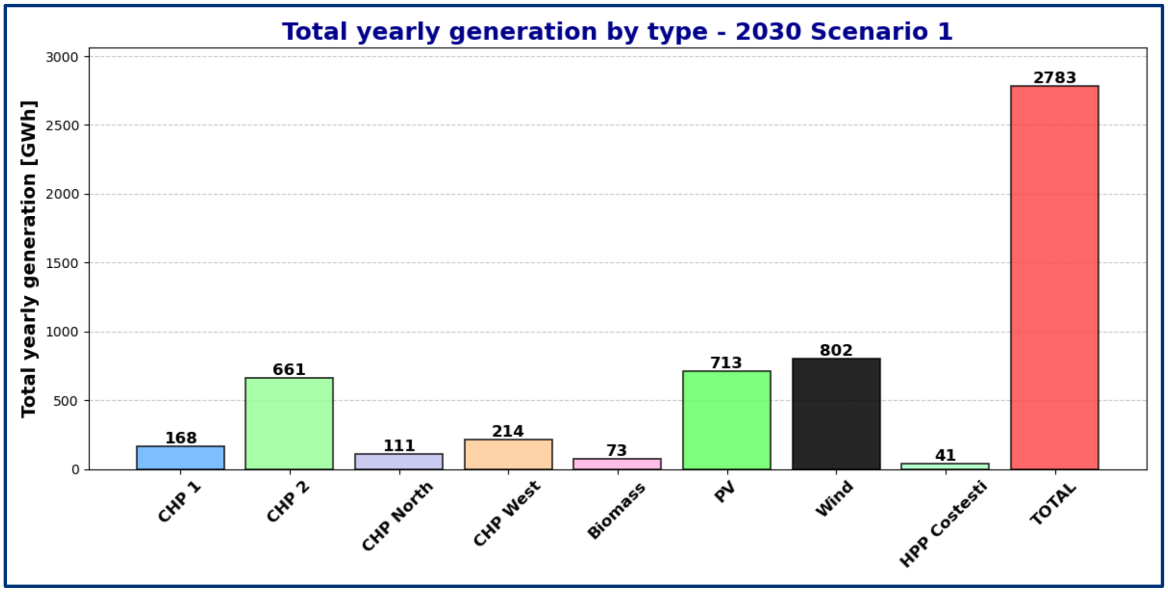

Figure 4-4 Total yearly generation for 2030 (right bank) – Scenario 1

Figure 4-5 illustrates the total renewable energy generation and spillage by type for 2030 in Scenario 1. The chart provides an overview of PV, wind and biomass generation, as well as RES spillage, highlighting the impact on RES integration. In comparison to the results for Scenario 1 in 2026, the spillage in the system has significantly decreased and is now almost negligible. In this scenario, spillage occurs only for three hours throughout the entire year. This reduction indicates more installed BESS capacities, new gas-fired units and a new interconnection with Romania. The 2023 results without BESS, which record total spillage at 1.91 GWh, imply that the integration of batteries into the system reduces spillage.

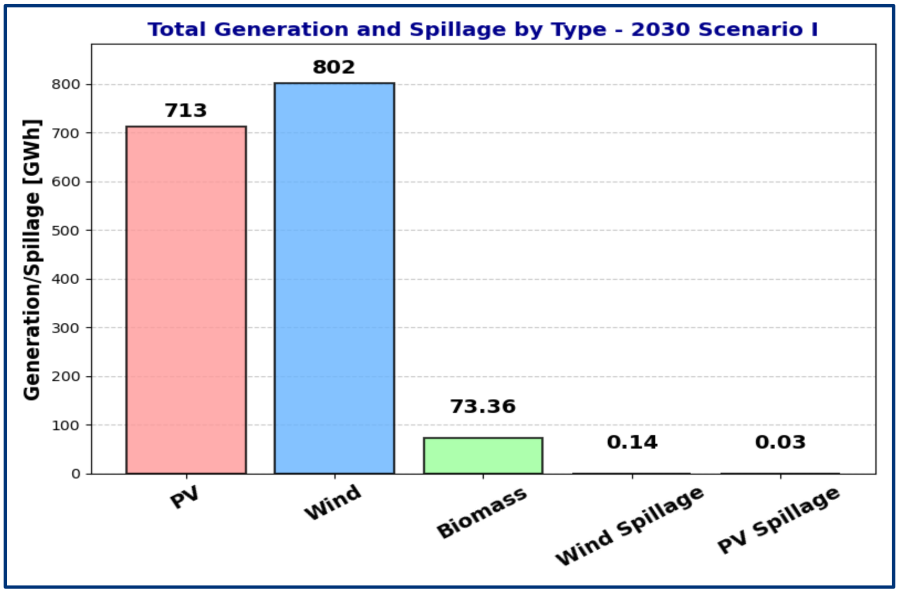

Figure 4-5 Results for 2030 (right bank) - Scenario 1

Figure 4-6 shows the load and the expected generation from all sources, including thermal, hydro, RES and BESS, for Scenario 1 in 2030. Based on these results, Moldova will import electricity throughout the year, considering the increase in consumption, the limited amount of new RES capacities, constraints on gas units and the unavailable energy from MGRES (which will only cover consumption on the left bank).

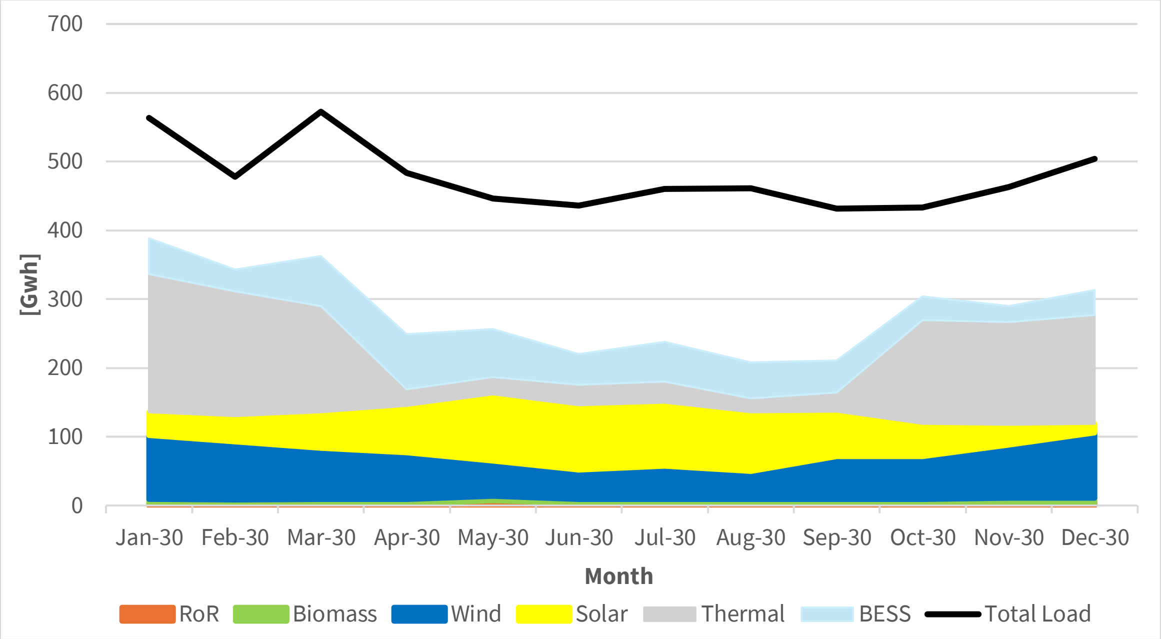

Figure 4-6 Monthly generation and load for Moldova (right bank) in 2030 with BESS – Scenario 1

4.3.3 RESULTS 2030 - SCENARIO 2

Table 4-9 shows the expected annual charge and discharge of BESS for Scenario 2, which assumes that BESS will cover the RES forecasting error associated with the additional RES capacities for 2030 (234 MW of solar PV and 310 MW of wind). The simulation results show that it is necessary to install BESS in the system with a capacity of 70 MW and a two-hour autonomy to address additional RES imbalances for 2030.

Table 4-9 BESS operation – Scenario 2

BESS operation [GWh]	
	Moldova
Discharge	27.5
Charge	32.31

Table 4-10 presents the results for Scenario 2, showing the generation, load, unserved energy, price and P2G values for Moldova (right and left bank of the Nistru River), Romania and Ukraine. Compared to Scenario 1 for 2030, there are no significant changes in the results.

Table 4-10 Results per country – Scenario 2

Results per country				
	Moldova (right)	**Moldova (left)**	**Romania**	**Ukraine**
Generation [GWh]	2 783	2 308	69 223	105 095
Load [GWh]	5 029	2 281	60 039	105 267
Unserved energy [GWh]	/	0.1	/	/

Results per country				
P2G [GWh]	/	/	109.74	/
Price [€/MWh]	82.34	146.67	80.85	80.2

The table below presents the net cross-border electricity exchanges involving Moldova, Romania, Ukraine and the rest of ENTSO-E for Scenario 2. There are no significant changes regarding exchanges across borders. Imports are higher by about 100 GWh, because there is less production from BESS than in Scenario 1 for 2030. Most electricity imports are expected to come from Romania and Ukraine, as in the previous scenario.

Table 4-11 Exchanges – Scenario 2

Exchanges per border	
Border	**Exchange [GWh]**
Moldova–Ukraine	-883
Moldova–Romania	-1 345
Romania–ENTSO-E	7 302
Ukraine–ENTSO-E	-628
Ukraine–Romania	-427

Figure 4-7 presents the total yearly electricity generation by type, illustrating the contributions of different generation sources, including CHP, biomass, PV, wind and hydropower. However, it is noticeable that the production from gas units has slightly increased compared to Scenario 1 for 2030, considering that there are fewer batteries connected to the system.

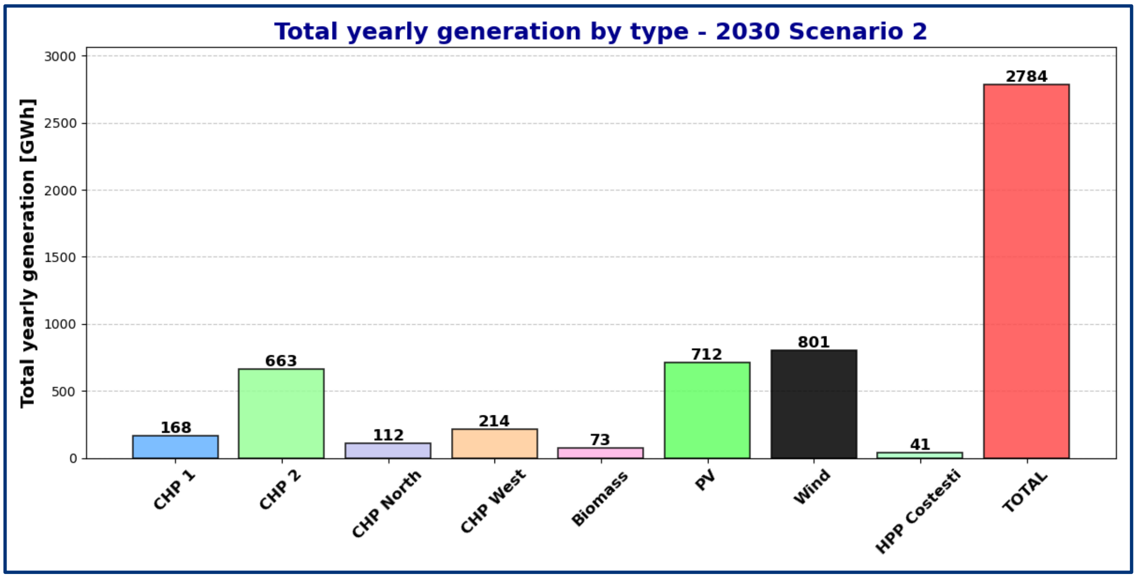

Figure 4-7 Total yearly generation for Scenario 2 – right bank

Figure 4-8 illustrates the total renewable energy generation and spillage by type for Scenario 2. In comparison to the results for Scenario 1 in 2030, the spillage in the system has significantly increased. In this scenario, spillage occurs in 16 hours throughout the entire year, which is more than in the previous scenario. The total amount of spillage is 1.81 GWh on an annual basis, which is comparable to the case without BESS.

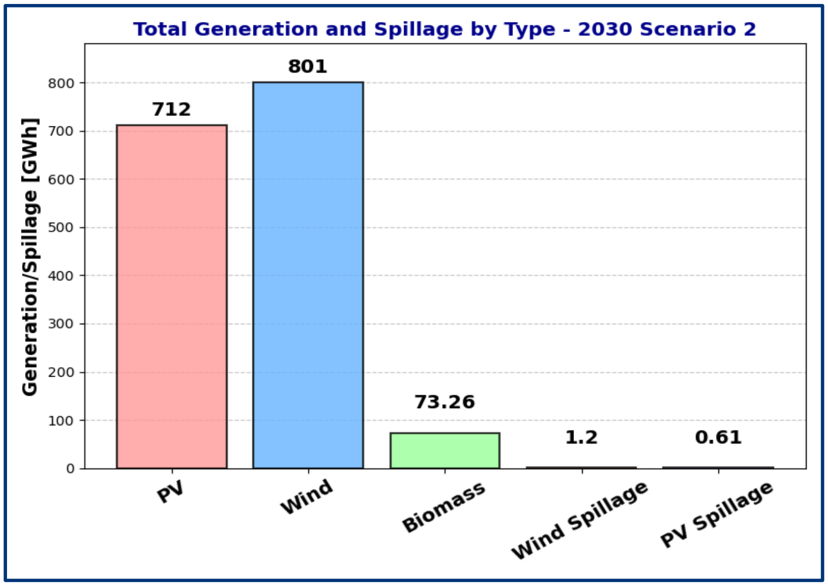

Figure 4-8 Results for Scenario 2 – right bank

Figure 4-9 shows load and expected generation from all sources, thermal, hydro, RES and BESS, for Scenario 2. Based on the results shown in the figure, Moldova will import electricity throughout the year, considering the increase in consumption, the limited amount of new RES capacities, constraints on gas units and the unavailable energy from MGRES (which will only cover consumption on the left bank).

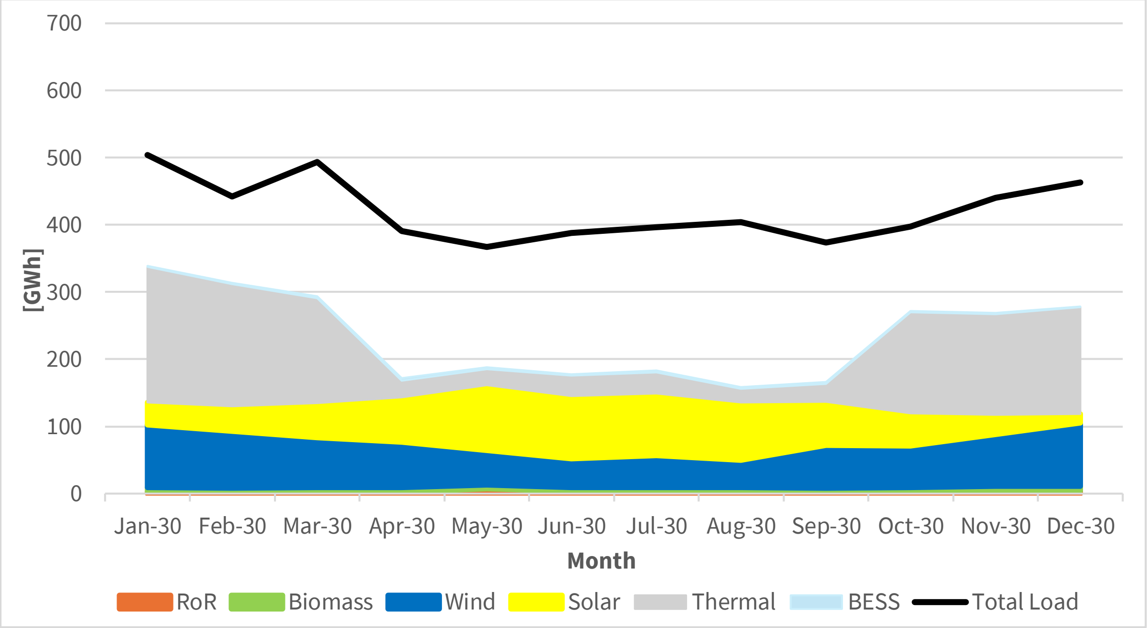

Figure 4-9 Monthly generation and load for Moldova (right bank) in 2030 with BESS – Scenario 2

4.3.4 RESULTS 2030 – SCENARIO 3

Table 4-12 presents the expected annual charge and discharge of BESS for Scenario 3, which assumes that BESS will cover the RES forecasting error for the 173 MW of wind capacity to be auctioned. The calculations show that the BESS capacity needed to address additional RES imbalances for 2030 is 22 MW with a two-hour autonomy.

Table 4-12 BESS operation – Scenario 3

BESS operation [GWh]	
	Moldova
Discharge	9.27
Charge	10.9

Table 4-13 presents the results for Scenario 2, showing the generation, load, unserved energy, price and P2G values for Moldova (right and left bank of the Nistru River), Romania and Ukraine. Comparing the results to other scenarios for 2030, there are no significant changes.

Table 4-13 Results per country – Scenario 3

Results per country				
	Moldova (right)	**Moldova (left)**	**Romania**	**Ukraine**
Generation [GWh]	2 782	2 309	69 246	105 147
Load [GWh]	5 029	2 281	60 040	105 288
Unserved energy [GWh]	/	0.14	/	/
P2G [GWh]	/	/	109.86	/
Price [€/MWh]	82.27	150.49	80.86	80.21

The table below presents the net cross-border electricity exchanges involving Moldova, Romania, Ukraine and the rest of ENTSO-E for Scenario 3. Exchanges across borders are similar to the previous scenario.

Table 4-14 Exchanges – Scenario 3

Exchanges per border	
Border	**Exchange [GWh]**
Moldova–Ukraine	-875.22
Moldova–Romania	-1 348
Romania–ENTSO-E	7 323
Ukraine–ENTSO-E	-588.21
Ukraine–Romania	-426.81

Figure 4-10 presents the total yearly electricity generation by type, illustrating the contributions of different generation sources, including CHP, biomass, PV, wind and hydropower.

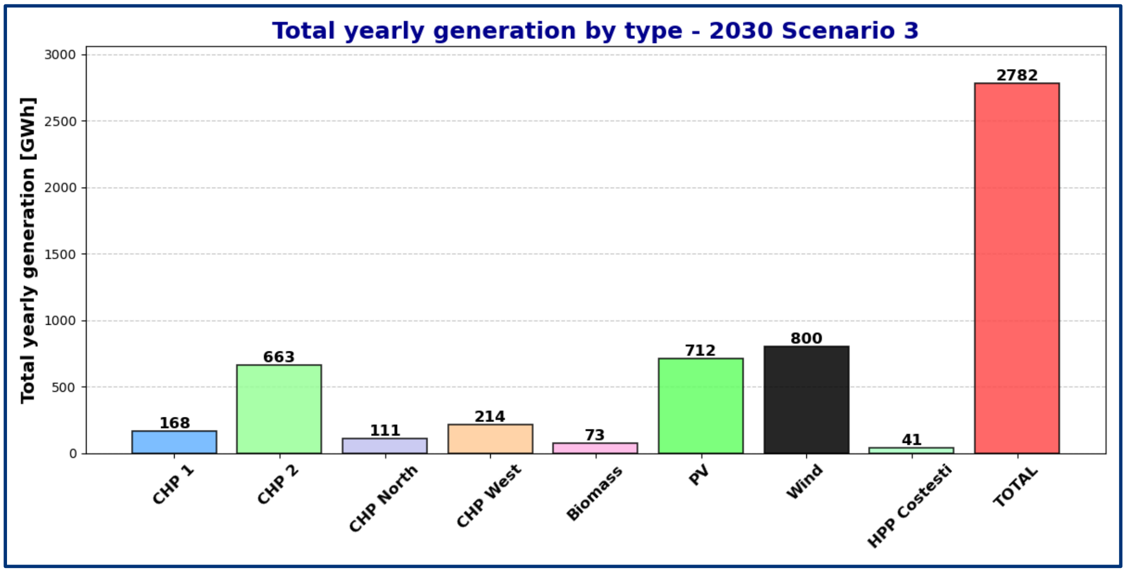

Figure 4-10 Total yearly generation for Scenario 3 – right bank

Figure 4-11 illustrates the total renewable energy generation and spillage by type for Scenario 3. In comparison to the scenario without BESS, the spillage in the system has increased from 1.91 GWh to 2.16 GWh, which is an increase of 0.25 GWh. In this scenario, spillage occurs for 20 hours throughout the entire year.

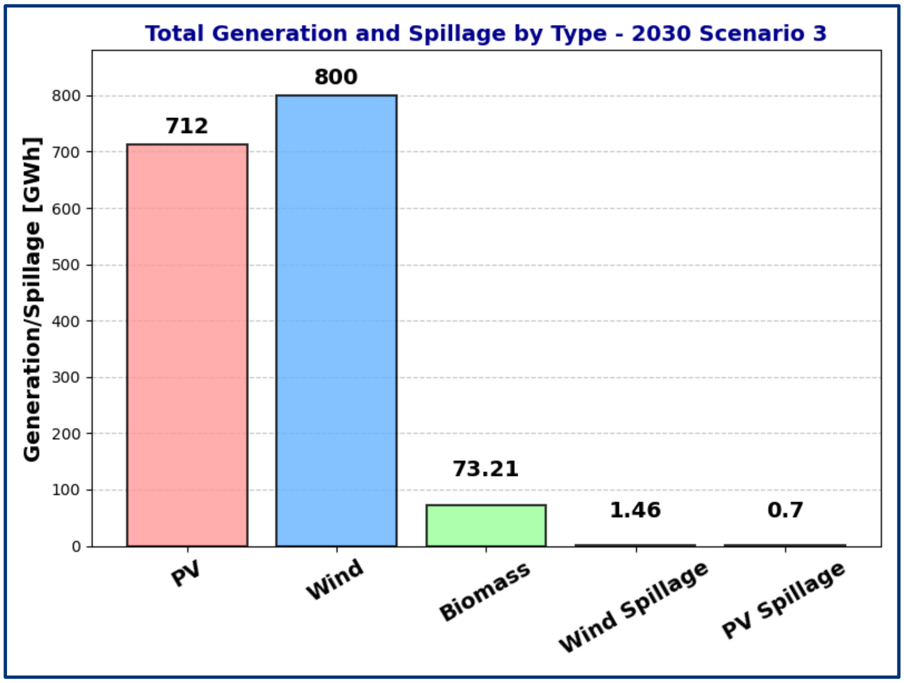

Figure 4-11 Results for Scenario 3 – right bank

Figure 4-12 presents load and expected generation from all sources, including thermal, hydro, RES and BESS, for Scenario 3. Like in Scenario 2, the graph shows that the production from BESS is negligible, amounting to approximately 9.27 GWh on an annual basis.

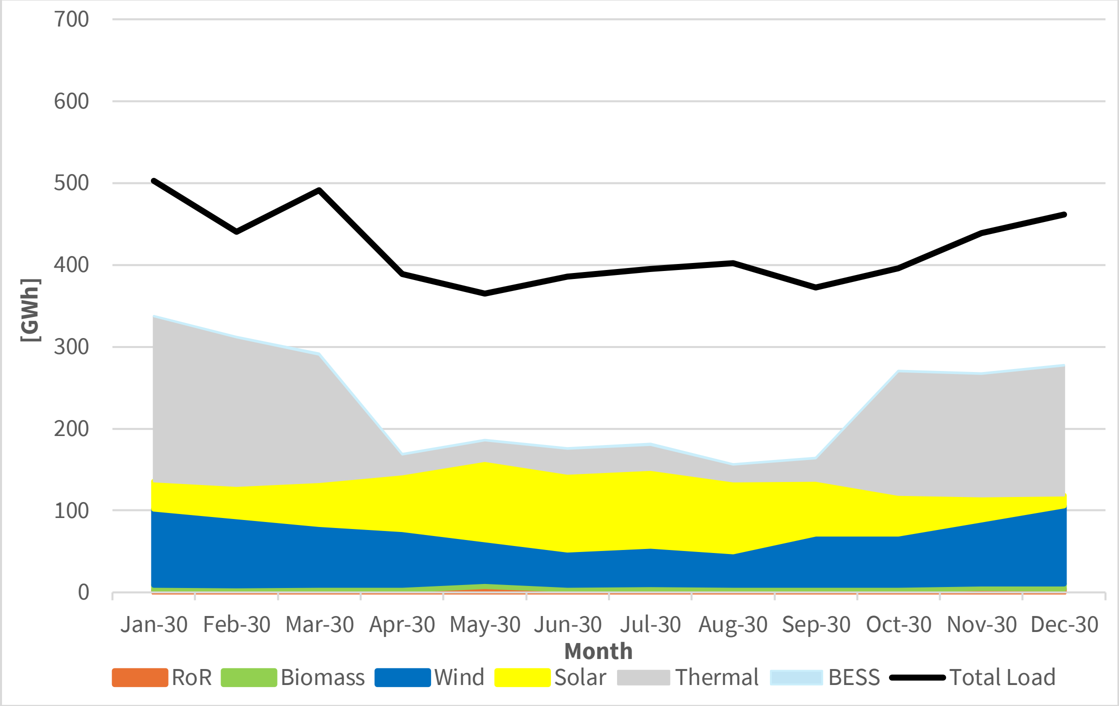

Figure 4-12 Monthly generation and load for Moldova (right bank) in 2030 with BESS – Scenario 3

5.0 SENSITIVITY ANALYSIS: IMPACT OF INCREASING BESS CAPACITY AND ITS EFFECT ON SPILLAGE REDUCTION

Previous sections observed that the level of spilled energy in all scenarios is quite low. In the scenario with the highest level of spilled energy (Scenario 3 – 2.16 GWh), the estimated annual value of spilled energy is approximately €0.18 million, considering the average yearly marginal price in Moldova. As the usual technical life of BESS is 15 years and the capital expenditure for BESS with a two-hour autonomy is approximately €1 million/MW,[2] in a theoretical case, 2.7 MW of BESS (which costs €2.7 million) could reduce the spilled energy to zero. In Scenario 3, the highest recorded power with spillage is 233 MW, which proves that there is no economic logic in adding additional BESS to pursue further spillage reduction. In other scenarios, spillage levels are even lower, thus making the potential benefit of spillage reduction even more insignificant.

6.0 CONCLUSION

Task 4 provides a structured, quantitative approach to defining the scale and function of BESS needed to enable the integration of higher shares of RES in Moldova.

The three scenarios examine the different models of BESS operation. While Scenario 1 allows BESS to operate on the balancing market, enabling it to also use arbitrage to optimize the charging/discharging cycles when dealing with overall system imbalances, Scenarios 2 and 3 limit the market options for BESS by restricting its use to covering RES forecasting errors. As such, the results can also provide some additional insights regarding

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[2] Tetra Tech, Flexibility Assessment of the Moldovan Power System, 2024.

how the wider use of BESS in multiple market segments will impact the size of the potential suitable BESS capacity.

Through progressive analysis—from initial sizing to targeted spillage reduction—it demonstrates how BESS can be strategically deployed to address operational imbalances and unlock the full value of renewable investments. Task 4 plays a crucial role in enabling high RES penetration by identifying practical storage requirements at each stage of the analysis:

1. Initial BESS capacity dimensioning
2. Dimensioning BESS to handle system/RES-induced imbalances
3. Analysis of BESS's operation and its impact on reducing spilled RES energy
4. Minimization of spillage through additional BESS capacity

The results show that in Scenario 2 and Scenario 3, which consider higher RES penetration levels, the required BESS charging/discharging power to effectively balance the RES generation forecast error and enable economic arbitrage ranges between 10-15 per cent of the RES capacity, with two hours of autonomy. Specifically, the optimal BESS capacities identified are 70 MW in Scenario 2 and 22 MW in Scenario 3, both providing two-hour energy autonomy to address RES imbalances in 2030. In Scenario 2 (Figure 4-8), despite the presence of BESS, annual RES spillage remains at 1.81 GWh, occurring over 16 hours, indicating that additional storage capacity would be needed to capture surplus energy during peak generation periods. In Scenario 3 (Figure 4-11), spillage increases slightly from 1.91 GWh to 2.16 GWh, with 20 hours of annual curtailment observed.

To balance the Moldovan power system in Scenario 1, significantly larger BESS capacities are needed. The need to cover gas-fired units' forced outages, which last for a significant number of hours, requires large charging capacity and energy capacity to store the volume of energy that should be used to mitigate the loss of generation. The standard practice is for BESS to cover the automatic frequency restoration reserve (aFRR) requirement, while fast thermal units (such as internal combustion engine technology) are responsible for covering the manual frequency restoration reserve (mFRR) requirement. The expected annual charge and discharge of the BESS are presented for Scenario 1 in both 2026 and 2030. For 2026, it assumes the integration of 1,314 MW BESS with four-hour autonomy into the system. In 2030, the system is expected to integrate 1,460 MW BESS with four-hour autonomy.

Comparing the results for all three scenarios shows that the BESS capacity that can be integrated into the power system is largely influenced by the market model used to generate revenue streams for these capacities. As Scenarios 2 and 3 indicate, using BESS only to cover RES forecasting errors is an underutilization of the batteries, with even a small amount of BESS capacity being able to resolve this type of imbalance and help firm up variable renewable energy generation. By contrast, Scenario 1 shows that if BESS is allowed to operate without restriction on several market segments, the capacity that can be integrated increases greatly, provided that this increase considers the cost-effectiveness of developing such capacities.

This report, along with the first three reports, has been prepared to advise decision making by the Moldovan Ministry of Energy for designing the future RES tender, anticipated in the second half of 2025.

APPENDIX A: COMPARISON OF RESULTS WITH AND WITHOUT BESS

Year	2026 without BESS		2026 with BESS	
	Moldova (right)	**Moldova (left)**	**Moldova (right)**	**Moldova (left)**
Generation [GWh]	2 331	2 067	2 322	2 073
Load [GWh]	4 658	2 041	4 657	2 042
Unserved energy [GWh]	/	3.16	/	0.16
Price [€/MWh]	76.58	127.54	80.58	102.64

Year	2030 without BESS		Scenario 1 2030		Scenario 2 2030		Scenario 3 2030	
	Moldova (right)	**Moldova (left)**	**Moldova (right)**	**Moldova (left)**	**Moldova (right)**	**Moldova (left)**	**Moldova (right)**	**Moldova (left)**
Generation [GWh]	2 784	2 304	2 783	2 307	2 784	2 308	2 782	2 309
Load [GWh]	5 029	2 281	5 029	2 281	5 029	2 281	5 029	2 281
Unserved energy [GWh]	/	0.09	/	0.18	/	0.1	/	0.14
Price [€/MWh]	82.26	138.76	82.91	146.69	82.34	146.67	82.27	150.49

Year	2026 without BESS	2026 with BESS
Border	**Exchange [GWh]**	
Moldova–Ukraine	-2 423	-2 570
Moldova–Romania	121	122
Romania–ENTSO-E	15 639	15 782
Ukraine–ENTSO-E	10 098	9 952
Ukraine-Romania	1 187	1 196

Year	2030 without BESS	Scenario 1 2030	Scenario 2 2030	Scenario 3 2030
Border	**Exchange [GWh]**			
Moldova–Ukraine	-1 423	-736	-883	-875
Moldova–Romania	-802	-1 592	-1 345	-1 348
Romania–ENTSO-E	7 289	7 141	7 302	7 323
Ukraine–ENTSO-E	-461	-889	-628	-588
Ukraine–Romania	-413	-484	-427	-427

Year	2026 without BESS	2026 with BESS
Zone	**Moldova (right)**	
PV generation [GWh]	711	713
Wind generation [GWh]	800	802
Biomass generation [GWh]	73	73.34
Wind spillage [GWh]	2.11	0.35
PV spillage [GWh]	1.55	0
RES spillage [h]	62	5
RES spillage [%]	0.23	0.02

Year	2030 without BESS	Scenario 1 2030	Scenario 2 2030	Scenario 3 2030
Zone	**Moldova (right)**		**Moldova (right)**	
PV generation [GWh]	712	713	712	712
Wind generation [GWh]	801	802	801	800
Biomass generation [GWh]	73	73.36	73.26	73.21
Wind spillage [GWh]	0.93	0.14	1.2	1.46
PV spillage [GWh]	0.98	0.03	0.61	0.7
RES spillage [h]	20	3	16	20
RES spillage [%]	0.12	0.01	.11	0.14

BESS operation in Moldova	Scenario 1, 2026	Scenario 1, 2030	Scenario 2, 2030	Scenario 3, 2030
Discharge [GWh]	784.66	598.94	27.5	9.27
Charge [GWh]	922.77	703.36	32.31	10.9