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Need for hydro storage due to the challenges arising from expansion of PV electricity generation

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Abstract. Hydropower has a crucial role in the clean energy transition (CET) due to the low-carbon electricity production, the sustainability, reliability and flexibility it provides. Both the fast response and storage potential make hydropower a basis for integrating wind and solar power whose output vary depending on external conditions. Many European countries have considerable remained feasible potential for hydropower development, among which is North Macedonia (MK). As a member of the Energy Community, MK aligns with European energy policies by adopting and implementing EU energy directives and regulations. The energy scenarios illustrate the country's energy transition, forecasting its reaction to EU policies and government efforts aimed at achieving a net-zero economy by 2050. However, the country's cost-competitive potential is constrained by factors like low wind speeds and inaccessible terrain in certain regions, making photovoltaics (PV) the fastest growing renewable energy source (RES) technology. Thus, the electricity production from PVs in North Macedonia experiences exponential growth throughout the last four years. The challenges arising from PV expansion are imposing the need for improvement of the energy system flexibility to accommodate the new and highly fluctuating demands. Hence, hydropower could play a major role as dispatchable power source to back up variable PV and balance variations from PV generation. Due to this, the current state of RES capacity and generated electricity with focus on hydropower in MK has been analysed in this paper. Subsequently, an investigation of the possibilities for increasing the electricity production from hydropower to add flexibility to the power system in MK is performed and finally the related challenges have been presented.

The steps towards higher flexibility of the energy system in North Macedonia are analysed including usage of existing hydropower plants (HPPs), but also construction of new storage HPPs and pumped storage HPPs for peak demand management and avoiding blackouts under critical circumstances. Some of the existing HPPs can be upgraded through equipment refurbishment and storage increase to gain flexibility. Due to being a technology able to address the flexibility challenges posed by the rise in photovoltaic (PV) installations, pumped storage hydropower was also recognised as a possibility. According to the energy strategy, construction of both large and small HPPs based on the remaining technically and economically feasible potential is envisaged. Small HPPs are prioritized due to their technical feasibility and lower investments. Financial support mechanisms are introduced to stimulate small HPPs and construction conditions are already established for some of them, however, an adjustment in accordance with the administrative requirements in certain areas is needed to ensure environmental sustainability. Moreover, integrating innovative technologies into hydropower can significantly enhance the energy transition at the national level, particularly by improving efficiency, flexibility, and environmental sustainability. Various challenges related to environmental protection, lifetime and maintenance of HPPs components so as economical limitations are being discussed.

Keywords: Flexibility, Storage, Pumped hydro, PV

1. Introduction

The Clean Energy Package is the latest update in the European energy policy framework, consisting of legislations and measures aimed towards decarbonised economy, energy efficiency and security, internal electricity market regulation and stimulating research, innovation and competitiveness in the energy and climate change sectors [1]. North Macedonia is Energy Community Contracting Party which follows the European energy policy. The five key dimensions of the Clean Energy Package are covered in the National Energy and Climate Plan (NECP) of North Macedonia, adopted in June 2022 [2]. The NECP is based on the Third Biennial Update Report (TBUR), the revised Nationally Determined Contribution (NDC) and the National Energy Strategy.

The legal framework for renewable energy sources in the country consists of:

- Energy development strategy
- Strategy for the use of renewable energy sources (RES)
- Encouraging utilization of RES
- Regulation on RES
- Preferential tariffs
- Law on Energy.

Regarding the decarbonization as one of the key dimensions, North Macedonia aims to reduce greenhouse gas emissions by 61,5% relative to 2005 levels till 2040 and attain 38% share of renewables in final energy consumption along with 66% share in gross electricity production. North Macedonia's NECP follows the energy targets presented in the National Strategy for Energy Development until 2040 whose main objective is to identify possibilities for exploitation of RES in the country and ways to accomplish RES targets. In addition to the RES potential overview, the Strategy describes the electricity system characteristics, capacity and influence by RES. The financing mechanisms for feed-in tariffs (FITs) are analysed, as well as the set of laws, regulations and organizational structure affiliated with RES. Moreover, the Strategy highlights the importance of increasing electricity independence.

The Strategy focuses on managing system flexibility to integrate more variable RES, harnessing RES while preserving the environment, promoting further development of renewable sources by establishing financial support mechanisms and enhancing implementation of the Energy Community acquis in the environmental sector.

Potential new RES contributions to final energy consumption are outlined in three energy scenarios which predict up to 1400 MW installed capacity of PVs so as up to 750 MW installed capacity of WPPs till 2040.

Total electricity production from renewable energy sources rises by 2.5% and 16.1% in the Moderate Transition and Green scenarios, respectively, when compared to the Reference scenario (Figure 1). New investments in wind power and PV capacities are expected to decrease the proportion of generated hydroelectricity from 64% (Reference scenario) to 54% (Green scenario). Although wind and solar power are projected to be the most rapidly expanding technologies, according to the scenario, HPPs will retain their largest share in electricity generation.

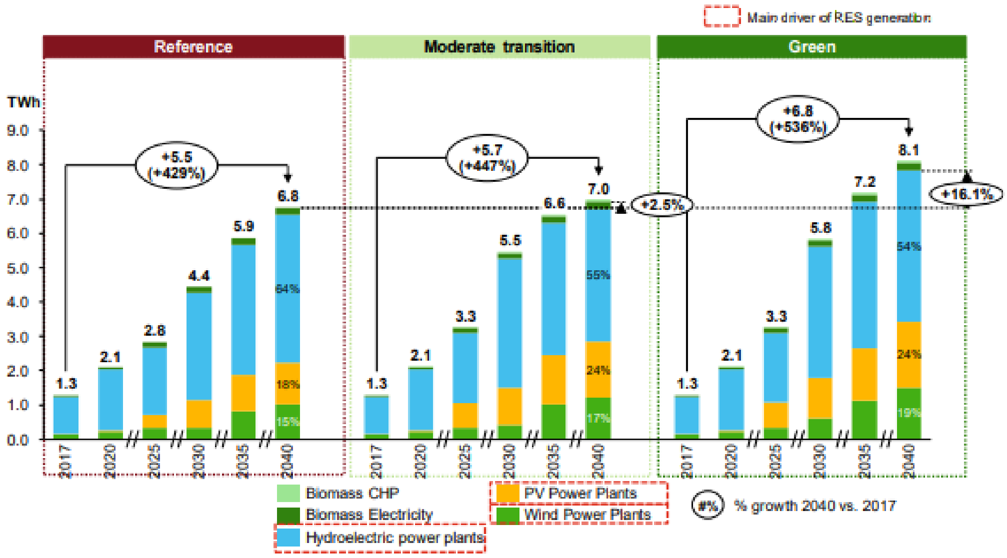


Figure 1. Electricity generation by RES technologies in North Macedonia – different scenarios according to the National Energy Strategy [3]

Two types of financial mechanisms, i.e., feed-in tariffs and feed-in premiums are introduced to enhance domestic RES production and support local businesses. The maximum planned supported capacity for RES from 2017 till 2040 is 570 MW [3]. At this moment, support is provided only for SHPPs.

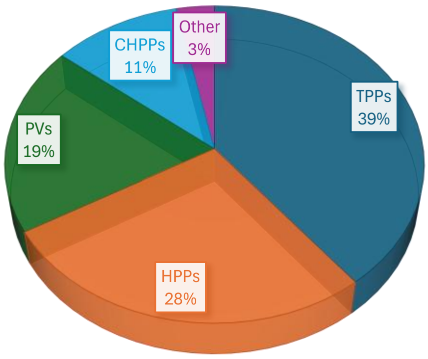
The production of electricity in North Macedonia relies primarily on thermal power plants which use coal, heavy oil and natural gas as a resource, so as on power plants which use RES (water, wind, solar energy, biomass and biogas).

The production of electricity from renewable sources is regulated in the Law on Energy. The 2020 Law on Energy Efficiency incorporated the provisions of 2012 Energy Efficiency Directive establishing specific targets and is aligned with the Clean Energy Package requirements. The present Energy Law aims towards full liberalization and improved functioning of electricity market which would be characterized by higher competitiveness. Inconsistencies related to secondary legislation and regulations would be resolved by revising the process of obtaining a license, redefining the rules for access to electricity grid set in the transmission code and determining conditions for preferential tariffs. Moreover, the roles of energy sector authorities responsible for coordination, monitoring and support of policies implementation, especially the central government, Ministry of Economy and Energy Agency are clearly defined. During 2023, a new draft Law on Energy and a draft Law on Renewable Energy Sources were prepared. For the first time, RES will be singled out by a special law, designed according to Directive 2018/2001, which is part of the EU Clean Energy Package.

2. RES integration in North Macedonia: recent developments

2.1 New RES installed capacity for electricity production

The overall installed capacity for production of electricity in MK in 2023 is 2632,6 MW out of which 39,28% refer to thermal power plants (TPPs), 27,34% are large and small hydropower plants (HPPs), 19,22% belong to photovoltaic power plants (PVs), 10,92% are represented by combined heat and power plants (CHPPs) and other power plants remain with 3,24% share. Current installed capacity in MW is shown in Figure 2.



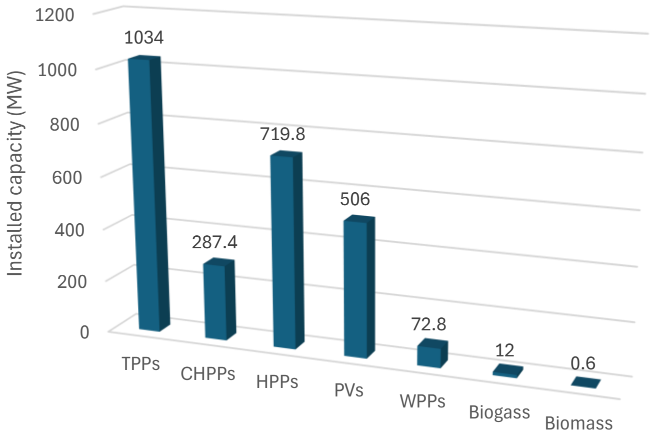


Figure 2. Installed capacity in 2023

In 2023, there are 531 new RES power plants (PPs) constructed with installed capacity of 367,3 MW, which is 40% increase compared to 2022. Out of them, 527 with installed capacity of 362 MW are photovoltaic power plants, 3 are biogas plants (3 MW) and one SHPP (1 MW).

At the end of 2023, RES have 50% share in the installed capacity for electricity production and the current state of RES installed power in North Macedonia is shown in Table 1.

Table 1. Installed capacity for electricity production from RES in 2023.

Type of PP	Number of PPs	Installed capacity (MW)
Large HPPs	10	587
Small HPPs (<10 MW)	124	133
PVs	1003	506
WPPs	2	73
Biogas	7	12
Biomass	1	1
Total	1147	1311

2.2 Electricity generation from RES

The overall electricity generation in North Macedonia in 2023 is 6553 GWh, which is 16,31% and 24% higher than in 2022 and 2021, respectively. Reasons for increased electricity production are:

- the higher electricity generation from PPs which use renewable energy sources
- the higher electricity generation from CHPP TE-TO AD Skopje
- putting into operation the thermal power plant TPP Negotino.

Highest share in electricity production in 2023 have the TPPs with 46,27%, then hydropower plants with 25,15%, CHPPs with 20,57% and the rest are with total of 8,01%, which is shown in Figure 3.

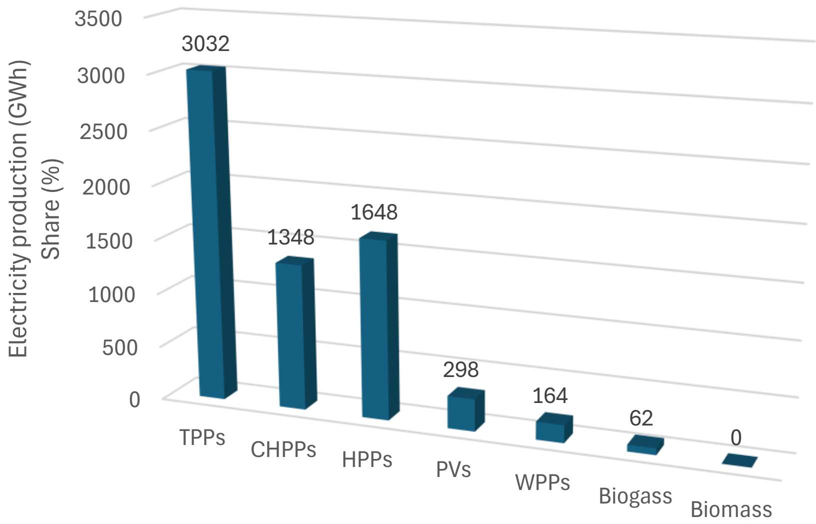


Figure 3. Electricity generated in 2023 by source

Electricity production from RES in 2023 is 2173 GWh with a total of 1147 PPs with installed power of 1311 MW, recording a 33% growth (equivalent to new 541 GWh) compared to 2022. Currently, RES participate with 33% in the overall generation of electricity in MK. Table 2 gives the current state of electricity generation from RES.

Table 2. Electricity produced from RES in 2023.

Type of PP	Number of PPs	Electricity produced (GWh)
Large HPPs	10	1277
Small HPPs (<10 MW)	124	371
PVs	1003	298
WPPs	2	165
Biogas	7	62
Biomass	1	0
Total	1147	2173

Most noticeable increase in electricity production is observed from PVs which generated 298 GWh in 2023, that is 287% rise compared to 2022. Figure 4 gives the change in electricity generation from PVs in the period from 2013 till 2023.

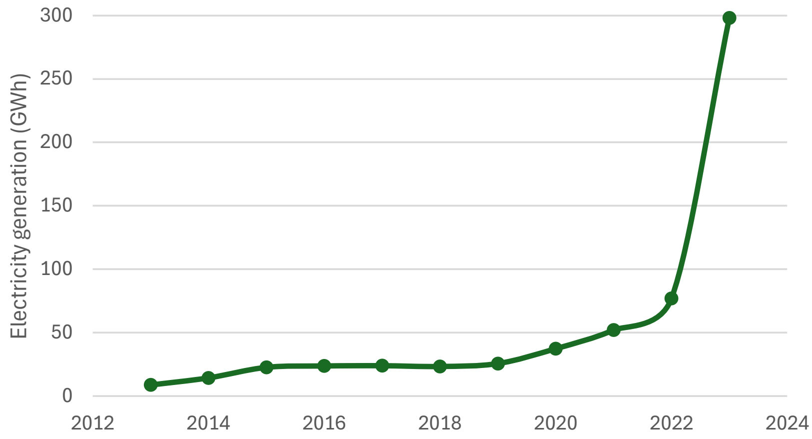


Figure 4. Electricity generation from PVs from 2013 till 2023 in North Macedonia

Compared to 2013, electricity production from PVs is increased for 3325%. The rapid PVs expansion creates a pressure for effective management of the electric system flexibility. This requires setting up a balancing mechanism in the short term with improved operation, monitoring and decreased imbalance costs along with usage of existing plants and construction of new facilities, for instance, storage HPPs, pumped-storage HPPs and gas fired PPs.

2.3 Electricity consumption

The investments in RES affected the electricity consumption in a way that there is an increase observed in providing electricity from own sources and a decrease in taking electricity from the electrical distribution system. The electricity consumption in 2023 is 6738 GWh, which is 5,18% (368 GWh) lower than 2022. Throughout the last couple of years, electricity import was 20-30% of the total electricity consumption, but in 2023 only 2,75 % are imported, while the rest is from domestic production. The reduced import is due to the increase in electric power generation and the lower electricity consumption. The electricity consumption, domestic production and net import from 2017 till 2023 is shown in Figure 5 [4].

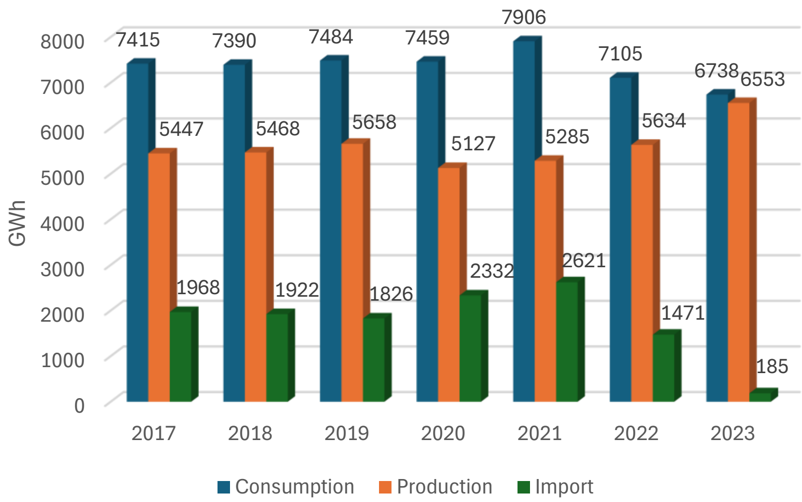


Figure 5. Electricity consumption, domestic production and net import in North Macedonia in 2017-2023

2.4 Measures to support RES

Support mechanisms, such as preferential tariffs and premiums, are available to facilitate domestic investments for efficient use of remained RES potential. The preferential tariff was introduced in 2007, while the premium in 2018. The selection of preferential producers is through a tender process, which includes an auction conducted by the Ministry of Economy.

The premium is an additional amount paid on top of the price that a preferential producer earns from selling electricity on the market.

The first power plants using preferential (feed-in) tariff started with operation in 2010. Currently, preferential tariffs are available only for SHPPs. The feed-in tariff represents a regulated price set for the purchase of electricity generated by preferential producers which is guaranteed for every kilowatt-hour (kWh) of generated electricity. The duration of the concession for water use in electricity production in the case of SHPPs is 20 years. A significant advantage is that the electricity market operator assumes the balancing responsibility for the preferential producer.

At this moment, 174 power plants on RES use preferential tariff which is 11% of the installed power in Macedonia from RES (5% of total installed capacity) and 23% share in the electricity production from RES (6% from total electricity production). 42 power plants on RES use the premium. According to the NECP, North Macedonia will continue to support renewables with feed-in tariffs and auctions.

3. Adding hydropower flexibility to the power system

North Macedonia aims to increase its future energy system flexibility to integrate present and new intermittent RES which add difficulties in maintaining grid stability.

3.1. Current state of hydropower in North Macedonia

The country is characterised by mountainous area, deep basins and valleys. Bisected by the Vardar River, MK is hydrologically divided into the Vardar, Crn Drim, Strumica and South Morava River Basins [5,6]. Hydropower has been a significant contributor to electricity generation in MK, thanks to its extensive river network and mountainous terrain. The primary function of the HPPs in MK is to handle variations in electricity consumption on daily level, which achieves greater flexibility and availability of the electricity system. On average, hydropower accounts for 20-30% of the total electricity production in North Macedonia, varying based on annual hydrological conditions (Figure 6).

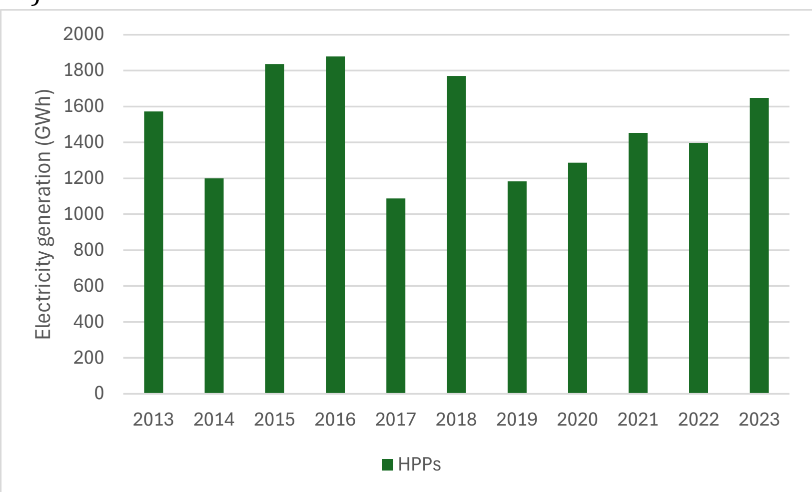


Figure 6. Electricity generation from HPPs in 2013-2023

Electricity production from large and small HPPs in the period from 2013-2023 varies as shown in Figure 6. Minimal production of 1088 GWh is obtained in 2017, while the highest production of 1837 GWh is observed in 2015. In 2023, electricity generated from hydropower is 1648 GWh which is 18% compared to 2022 and 51,5% compared to 2017.

There are 10 (ten) large hydropower plants in North Macedonia, out of which two 2 run-of-river HPPs – Raven and Vrben, and 8 storage HPPs – Vrutok, Shpilje, Globochica, Tikvesh, Kozjak, Sveta Petka, Matka and Kalimanci. Their installed power is given in Table 3.

Table 3. Installed capacity of large HPPs

HPP	Installed capacity (MW)
Vrutok	165,6
Shpilje	84
Globochica	42,56
Kozjak	82
Tikvesh	113
Sv. Petka	36,4
Raven	21
Vrben	12,8
Matka	12
Kalimanci	17,25
Total	586,61

There are 124 SHPPs with installed capacity of 133 MW. 90 of them use preferential tariff.

Today, with the existing hydropower sources in North Macedonia, only 26,6 % of the technically feasible potential is used. The majority of large-scale hydropower potential in North Macedonia is concentrated along the Vardar River, with a smaller degree of potential found on the Black Drim River.

The increased adoption of RES, especially solar power, has been central to the energy transition in MK. However, ensuring stability and consistency in supplying electricity, so as balancing demand and supply becomes difficult. The intermittent nature of RES imposes the need for higher flexibility of the power system. Several solutions which significantly differ according to the type and duration of flexibility offered already exist, such as gas fired power plants, HPPs, demand side management, batteries and sector coupling [7].

The main source of flexibility in MK are the storage HPPs which use dam to store water in a reservoir. The stored water can be released from the reservoir through a turbine to generate electricity, after which it flows away. As a result of water storing, reliance on variable hydrological inflow is reduced. Duration of water storage depends on reservoir volume, however, storage HPPs are usually designed for seasonal storage, to supply water during dry seasons. Another benefit is provision of ancillary services such as flood control and irrigation support [8].

Storage HPPs provide continuous and stable electricity supply thanks to automated control and regulation systems that adjust water flow, manage turbine start-stop sequence and ensure optimum running control of power (real and reactive), voltage and frequency. Storage HPPSs can go from a standstill to full power output in a matter of minutes or even seconds. Consequently, they can provide baseload power, as well as peak load. Due to the rapid response time, electricity grid is balanced especially when used in conjunction with intermittent RES.

3.2. Possibilities for improving hydropower flexibility

The Energy Development Strategy recommends new hydropower capacity to be added until 2040 in all scenarios (Figure 7), through extension of existing HPPPs and construction of new HPPs among which storage HPPs, pumped storage HPPs for peak demand management, so as SHPPs.

Plant	Tech-nology	Capacity (Net, MW)	% on tot.	Entrance (Year)
New Wind promoted	Wind	113	5%	2018-2023
New Wind non-prom.	Wind	350	15%	2031-2040
New PV promoted	Solar	457	20%	2020-2040
New PV non-prom.	Solar	400	17%	2028-2036
New Biogas	Biogas	23	1%	2020-2040
Cebren	Hydro	123 – 458	20%	2029-2037
Gradec	Hydro	75	3%	2030
Veles	Hydro	96	4%	2030
Globocica II	Hydro	20	1%	2037
Kanal Vardar – Kozjak	Hydro	126	5%	2030
New Small Hydro	Hydro	223	10%	2019-2040
Total new capacity (GW)		2.3	100%	2018-2040

Figure 7. Planned key generation capacity investments – reference scenario [3]

North Macedonia has invested in the development of its hydropower infrastructure, including refurbishing older plants, optimizing operational efficiency, constructing SHPPs and exploring opportunities for expansion of existing HPPs or for establishing new hydropower projects.

3.2.1. Expanding existing capacity of large HPPs

Upgrading the installed power of existing large hydropower plants in North Macedonia is already a subject of research. There are a couple of possibilities being considered.

Tunnel Vardar-Kozjak: Hydropower systems Mavrovo and Treska have 50% installed capacity share in the total electricity production from hydropower in North Macedonia. Their hydrological connection would contribute the same water flow that is already used in HPP Raven (Vardar River) to be transferred and utilized in HPP Kozjak (Treska River) in order to gain additional production. Except for the idea to construct the tunnel for transferring the waters, there are several potential technical solutions which include constructing additional hydropower plant (conventional or pumped-storage) on the Raven-Kozjak section. According to the Strategy, the new investment tunnel Vardar-Kozjak would add 126 MW capacity for electricity generation.

The highest investment facilities (Globochica 2 and Shpilje 2) are additions to installed capacities of existing HPPs and they would act as peak power plants. With these facilities, the overflows would be used for additional production and additional power would be obtained.

HPP Globochica 2 - to build a HPP using overflow waters in order to improve balancing RES in the energy system. With a 70m head, there is a possibility to gain 18 MW installed capacity for 30 m^3/s water discharge or 36 MW for 60 m^3/s water discharge.

HPP Shpilje 2 - upgrade of existing system with an additional turbine with same installed capacity (28 MW, 36 m^3/s) as the existing ones in the same building.

3.2.2. Revitalization of large HPPs

A loan agreement was signed for the implementation of the third phase of the "Rehabilitation of Six Large Hydro Power Plants" which is expected to be entirely realized until 2026. The activities within the project include replacement of outdated and obsolete equipment with an aim to achieve increased reliability and stability of the system, as well as environmental protection. The main benefits would be increased annual production and extended lifetime of hydromechanical equipment. It is predicted that the HPPs which are part of HPS Mavrovo, HPS Crn Drim and HPS Tikvesh will together gain additional capacity of 13,5 MW and annually produce additional 47,5 GWh.

3.2.3. Construction of pumped-storage hydropower

North Macedonia is evaluating the potential for pumped hydro storage, where water is pumped to a higher elevation during periods of low electricity demand (or when excess renewable energy is available) and released to generate electricity during peak demand. This method can help balance the grid and provide a reliable backup for wind and solar power. The following projects are planned:

Pumped-storage HPP Tashmarunishte: it would use the lower reservoir of HPP Globochica. The available head is 310 m. PHPP Tashmaruniste will be significant as an energy storage facility in the electrical energy system with is characterized by high installation of photovoltaics and wind power plants. This facility has priority in relation to the other new facilities HPP Globocica 2 and HPP Shpilje 2.

Pumped-storage HPP Chebren: the planned capacity of the hydroelectric power plant is 333 MW. It would be constructed on the river Crna Reka (Black River) in the southwestern part of MK.

3.2.4. Construction of new SHPPs

A study conducted in 1982 on the potential for small hydropower in North Macedonia indicates the feasibility of building 406 SHP plants with a combined installed capacity of 258 MW and an estimated annual electricity generation of 1094 GWh. Their individual capacities would be between 50 kW and 5 MW. The potential projects include the Vardar Valley SHPPs and other SHP projects already began in 2019 [9].

Vardar Valley: Small HPPs on the Vardar River are prioritized due to their technical feasibility and lower investments compared to the rest. The HPP Negotino is a facility for which there are already previous technical and construction conditions for the water intake of TPP Negotino. This facility has the lowest investment. It would be the first of the small HPPs in the Vardar Valley, which would encourage to continue with the other five small HPPs on the stretch from Veles to Gradsko.

Furthermore, as small HPPs, there are also the potential facilities at the inlet of the Shara Channel, where 13 locations have been noted. For these locations of small HPPs there are prerequisites regarding construction. An additional activity that should be done is the adjustment of the projects according to the administrative requirements of the construction of the SHPPs in the part of national parks Shara and Mavrovo considering environmental aspects.

Furthermore, existing water supply systems could be leveraged for developing small hydropower if economic and technical requirements are fulfilled. The growth of SHP in MK is promoted by the availability of bank loans for project financing and feed-in tariffs.

3.2.5. Floating PV systems on hydro reservoirs

Optimized complementarity between different intermittent energy sources can be a key strategy to achieve both optimal energy production and time stability [10].

Floating photovoltaic power generation system is a relatively novel idea, showing significant advantages over the onshore PVs. Competitive benefits include enhancing energy efficiency, conserving land resources and mitigating ecological impact.

A dispatchable power plant system can be created by integrating a floating PV with a hydroelectric facility adding significant flexibility to the grid by reducing power fluctuation. On a daily level, PV generates electricity during the day, while hydropower can be used to meet demand during the night or cloudy periods. This enables better load balancing and can help prevent grid overloads during times of high solar generation. On a yearly basis, PV panels yield maximum energy during the hot season when hydropower generation decreases as a result of the seasonal water cycle, allowing a significant reduction in the annual electricity production fluctuations. The use of existing infrastructure is maximized while ensuring stable and continuous energy supply [11–13].

North Macedonia is exploring the potential for floating photovoltaic (FPV) systems on existing hydropower reservoirs and intends to invest in their construction. A potential for constructing floating photovoltaic power plants is noted at four locations: Kozjak Lake, Mavrovo Lake, Tikvesh Lake and Debar Lake. A suggested strategy by [14] involves installing a FPV power plant equivalent in capacity to the existing HPP and employing an active control system to meet grid demands without requiring batteries or other storage devices. HPP electricity production is lower during the day when the FPV operates, and increased at night, in cloudy conditions, or during peak demand.

Identifying Lake Debar (HPP Shpilje) as a potential site for FPV installation, the conducted analysis shows possible additional production of electricity estimated to 176,1 GWh per year. The cost of FPV is lower than in case of an onshore PV plant especially due to the existing infrastructure and grid connection.

Further studies are necessary to obtain the optimal sizing and operational strategies for combined floating PV and HPP to maximize grid benefits. Moreover, thorough research on the environmental impacts of floating PV systems on aquatic ecosystems is needed to ensure sustainable deployment.

Specific hybrid wind-hydro projects in North Macedonia are not yet formalized.

3.3. Challenges

As the interconnection between water, energy and land grows crucial in terms of sustainable development, it's essential to focus on finding solutions to minimize negative environmental effects and fulfilling socio-economic requirements at the same time. Several challenges can limit or complicate this flexibility, especially as energy systems evolve. Addressing these challenges requires a combination of technological upgrades, careful management of water resources, consideration of environmental impacts, and alignment of economic incentives.

3.3.1. Environmental protection

Rapid changes in water discharge (e.g., ramping up or down quickly) can disrupt aquatic ecosystems, harm fish populations and lead to bank erosion. Consequently, many hydropower plants are subject to strict environmental regulations, designed to protect aquatic ecosystems, maintain water quality and ensure adequate water flow for downstream users.

Therefore, hydropower projects in protected areas in North Macedonia such as Boskov Most and Lukovo Pole are not considered anymore. Development of new SHPPs should be carefully evaluated to prevent environmental harm on the account of electricity production. Additionally, enhancing administrative capacities is needed to improve environmental impact assessments.

Some mitigation strategies that can be taking into consideration to address environmental concerns connected with construction of new large and small hydropower plants in North Macedonia are upgrading to fish-friendly turbines, maintaining minimum flow levels downstream of HPPs, managing buildup in reservoirs, habitat restoration.

3.3.2. Future HPP operation and degradation due to faster start up and more start-stops

Storage and pumped-storage HPPs operate with a higher number of start and stop cycles. However, these fast changes of operating conditions cause significant mechanical stress on components, which induces additional damages and reduces the lifetime of the hydro power plant equipment [15]. The hydraulic turbine degradation affects operation and maintenance, influencing the overall costs of the installation [16]. For instance, the generator of a HPP has a long service life, however an unexpected winding failure can lead to a shutdown of up to one year [17]. Therefore, a more detailed knowledge is needed to mitigate the negative impact on equipment lifespan to make reasonable economic decisions regarding operation and maintenance.

A possible solution is an upgrade to variable-speed technology, allowing change of runner speed according to the hydraulic conditions, thus increasing the efficiency of hydropower generation, extending equipment life and reducing long-term maintenance requirements [18,19]. Wear and tear are minimized because of the smoother start-stop cycles, while fatigue is lower due to optimal turbine operation which reduces the cyclical stress on components. Longer service time of turbine is benefited from reducing noise, vibration and cavitation problems [20,21]. However, the cost of implementing variable-speed technology, including the installation of frequency converters and potential retrofitting of existing systems, must be justified by the predicted gains in efficiency, equipment longevity and operational flexibility.

3.3.3. Economic considerations

Operating a hydropower plant in a highly flexible manner can increase operational costs due to more frequent maintenance and the need for sophisticated control systems that can balance multiple variables (e.g., water levels, grid demand, environmental regulations) in real time.

Many hydropower plants are decades old and were not designed with modern flexibility requirements in mind. Retrofitting these plants to enhance flexibility can be expensive and technically challenging [22].

4. Conclusions

North Macedonia seeks to promote a socially responsible energy transition, in line with the European Green Deal goals. The NECP set energy efficiency targets with realistic dynamics which are consistent with the five key dimensions of the Clean Energy Package. The plan emphasizes the ambitions to encourage the use of renewable energy for electricity generation and to introduce measures for energy efficiency. Consequently, dependence on energy imports is expected to be reduced.

Acceleration of low-carbon technologies development to prompt clean energy transition is enabled by officially adopted documents including the Law on Energy, National strategy for energy development, Strategy for the use of renewable energy sources, Encouraging the use of RES, Regulation on RES, Preferential tariffs.

With the current energy situation and environment, stricter environmental criteria and intensive construction of RES technologies (photovoltaics and wind power plants), the need for balancing and flexibility of the production system has increased. In that direction, the construction of new hydropower facilities and capacities, especially reversible hydropower plants, would mean greater flexibility in the technical operational management of electrical energy system, as well as improve the financial portfolio in the new conditions of the regional electricity market. Therefore, while aiming to ensure strong integration into European markets, North Macedonia focuses on providing necessary flexibility for higher incorporation of RES through new hydropower projects. North Macedonia has invested in the revitalization of older plants, while optimizing operational efficiency, so as in the construction of SHPPs and is exploring opportunities for expansion of existing HPPs or for establishing new large hydropower projects to add flexibility in the power system. In addition, by leveraging innovative technologies such as floating PVs on existing hydro reservoirs or variable-speed technology integration, North Macedonia can significantly strengthen the role of hydropower in its energy transition, ensuring a more sustainable, reliable, and flexible energy system.

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