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Assessment of hydropower potential of some existing obstacles on rivers. Case study: Arges-Vedea basin, Romania

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Abstract. Hydropower represents one of the oldest and most developed technologies for electricity generation. Combined with more and more harsh environmental & societal restrictions, this led to a lack of available sites for developing new hydropower plants. At the same time, water streams are usually equipped with different hydrotechnical works for preventing flooding or assuring/supplying water to various beneficiaries. This is why in the latest years there is a new trend related to empowering existing hydrotechnical structures. This paper presents an assessment of the theoretical hydropower potential for 7 existing water barriers in Arges-Vedea hydrographic basin, Romania. Based on historical river discharge data and forecasted data for two climate change scenarios, RCP 4.5 and RCP 8.5, the gain in clean energy is presented and compared with the results for the reference period. The results show that while the cost of empowering the considered sites is around 760,000 Euro, a total energy generation of over 600 MWh/year can be obtained.

1 Introduction

Hydropower, with its almost 1,400 GW (1,397) installed capacity globally, is the most widely used renewable energy source, providing 4400 TWh yearly, over 15% from the total electricity [1]. It also brings supplementary benefits to society: domestic and industrial water supply, irrigation, flood control, fishing resources, local development, recreational. In addition, on our way to Net zero by 50, hydropower can help not only by delivering clean energy but also by backing up wind and solar photovoltaic electricity generation, assuring the stability and flexibility of the power grid.

According to International Hydropower Association and International Renewable Energy Agency, to achieve the global net zero energy system with the lowest costs requires the development of over 2500 GW, including pumping storage hydropower (almost 45 GW/year) [1]. This is not an easy task, but opportunities exist, and the energy sector must consider the development and deployment of new hydropower plants, as long as we can

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still find economically viable sites. It also worth mentioning that many of the current hydropower plants and hydropower developments are old, requiring important investments, which can be used not only for assuring the safety operation, but also for modernization, refurbishment, upgrading, retrofitting.

As nowadays the environmental constraints and social acceptance are more and more strict and hard to reach, Hydropower Sustainability Standards has been developed and the new hydropower projects are encouraged to use it [1].

This is mainly due to the fact that dams generate important negative environmental effects, increasing greenhouse gas emissions, disrupting the river connectivity, obstructing the nutrients and sediment flow, changing the groundwater levels, limiting the migratory pathways and reproductive places for fishes, encouraging the loss of biodiversity and proliferation of invasive species, altering the hydromorfological characteristics of the river [2]. These downsizes are valid to any kind of dam or river obstacle (e.g. hydrotechnical work), no matter its dimension, characteristics, geographical position, or purpose. When looking at the numbers related to the worlds' dam, one can be surprized since, just 21% of single purpose use reservoirs and 16% of multipurpose use reservoirs from a total of about 59,000 large dams and reservoirs (over 15 m height and 3 Mm^3, respectively) have among water uses energy generation. [1]. Also, many obstacles on rivers are quite old, requiring more maintenance works and funds, being prone to collapse while not providing any benefit to society. In Europe only, there are over 1.2 million obstacles which blocks the rivers (68% being under 2 m height), from which 50,000 are obsolete [3, 4].

Thus, in recent years, there are more and more voices advocating for dams' removal, mostly focusing on obsolete river barriers, in order to permit the restoration of river habitats. In 2016, AMBER project (Adaptive Management of Barriers in European Rivers) started, aiming to restore the river connectivity in an efficient way, by developing instruments to be used by hydropower industry and water resources managers, allowing the maximization of benefits with minimal environmental impacts, assessing the different restauration manners, increasing the energy security, protecting jobs, boosting rural economies. At the same time, the project helps reducing the river fragmentation and promotes habitat connectivity. Among the results of AMBER, there is the first atlas of European river barriers, Figure 1 [5].

Dam Removal Europe (DRE) formed by the World Wildlife Fund, The Rivers Trust, The Nature Conservancy, the European Rivers Network, Rewilding Europe, Wetlands International Europe, and the World Fish Migration Foundation, but including also numerous individual members (over 6000), is a movement to restore free-flowing rivers for the benefits of nature and society, and aims to implement the removal of river barriers as a restauration technique. DRE by the actions undertaken provides counselling for interested parties in obstacles removal, rise the awareness of the importance of river connectivity, helps organizations to find funds for their removal projects, find existing and removed barriers and provide yearly reports on the status on dam removal in Europe. The number of barriers removed is increasing year after year, Figure 2 presenting the interactive map of dam removal in Europe [6].

It must be emphasized that both AMBER project and DRE acknowledge the benefits brought by hydropower and focuses on obsolete barriers, which not only that does not bring any gain to actual society or to the rivers and nature (morphology and/or ecosystems), but can represent threats to human lives and, in case of the very old ones, structural failure can even lead to high economic losses [6].

Returning to hydropower development, at this moment, there are not many sites proper (economically and environmentally) for setting up large hydropower plants in Europe. This is way a shift has appeared, and numerous studies and research projects promotes the empowering of existing water infrastructures, e.g. the development of micro, mini and small hydropower plants [7, 8]. Such an approach leads not only to a minimum environmental impact, but also to lower costs.

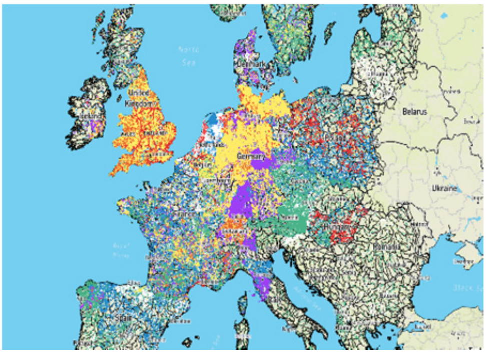


Fig. 1. The AMBER Barrier Atlas.

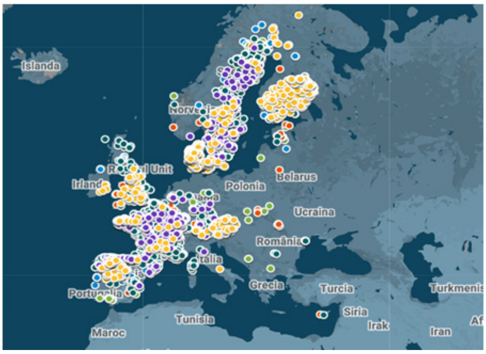


Fig. 2. Dam removal Europe map.

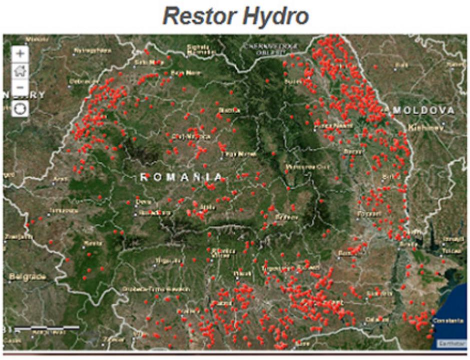
In this context, this paper presents the assessment of hydropower potential of several existing barriers on streams and rivers from Arges-Vedea hydrographic basin. Also, future predictions in terms of available river discharge and energy generation are presented.

2 Material and method

As previously mentioned, numerous research projects and studies investigated the untapped potential of existing water infrastructures, and several figures have been reported: an economic potential of hydrokinetic turbines in rivers of 1.2 TWh/year, a hydropower potential of water and wastewater networks of 3.1 TWh/year, 6.8•TWh/year generated at historic hydro sites (watermills, weirs and other) in Europe [7, 8].

RestorHydro project identified over 50,000 potential small hydropower sites in Europe, illustrating thus the considerable small hydropower potential of and its benefits to a decarbonised and decentralized energy strategy [8]. Among these sites, over 4000 are located in Romania, presented in Figure 3 [8].

This study asses the theoretical hydropower potential of 7 of the sites identified by the Restor Hydro project, Figure 4 [Google earth].



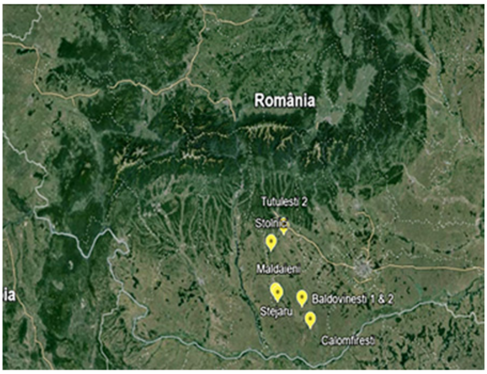


Fig. 3. Small hydropower sites in Romania.

Fig. 4. The 7 considered sites.

All 7 sites are situated in the south of Romania, in the Arges-Vedea hydrographic basin, which is one of the best equipped and developed in terms of hydropower generation. The red dots in Figure 3 represents the existing barriers on the Romanian rivers (4471 sites), and the map being interactive, when clicking on a specific dot, the name of the obstacle, the river name and its height appear. Table 1 contains the name of the site, the river and estimated height of the obstacles from the considered sites.

Table 1. Characteristics of the considered sites.

Name of the site	River/stream	Height [m]
Stolnici	Ursoaia	5
Calomfiresti 1	Nanov	3
Tutulesti 2	Gliganu	6
Baldovinesti 1	Paraul Cainelui	4
Baldovinesti 2	Paraul Cainelui	4
Stejaru	Bratcov	7
Maldaieni	Bratcov	5

Assessment of the theoretical hydropower potential of a river or a stream sector, 1-2, can be done using the following equations:

$$P_{b_{1-2}} = 9.81 \cdot Q_{1-2} \cdot H_{b_{1-2}} [\text{kW}], \quad (1)$$

in terms of power, or, in terms of energy:

$$E_{b_{1-2}} = 0.002725 \cdot V \cdot H_{b_{1-2}} [\text{kWh}], \quad (2)$$

where $P_{b_{1-2}}$– hydraulic power [kW], Q_{1-2} – mean flow [m^3/s], $H_{b_{1-2}}$ – gross head [m], $E_{b_{1-2}}$– mean annual hydraulic energy [kWh], V – available water volume, considered for the mean hydrological year [m^3].

Because of the overall efficiency of the small hydropower plant, of around 70%, and the fact that it will produce electricity only around 70% of the year, the energy generation of such a SHPP can be estimated with the help of relation (3):

$$E_{n_{1-2}} = 0.5 \cdot 0.002725 \cdot V \cdot H_{b_{1-2}} [\text{kWh}] \quad (3)$$

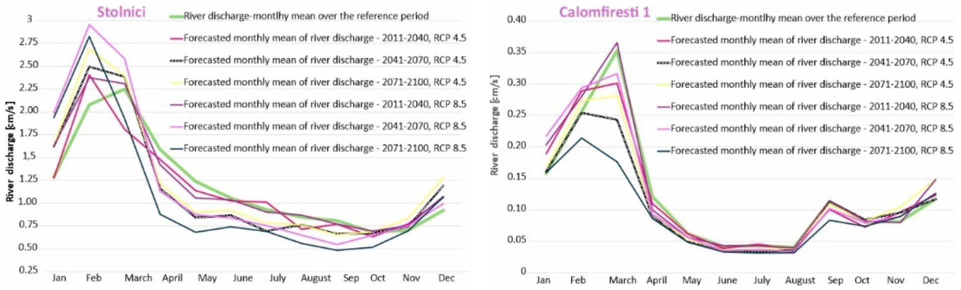
where $E_{n_{1-2}}$ is the net energy generated and the rest of the notation are the same as in the previous equation.

To be able to compute the power and energy values, river discharge data have been obtained from SMHI HypeWeb [9], an online platform which provides world-wide historical hydrological data, hydrological predictions and climate change data [10, 11]. Thus, based on the site location (longitude and latitude), the historical data of the river discharge have been downloaded and used to compute the multiannual monthly mean discharges over the reference period. For investigating the future trends in river discharge and energy production, the change coefficient for two climate change scenarios, RCP 4.5 and RCP 8.5, have been also downloaded, from SMHI Climate Information Portal [12]. Data for climate change scenarios are split into three intervals: I between 2011-2040, II from 2041 to 2070 and III from 2071 up to 2100.

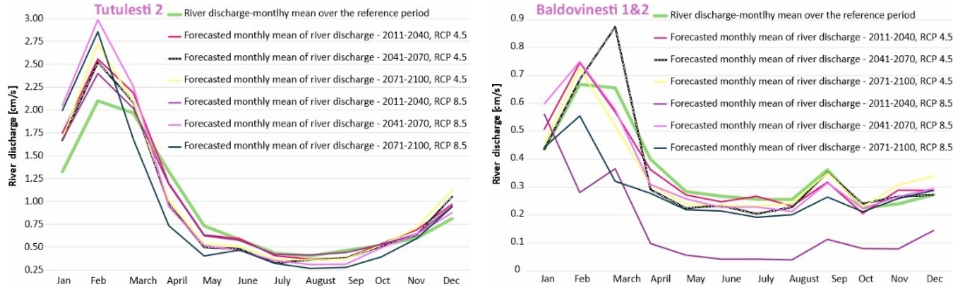
RCP 4.5 is, according to IPCC, the intermediate scenario, in which greenhouse gas emissions increase until 2040 and then start to reduce, while RCP 8.5 is the worst scenario, in which emissions continue to increase in the next decades.

3 Results and discussion

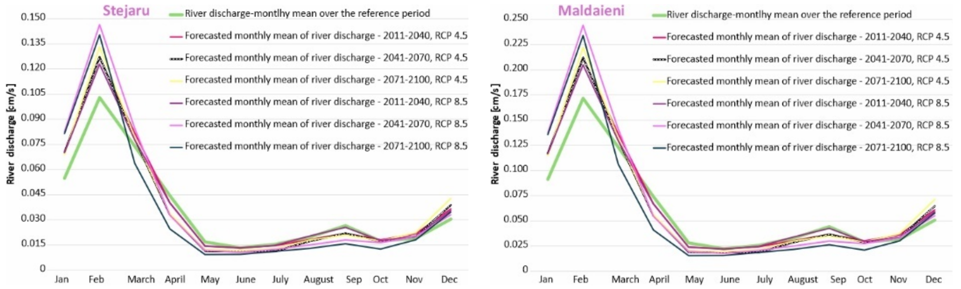
Values of multiannual monthly mean discharges for the considered sites are presented in Figure 5,a to Figure 5,f.



a) Stolnici b) Calomfiresti 1



c) Tutulesti 2 d) Baldovinesti 1 and 2



e) Stejaru f) Maldaieni

Fig. 5. Multiannual monthly mean discharges for the considered sites, for the reference period and forecasted (Authors own conception, calculation & representation using MS Excel).

It can be noticed that for Stolnici site, just January, February, November and December have higher values, the rest of the year the discharge being much lower. The most dramatic change is reported for the RCP 8.5 scenario, between 2071 and 2100, when, according to the forecast, the discharge drops with over 30% of the reference values (as example, in April drops from 1.59 m^3/s to 0.88 m^3/s, in May from 1.24 m^3/s to 0.68 m^3/s). For four of the sites: Calomfiresti, Tutulesti 2, Stejaru and Maldaieni, for both climatic change scenarios, the forecasted values are higher in the first three months of the year and for the last two. Between March and November, the river discharge is either comparable to the reference one, or slightly lower. Baldovinesti 1 and 2 have a similar trend, excepting the RCP 8.5 scenarios, 2011-2040 and 2071-2100, when river discharge values are much lower than the reference ones. Thus, in February drops from 0.68 m^3/s to 0.28 m^3/s (2011-2040), in March from 0.65 m^3/s to 0.36 m^3/s (2011-2040) or to 0.32 m^3/s (2071-2100), in April from 0.4 m^3/s to 0.1 m^3/s (2011-2040) or to 0.28 m^3/s (2071-2100), and so on.

When referring to the energy production, based on historical river discharge data, by empowering the considered hydrotechnical structures/barriers, an annual energy generation of nearly 660 MWh can be obtained (Figure 6), with the highest production in Stolnici site of 256 MWh, followed by Tutulesti 2 with 240 MWh and Baldovinesti 1 & 2 with 62 MWh each. The remaining 3 sites can produce between 10 MWh (Stejaru) and 15 MWh (Calomfiresti).

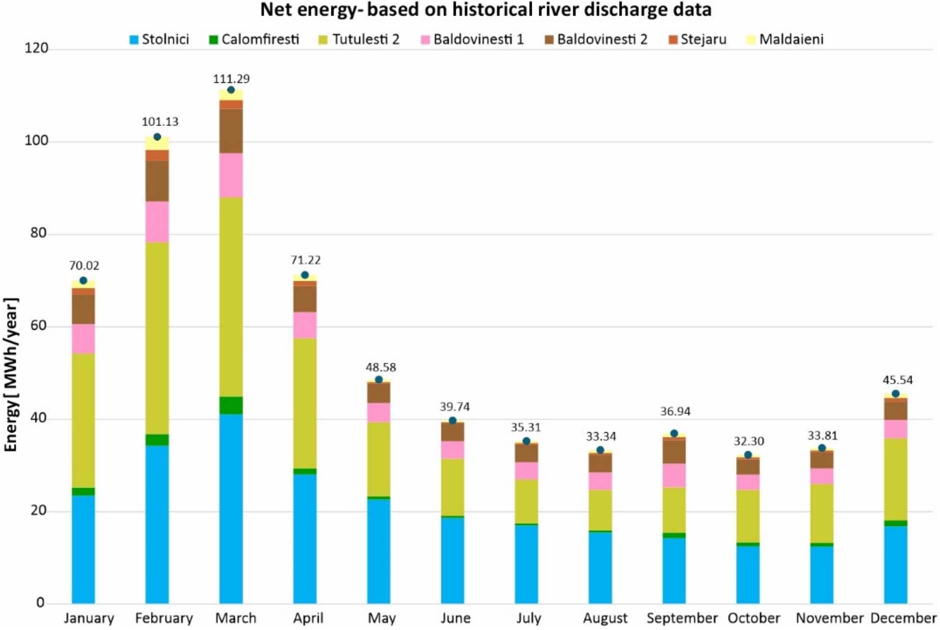


Fig. 6. Yearly energy generation from the considered sites (Authors own conception, calculation & representation with MS Excel).

Considering the development costs reported in the literature – 5000 Euro/kW, the total cost for these sites is only about 757,000 Euro [7].

For each site, in Table 2 are presented the mean flow and the technical potential in terms of power (estimated electrical power to be produced in SHPPs).

Table 2. Available mean flow, technical potential and type of SHPP for the analysed sites.

Name of the site	Mean flow [m^3/s]	Technical potential in terms of power [kW]	Type of SHPP
Stolnici	1.2	58.8	micro
Calomfiresti	0.12	3.6	pico
Tutulesti 2	0.93	55.2	micro
Baldovinesti 1	0.36	14.15	micro
Baldovinesti 2	0.36	14.15	micro
Stejaru	0.036	2.5	pico
Maldaieni	0.06	2.96	pico

3.1 RCP 4.5 scenario hypothesis

In terms of possible energy generation, RCP 4.5 scenario leads to the following values: 696.70 MWh/year from 2011 to 2040, 657.27 MWh/year from 2041 to 2070 and 677.61 MWh/year from 2071 to 2100.

The maximum production results, as expected, given the forecasted flow, are in the first three month of the year:

- January: 90 MWh (2011-2040); 84.5 MWh (2041-2070); 85.8 MWh (2071-2100),
- February 121.2 MWh (2011-2040); 118 MWh (2041-2070); 126.7 MWh (2071-2100),
- March: 118.1MWh (2011-2040); 121.7MWh (2041-2070); 112.2 MWh (2071-2100).

The values for the net energy generation obtained for RCP 4.5 scenario are presented in Figure 7.

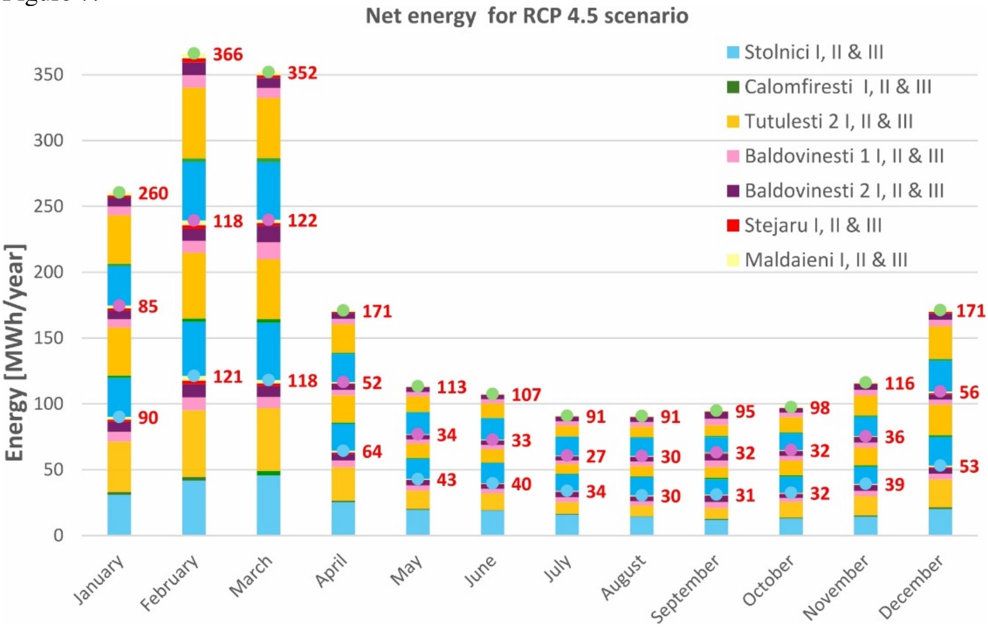


Fig. 7. Net energy generation per year for RCP 4.5 scenario. (Authors own conception, calculation & representation with MS Excel).

3.2 RCP 8.5 scenario hypothesis

RCP 8.5 scenario leads to lower values of possible energy generated: 615 MWh/year from 2011 to 2040, 673.34 MWh/year from 2041 to 2070 and 596.55 MWh/year from 2071 to 2100 (Figure 8).

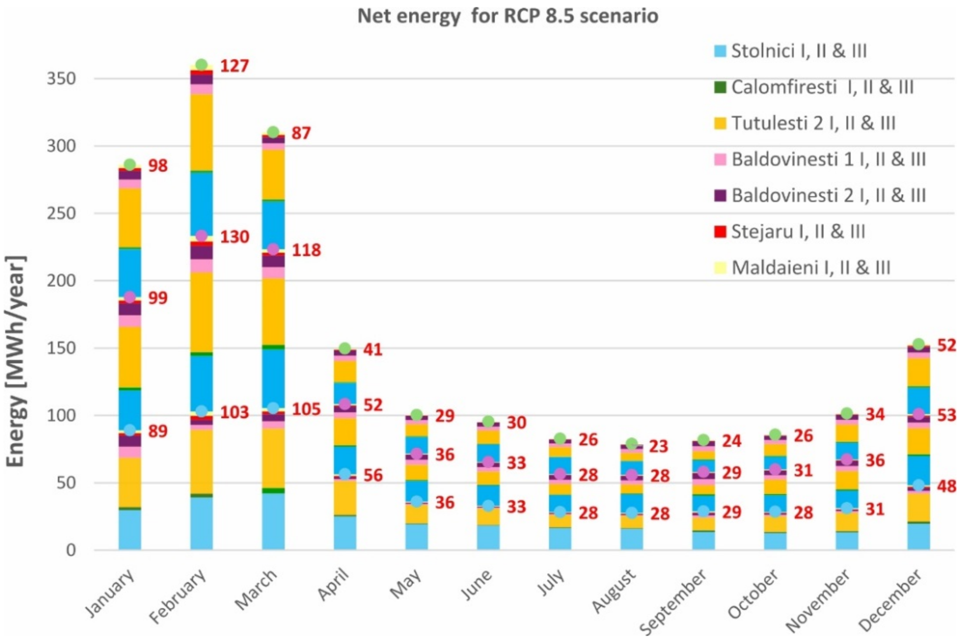


Fig. 8. Net energy generation per year for RCP 8.5 scenario (Authors own conception, calculation & representation with MS Excel).

4 Conclusions

The potential energy gain from empowering 7 existing barriers on the rivers and streams belonging to Arges-Vedea hydrographic basin is discussed in this paper. The seven selected sites are in a very well-developed hydrographic basin in terms of hydropower potential, so numerous advantages, besides the supplementary clean and flexible energy can be mentioned: short distances to transformation points, easy solution for connecting to the national power system/grid, existing infrastructure and well trained personal in the area, etc.

Based on historical river discharge data and forecasted data for two climate change scenarios, RCP 4.5 and RCP 8.5, the gain in clean energy is presented and compared with the results for the reference period. The results show that with a cost of around 760,000 Euro for transforming these river barriers in small- or pico- hydropower plants, 600 MWh/year can be obtained. The limitations of this study are given by the fact that these values are approximate ones, since we consider an overall efficiency, we don't specify a certain type of hydraulic turbine to be used and didn't consider the environmental flow. A more precise study must consider the particularities of each site, which determine the construction requirements, the type of turbine to be used, which also influence the final cost and the production, as well as available flow and the possibilities to connect the new production units to the national power system/grid.

When comparing to the values obtained for RCP 4.5, it can be noticed that for the period between 2011 to 2040, the biggest differences are recorded for June (17.2%), July (16.9%) and November (20%), while between 2041 and 2070 the most important differences are in January (17%), February (10%) and September (9 %). The latest period is the one with the most significant variance: March, April, May, August, September and October differ with over 20% (up to 25% in September), November and December with 16% and January, June and July with 14%. The only month in which the difference is neglectable is February: 0.12%. As it was expected the climate change will influence the available flow in this part of Romania, and even if the differences are not so important, they must be considered in any study and project related to water resources management. This is because in this study were considered only hydrotechnical works on rivers, so there are not any water retention structures and the energy production is based only on daily available flow.

This study shows that is possible to increase the reliable renewable energy provided by hydropower structures with minimum cost and low environmental impacts and can be used by water resources managers or any other stakeholders as a theoretical study to assess the possibilities of developing new hydropower production sites.

Even if Romania has reached the renewable energy target imposed by EU for 2020 and is on good path related to further targets due to large developments in wind and solar facilities, hydropower development must continue, at least on the path described in this paper, by empowering existing infrastructures. Among these infrastructures are, of course, the unused river barriers for which associated costs are minimal, due to the rapid evolution of low-head/low-flow turbines.

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