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Pumped-Storage Solution towards Energy Efficiency and Sustainability: Portugal Contribution and Real Case Studies

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Abstract

This paper aims at presenting different pumped-storage solutions for improving the energy efficiency and economic sustainability of water systems. The assessment of pumped-storage solutions, either using fresh water or sea-water, is seen as a viable option to solve problems of energy production, as well as in the integration of intermittent renewable energies, providing system flexibility due to energy loads' fluctuation, as long as the storage of energy from intermittent sources. Pumped-storage is one of the best and most efficient options in terms of renewable resources as an integrated solution allowing the improvement of the energy system elasticity and the global system efficiency. Two real case studies are presented: a fresh water system installed in a river dams—the Alqueva system, in Portugal—and a sea-water system in an arid region of the Cape Verde Islands in Africa. These cases demonstrate the benefits associated to pumped-storage solutions, depending on the storage volume capacity, operational rules and energy tariffs.

Keywords

Pumped-Storage, Hydropower, Energy Efficiency, Renewable Energy

1. Introduction

Renewable energy sources, such as wind, sun, water and geothermal heat, have several advantages over the use of Fossil fuels (e.g., coal, petroleum and natural gas), namely: i) being unlimited energy sources, while other options can be exhausted; ii) low environmental impact sources, a positive aspect that should be mentioned [1]-[3]. It is well-known, that in comparison to carbon-base, renewable energies have a reduced impact to the environ-

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ment [4]-[7]. They produce clean energy when compared to nuclear or fossil fuels, which tend to cause environmental contamination. Furthermore there are no negative impacts on health, and they do not generate CO_2 emissions. In addition, the installations are easy to disassemble once they are no longer working or useful, especially when comparing with nuclear plants [8]-[12].

The investment in renewable energies has been significantly growing in the last decades. The most popular sources are the sun and the wind (onshore and offshore), and the hydropower, in dams, as well as in the sea (tidal and wave power). As the interest grows, the capital costs of novel solutions has started to decrease, which led a higher competition in the sector. This fact has stimulated innovation and created job opportunities. In 2010 [13], 35,800 MW of wind energy and 3,700 MW of nuclear energy have been installed in the world, which made the leadership of wind over nuclear very evident. In Portugal, there are many renewable sources like the sunlight, wind, tides, waves and water in rivers (see **Figure 1**). The objective is to reach 31% of renewable energy consumption by 2020 [14]-[19]. This objective and the investments in this sector necessarily need to be followed by storage systems, in order to avoid wasting the generated renewable energy. The pumped-storage system is a good option, or can even be considered the best, to solve the problem of intermittency in generation of energy by renewable sources [20]-[25]. Another important aspect for the generation and supply of energy is to guarantee the electricity supply. The daily and weekly demand of energy is very varied, and contains high peaks of demand, where the supply needs to be guaranteed. While the demand during the night is almost non-existing, during the morning and late afternoon it is very high. This fact leads to have major differences in the tariffs of energy during the day, being during peak hours almost three times higher than in night periods. Besides this high daily variation, during the week there are also significant variations in energy demand. Weekends and bank holidays have a lower demand than the working days, from Monday to Friday [26]. Pumped-storage has the goal to balance these variations and differences between demand and supply.

Hopefully, in the future, Portugal will have a huge increase in hydro energy, where an important investment and offer is taking place concerning pumped-storage. Pumped-storage represents a technology for storing electrical energy during periods of low demand. The major tasks within a country's national grid are:
- the ability to equalize power supply and demand;
- the possibility to provide balancing power and helping to control the grid voltage and frequency;
- the skill of responding within seconds to stabilize the electrical grid during periods of rapidly changing demand.

This technology is viable from an economical point of view, since it uses electricity in low demand hours, and storages it, keeping it for hours of high demand.

Pumped-storage is expected to increase together with hydro energy from 2010 to 2020, as presented in **Figure 1**. Additionally, this figure shows the expected growth in using renewable energies and decrease using in fossil fuels during this decade.

2. Pumped-Storage Solutions

2.1. Europe

Due to the growth of the share of renewable energies in the total electricity generation, load fluctuations caused by energy of wind, and photovoltaic have to be compensated by storage, which lead to a boom of construction of

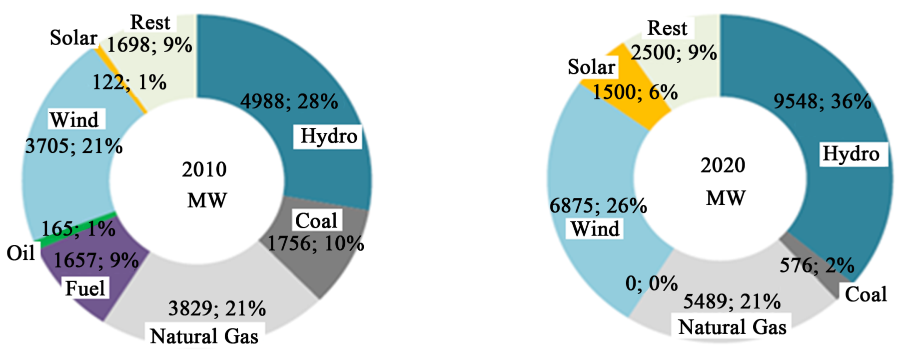

Figure 1. Installed power of national electricity generation (2010 vs 2020) (adapted from [13]).

such facilities. Figure 2 shows wind energy capacities, in some selected countries as well as their expected development until 2020. Countries with proper natural conditions for such systems are the ones that will focus on this option. Examples of these countries are Austria, Switzerland, Spain or Norway (see Table 1), mainly due to their topographic characteristics.

Figure 2 and Table 1 illustrate how the wind capacity is going to increase very much in Europe. Not only onshore wind power generation will be included, but also offshore wind farms. For example, in Germany which is a very big investor in wind energy, offshore projects are supposed to generate 10,000 MW by 2010.

2.2. Portugal Contribution

In Portugal, most electricity used in peak hours is generated in large hydropower plants such as pumped-storage power plants, or simple storage power plants. This share is supposed to increase enormously in the future and the installed capacity of pumped-storage power plants is expected to double in the next years. Table 2 presents some figures in Portugal, highlighting the importance of pumped-storage power plants.

Nowadays, there are several new projects of hydropower plants to constructed or to be expanded in Portugal. Some of these include pumped-storage. Most of them are managed by EDP, Energias de Portugal [26]. The projects of EDP, of which some will be described, represent an investment of almost 3400 million euros in Portugal until 2020.

2.2.1. Baixo Sabor

Baixo Sabor is a hydropower plant under construction and is located in the Saborriver, in the Douro river basin. It has a storage strategic role added to the electricity generation and is equipped with reversible units. The main characteristics of this project can be found in Table 3.

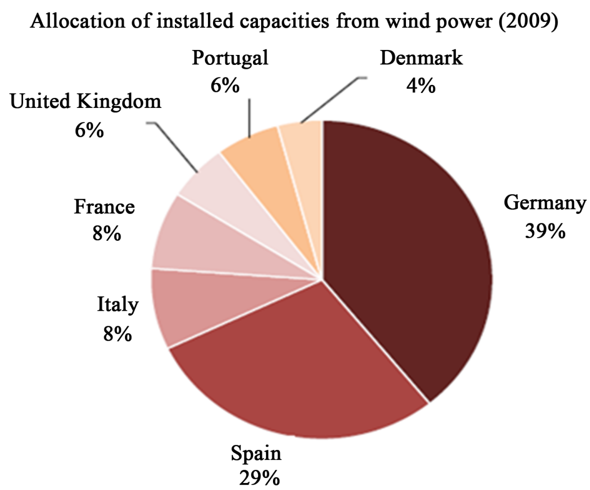

Figure 2. Wind energy plant capacities in selected countries [27].

Table 1. Wind energy in countries in Europe [27].

Country	2010 (MW)	2020 (MW)	In percent
Germany	27,526	45,750	+68%
Spain	20,155	38,000	+89%
Italy	5800	12,680	+119%
France	5542	25,000	+351%
United Kingdom	4040	28,000	+593%
Portugal	4256	6875	+62%
Denmark	2923	3950	+35%
Total	**70,242**	**125,150**	

Table 2. Portugal pumped-storage systems.

Portugal			
Inhabitants	10,707,000	Area [km^2]	92,345
Number of pumped-storage plants (PSP)	4	Capacity [MW]	1089
Number of storage power plants	36	Capacity [MW]	4526
Share of PSP of renewable energies [%]	14.2	Share of PSP of total electricity gen. [%]	4.6

Table 3. Main characteristics of Baixo Sabor hydropower plant.

Main indicators	
Construction works (started)	2008
Commissioning year (estimated)	2014
Normal operating capacity	642 hm^3
Number of units	4 (reversible)
Power	171 MW
Annual average capacity	444 GWh (with pumping)
Reduction in CO_2, equivalent per year	1037 kt
Estimated investment (ref. 2009)	491 M€
National contribution	75% to 80%

2.2.2. Ribeiradio-Ermida

Ribeiradio-Ermida hydropower plant, also under construction, is located in the Vouga River and compromises two dams and two hydro-power plants installed in series: the upstream one is equipped with one unit whereas the downstream one has two units. This project has characteristics presented in **Table 4**, butit does not include reversible units.

Figure 3 shows the hydraulic circuit of Ribeiradio-Ermida hydropower plant. This power plant is relatively small with an installed power of 77 MW. Pumped-storage is not taking place in this case, and there are no reversible units.

2.2.3. Carvão-Ribeira

Carvão-Ribeira project is not yet in construction. It is supposed to be located in the Távora River, and includes an underground powerhouse, in cave, equipped with two reversible units and a hydraulic circuit by tunnel. The main characteristics are shown in **Table 5**.

This hydropower plant includes reversible units that will, therefore, be working with pumped-storage. The particular characteristic of this case is that it will be the first project in Portugal with pure reversibility cycle. The other existing systems that include storage, such as Alqueva, Venda-Nova or Aguieira have are two-fold: pump-storage and river-flow regulation.

The two following systems consist of expansions of two existing hydropower plants, namely Alqueva II and Venda Nova III. These are only two examples of the several others that are being expanded as well (e.g. Salamonde II, Paradela II, Bemposta II or Picote II).

2.2.4. Alqueva II

The particular case of the Alqueva I will be discussed more extensively further on, since it will be one of the included case studies in this paper. This project is located in the right bank of the Guadiana River. The additional powerhouse will be equipped with two reversible units and a hydraulic circuit with independent tunnels. The main characteristic parameters of this project are presented in **Table 6**.

Figure 4 shows the longitudinal profile of the hydraulic circuit. This example presents a lower value of the

Figure 3. Hydraulic circuit.

Table 4. Main characteristics of Ribeiradio-Ermida hydropower plant.

Main indicators	
Construction works (started)	2009
Commissioning year (estimated)	2013
Normal operating capacity	87 hm^3
Number of units	3
Power	77 MW
Annual average capacity	134 GWh
Reduction in CO_2, equivalent per year	70 kt
Estimated investment (ref. 2009)	171 M€
National contribution	75% to 80%

Table 5. Main characteristics of Carvão-Ribeira hydropower plant.

Main indicators	
Construction works (started)	2010
Commissioning year (estimated)	2020
Number of units	2 (reversible)
Power	555 MW
Annual average capacity	860 GWh
Reduction in CO_2, equivalent per year	744 kt
Estimated investment (ref. 2009)	333 M€
National contribution	80% to 85%

Table 6. Main characteristics of Alqueva II hydropower plant.

Main indicators	
Construction works (started)	2008
Commissioning year (estimated)	2012
Number of units	2 (reversible)
Power	256 MW
Annual average capacity	381 GWh
Reduction in CO_2, equivalent per year	235 kt
Estimated investment (ref. 2009)	171 M€
National contribution	80% to 85%

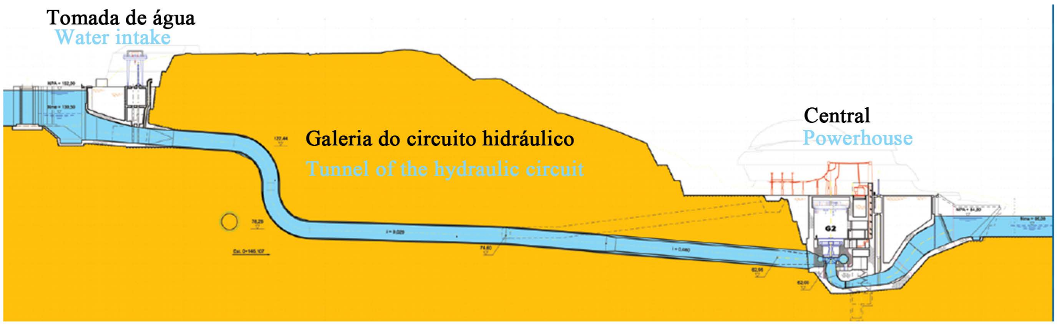

Figure 4. Longitudinal profile of the hydraulic circuit.

power, in comparison to Carvão-Ribeira. However, this system complements its duties of regulating the flows with the advantages of having pumped-storage too.

2.2.5. Venda Nova III

The expansion of Venda-Nova, that is now under construction is located in the left bank of Cávado River. An additional underground powerhouse is included, and it is equipped with two reversible units, and a hydraulic circuit. This case was chosen because it has the particularity of becoming, once it is ready, the largest hydropower plant existing in Portugal. The main characteristics are presented in **Table 7**.

These cases justify the conclusion that hydropower (including pumped-storage) has a lot of positive aspects and is, therefore, a sector where major investments are being done. **Figure 5** shows a market forecast for Portugal referring the number of pumped-storage power plants and the installed capacity. The presented examples are only a few of the planned investments that will contribute to the installed capacity of the country.

The projection shown in **Figure 5** was developed in 2011. It shows the pumped-storage installed capacity will be double in next years. These plants will undoubtedly contribute to the development of the country and local communities, taking into account all the positive aspects of such engineering project when compared with other conventional energy solutions. Dams are considered a winning solution for the environment. They promote regional development, allowing the improvement of roads, support for entrepreneurship, promoting several benefits:

- Tackling global warming and contributing to a reduction in CO_2 emissions by replacing fossil fuels;
- Reduction of external energy dependency;
- establishing conditions for regional development and stabilization of local populations;
- irrigation and agricultural improvement;
- guarantee of supply for the electricity system in situation of normal variations in load, even in periods of low water availability;
- hydroelectric power plants equipped with pumped-storage can use surplus wind power production, since they can store this power at off-peak times for subsequent use at times of greater demand;
- water supply reserves for domestic and industrial use;
- management of floods and droughts;
- development of inland navigation;
- support in forest fire fighting;
- development of tourism and recreational activities.

The examples described above depict how huge the installed hydro-power with pumps-storage is in Portugal. High hydropower installation results in a larger reduction of CO_2, which means a significant Portuguese energy contribution to reach the 31% aimed at a word level, as well as a major investment in this sector.

3. Case Studies

3.1. Brief Description

The case studies, namely the upgrade project of Alqueva II [26] and the seawater pumped storage project in Cape Verde Islands, will be described in the following sections, aiming to show different functions and characteristics of these hydropower solutions. In the first one it will be shown how this particular project deals with the

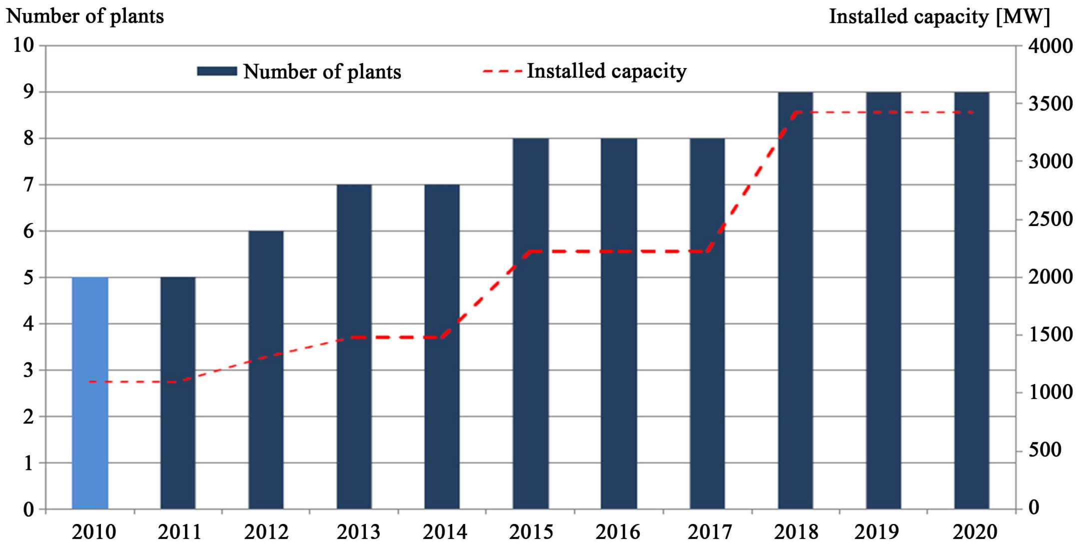

Figure 5. Market forecast: Portugal [28].

Table 7. Main characteristics of Venda Nova III hydropower plant.

Main indicators	
Construction works (started)	2010
Commissioning year (estimated)	2015
Number of units	2 (reversible)
Power	736 MW
Annual average capacity	1273 GWh
Reduction in CO_2, equivalent per year	1000 kt
Estimated investment (ref. 2009)	295 M€
National contribution	80% to 85%

variations of demand and supply, for its own advantage, generating profit by using the natural available resources. The second case study, that has the particularity of presenting a pumped-storage system with seawater [29]-[31], is going to examine if such a system is viable in arid regions. Furthermore, it will also be demonstrated a process of selection of the best location to build this system and if it is a viable option for this archipelago [32].

3.2. The Expansion of Alqueva Project

The hydropower station of Alqueva I is located at the Guadiana river, and started operating in 2004, with the objectives of electricity supply, public water supply, irrigation of 115,000 ha of agricultural land and implementation of leisure and tourism infrastructures.

The Alqueva I powerhouse is equipped with two Francis pump-turbine units, which have a total capacity of 2 × 128 = 256 MW in turbine mode. Due to the actual progress in the installation of renewable energies, especially wind energy, and due to the need of compensating its intermittency and impossibility of storage, it was decided to upgrade project in Alqueva, increasing the installed power. This upgrade, which is at this moment in construction, intends to use the available resources, namely the two available reservoirs. Alqueva II will have an identic scheme to Alqueva I, being equipped with two groups of reversible Francis turbines, with the same power of 256 MW (**Figure 6**).

The new powerhouse of Alqueva II will mainly be used for the regulation of the electric grid. It will pump

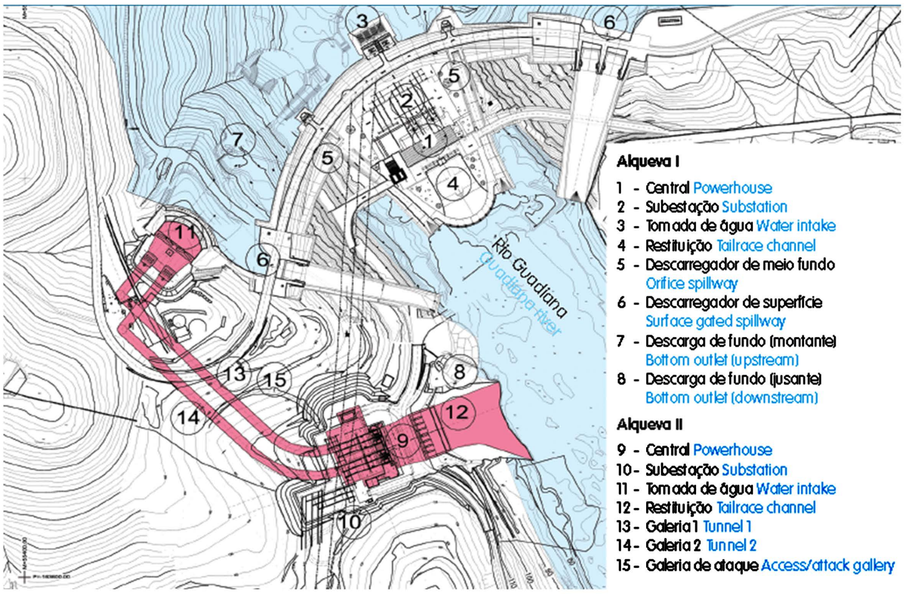

Figure 6. General layout—Plan of Alqueva I and II [26].

water in hours of low demand, when energy is at a low cost, and it will turbine the same water, once the energy is mostly needed, at peak hours, with the highest price. As it was mentioned before, the power station of Alqueva I will work in the same way, when there is no need of turbine water of own inflows.

Alqueva II will work in a pure reversible cycle, and considering that inflows will be regulated by Alqueva I, the pumped volume of water should be the same as the turbine volume of water. In a simulating operation of the Alqueva-Pedrógão system, it was seen the average level in Alqueva is around the elevation of 147. Considering in Pedrógão a level that corresponds to half of the capacity, elevation 82.5, the average head will be of 64.5 m. For this head, each turbine will discharge $Qt = 192\ m^3/s$ and will pump $Qp = 162\ m^3/s$ respectively, which means a ratio of $Qt/Qp = 1.19$.

Admitting only a daily cycle, the system could operate 5 hours per day in turbine mode and 6 hours in pumping mode. However, this daily operation cycle does not make it possible to maximize the value of reversibility, since there are big opportunities for pumping in weekends, when the energy price reaches the minimum level. In **Figure 7**, the weekly variation of the stored volume in Pedrogão per group is presented.

In this case, during winter with no downstream discharges, the system will operate 47 hours per week as a turbine (43 hours during the week and 4 hours during weekend) and 53 hours as a pump, of which 26 of them are in early mornings during the week and 27 during weekends. Pedrógão reservoir (at downstream dam) will empty itself during weekends due to the long period of pumping. During the week this reservoir will gradually get full again, since the turbine volume per day (8 hours) is higher than the pumped volume per day (5 hours). The maximum level of the Pedrógão reservoir will be achieved on friday around midnight. This operation involves 33 hours of pumping during weekends and monday mornings, with only 4 hours of turbine. This leads to a balance of approximately 29 hours of pumping during which the Pedrógão reservoir will change from the situation of maximum emptiness to maximum fullness. The need to store per group will be $V = 33 \times 162 \times 3600 - 4 \times 192 \times 3600 = 16.5 \times 105\ m^3$, in which 33 h and 4 h are the pumping and turbine time during weekends respectively, and $162\ m^3/s$ and $192\ m^3/s$ are pumping and turbine discharge, respectively. The used volume will depend on the following factors: level in Alqueva, month of the year, energy tariff, and the inflow.

The installation of a new powerhouse and the two new reversible groups brings several advantages. However it is necessary to be aware of the limiting factor associated with the storage capacity of the Pedrógão reservoir, which forbids the installation of higher power capacities. As much as a higher capacity would be able to pump a higher quantity of water to the Alqueva reservoir, but the restrictive size of Pedrógão reservoir limits the operation as well.

With this case study, it was shown how advantageous is a pumped-storage system, and how the power generation can be maximized. The only way to increase the efficiency would be to increase the water volume in Pedrógão, in order to have more water available to pump and turbine.

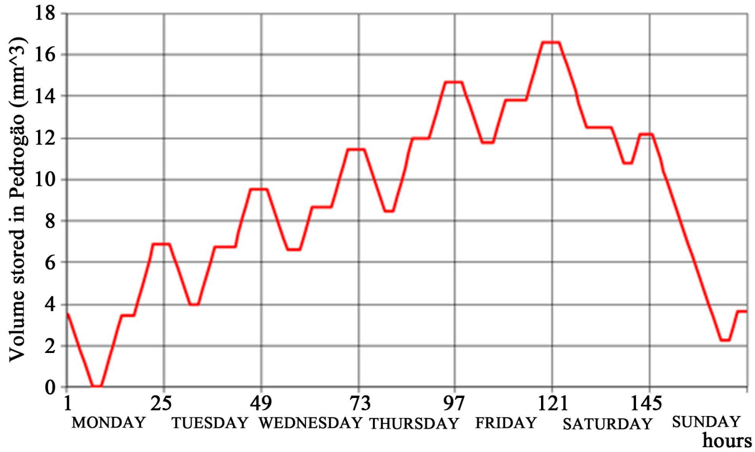

Figure 7. Variation of the stored volume in Pedrogão (per group).

3.3. Seawater Pumped-Storage Project in Cape Verde Islands

A seawater pumped-storage power station (SPSPS) is identical to a regular pumped-storage system. The main difference consists of the lower reservoir, which is the sea presenting an unlimited volume of water and storage. The first system of this type was built in the Okinawa Island, in Japan, to compensate the existing energy peaks. In such system, all the equipment needs extra protection against corrosion and problems with marine organisms, presenting some disadvantages, which highly increase the necessary investment. However, this option can be viable in arid regions, where rivers and fresh water are scarce. For this case study, the archipelago of Cape Verde is analyzed. Fresh water is far from abundant, but there are more than 300 days of sun per year, and the strong winds from the Atlantic Ocean represent a strong source of renewable energy.

Considering the favorable characteristics referring to renewable sources, a project "Cape Verde 50% renewable" was studied. A storage facility is needed, in order to store the excess of energy produced. Under this subject, pumped-storage presented itself as a good option to overcome the storage problem.

Hence the integration of renewable energies in Cape Verde system needs to be compensated by a storage solution that will help to solve the problem of demand and supply. The supply always needs to be guaranteed, and with the intermittent characteristic of renewable sources, storage is unavoidable. A seawater pumped-storage power station (SPSPS) was analyzed and the potential will be examined in **Figure 8**.

There are some places that present some potential based on a GIS study. It is also necessary to find good engineering conditions in order to implement the needed infrastructures, namely reservoirs, dams, penstocks and hydropower stations. Considering São Vicente Island, this led to three different possible locations. After the performance of a site assessment, the result for the best option was Monte Goa, represented with a yellow number one, in **Figure 8**. The option of pumped-storage with sea-water, called Monte de Goa-A, and the option with desalinated sea-water, called Monte de Goa-B.

The sea-water desalination is the only solution of reinforcing water supply to the population in the island. For this solution, the equipment does not need extra protections due to corrosion problems. The desalination of the water could be done in two places. Either in the upper reservoir in order to provide water to the population, or just after the lower reservoir, so that the pumped water would be desalinated already and therefore the equipment and the reservoir would not need to be protected against corrosion. This last option will be the one studied, since it has the advantages of the first one plus the decrease of the costs, due to the spare of corrosion preventive methods in all hydraulic conveyance system. The schemes would accordingly be the following represented in **Figure 9** and **Figure 10**.

After the procedure of site assessment, one SPSPS was considered. The main features and the corresponding budget estimation for Monte Goa solutions with the options A and B are presented in **Table 8**.

Table 8 shows that Option A, without desalination of the seawater, is less expensive; however, from the social and environmental points of view, Option B is preferable, since the associated costs are only 15% higher. Comparing the two solutions, it is possible to conclude the SPSPS in Monte de Goa has a price of annual production of 0.97 €/GWh.

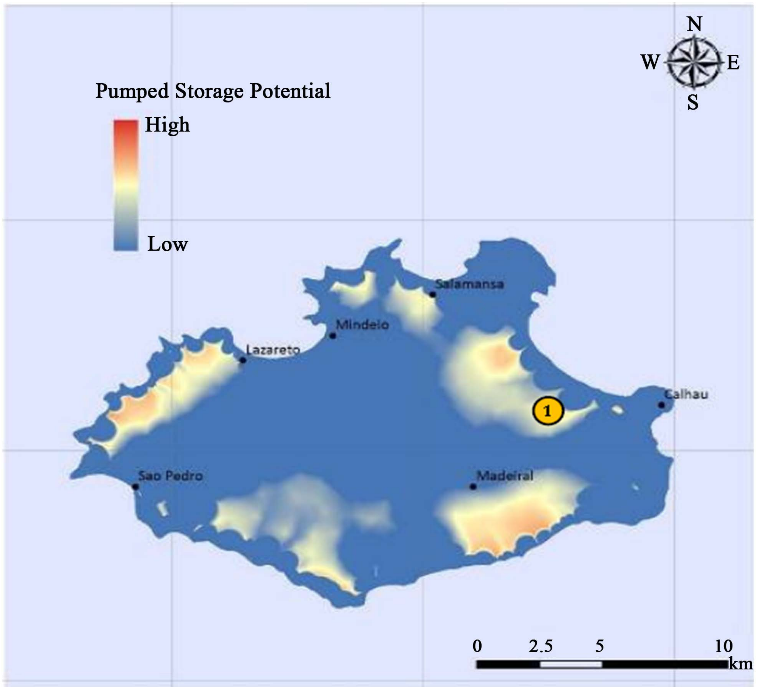

Figure 8. Seawater pumped storage potential for São Vicente Island.

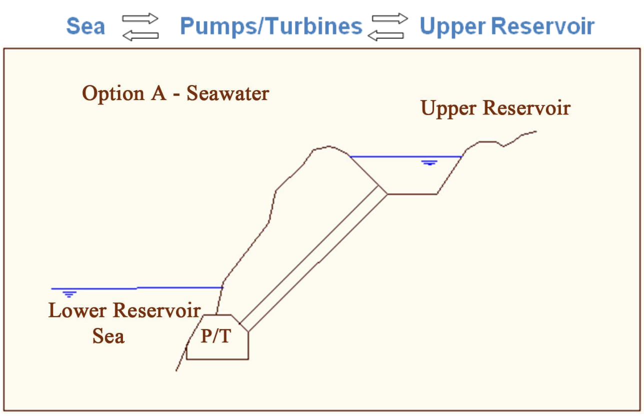

Figure 9. Option A—System with seawater—Monte de Goa A.

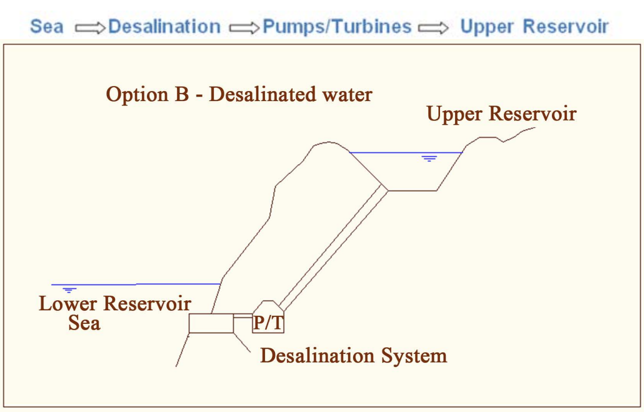

Figure 10. Option B—System with desalinated water—Monte de Goa B.

Table 8. Main features and budgetary estimation of SPSPS for Monte Goa.

Features		Monte Goa A	Monte Goa B
Energy	Gross head	444 m	409.3 m
	Net head	427.3 m	401 m
	Installed power	15,000 kW	15,000 kW
	Mean annual production	32.9 GWh	32.9 GWh
Upstream Reservoir	Normal water level	444 m	444.5 m
	Minimum operation level	432.5 m	432.5 m
	Max. reservoir height	11.5 m	12 m
	Net reservoir volume	183,800 m^3	194,700 m^3
Downstream Reservoir/Intake	Type	onshore water intake	reservoir
	Normal water level	0	35
	Minimum operation level	−10	24
	Max. reservoir height	-	11
	Net reservoir volume	-	221,000 m^3
Hydraulic Circuit	Cross section	□1200	□1400
	Length	1900 m	1870 m
Power House	Type	underground	underground
	Turbines	2 × Francis reversible vertical axis	2 × Francis reversible vertical axis
	Axis elevation	−40.0 m	−16 m
	Max. generating flow	4.2 m^3/s	4.4 m^3/s
	Max. pumping flow	3.0 m^3/s	3.2 m^3/s
	Net head	427.3 m	401 m
Transmission Line	Voltage	60 kV	60 kV
	Length	15 km	10.58 km
Total Cost Estimate		32 M€	37.4 M€

4. Conclusions

In countries with significant available natural resources, the subject of this research is of particular relevance. Renewable energies (e.g. when sun, wind, ocean, rivers are abundant) are viable, but better if a storage facility exists to cover their flaws. Without a storage system, part of the energy produced may be completely wasted, if it is not needed at the moment in which it is available.

The present work presents a special storage system—the pumped-storage system—which has proven to be a possible and a good energy option as described in the two case studies (*i.e.* based on river dams and sea-water solutions). Pumped-storage represents a technology of storing energy during periods of low demand. This technology is viable, since it uses electricity in low demand hours to pump water, and use it in hours of high demand. Evidence was given, that such systems should stick to some limitations in order to guarantee success. One of the goals was to verify and compare characteristic parameters that will lead to a successful implementation of such system. Variables as power, head, flow and price of the energy, were examined and proven to be decisive factors on the level of accomplishment of a pumped-storage system. It was concluded that these systems present several positive characteristics, namely to store energy, to generate profit, to provide flexibility regarding start-ups and shut-downs and to compensate the energy load fluctuations. One of the major outcomes is the possibility to provide the storage of energy from intermittent sources (e.g. wind and solar) making the whole system more flexible and reliable, with a better performance, and improving the elasticity and water-energy nexus most valorized.

In Portugal, a large part of electricity is generated in large power plants such as pumped-storage power plants, or simply storage power plants, which are supposed to increase in the near future and the installed capacity is expected to double in the next years. Through the first case study, evidence is given that renewable energy together with pumped-storage is a feasible option that can generate profit. The Alqueva II project demonstrates how the profit can be maximized, being a strong alternative to fossil fuels. The second case study of Cape Verde is more ambitious, analyzing a possible solution of pumped-storage in an arid region. Pumped-storage with seawater, as well as an option of desalination in order to provide fresh water to the citizens was also examined. Studies regarding renewable energy penetration, investments, employment, decrease in imports and fuel costs and the reduction of CO_2 emission helped to prove this system viability.

On the overall, energy pumped-storage solution is a good and competitive option to store energy from intermittent sources (e.g. solar, wind). Besides being technically and economically viable, it is an option that fulfills the current energy objectives and reflects the importance of improving the energy efficiency, since it produces clean energy, using natural resources, without wasting them, harming the environment, releasing CO_2 or contributing to the global warming.

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References

[1] Ramos, J.S. and Ramos, H.M. (2009) Sustainable Application of Renewable Sources in Water Pumping Systems: Optimized Energy System Configuration. *Energy Policy*, **37**, 633-643. http://dx.doi.org/10.1016/j.enpol.2008.10.006 .

[2] Ramos, J.S. and Ramos, H.M. (2010) Multi-Criterion Optimization of Energy Management in Drinking Systems. *Water Science & Technology*: *Water Supply—WSTWS*, **10**, 129-144. http://dx.doi.org/10.2166/ws.2010.011

[3] Ramos, H.M., Vieira, F. and Covas, D. (2010) Energy Efficiency in a Water Supply System. *Water Science and Engineering*, **3**, 331-340. http://dx.doi.org/10.3882/j.issn.1674-2370.2010.03.009

[4] Gonçalves, F.V., Costa, L.H. and Ramos, H.M. (2011) Best Economical Hybrid Energy Solution: Model Development and Case Study of a WDS in Portugal. *Energy Policy*, **39**, 3361-3369. http://dx.doi.org/10.1016/j.enpol.2011.03.031

[5] Ramos, H.M., Kenov, K.N. and Vieira, F. (2011) Environmentally Friendly Hybrid Solutions to Improve the Energy and Hydraulic Efficiency in Water Supply Systems. *Energy for Sustainable Development*, **15**, 436-442. http://dx.doi.org/10.1016/j.esd.2011.07.009

[6] Gonçalves, F.V. and Ramos, H.M. (2011) ANN for Hybrid Energy System Evaluation: Methodology and WSS Case Study. *Water Resources and Management* (*WARM*), **25**, 2295-2317. http://dx.doi.org/10.1007/s11269-011-9809-y

[7] Wood, L. (2011) Manage Renewable Risk: Assessing Offshore Margins. Renewable Energy World Magazine. http://library.certh.gr/libfiles/E-JOURS/FULL-TXT/REW-V-14-I-6-PP-124-Y-ND-2011.pdf

[8] EUROPEAN COMMISSION. European Energy Pocket Book 2010. http://ec.europa.eu/energy/publications/doc/statistics/part_2_energy_pocket_book_2010.pdf

[9] Miller, R.R. and Winters, M. (2009) Energy Storage: Opportunities for Pumped-Storage: Supporting Renewable Goals (www.hydroworld.com), Hydro Review. http://www.hydroworld.com/articles/hr/print/volume-28/issue-5/Featured_Articles/energy-storage-opportunities-for-pumped-storage-supporting-renewable-energy-goals.html

[10] Vieira, F. and Ramos, H.M. (2009) Optimization of Operational Planning for Wind/Hydro Hybrid Water Supply Systems. *Renewable Energy*, **34**, 928-936. http://dx.doi.org/10.1016/j.renene.2008.05.031

[11] Vieira, F. and Ramos, H.M. (2009) Optimization of the Energy Management in Water Supply Systems. *Water Science & Technology*: *Water Supply—WSTWS*, **9**, 59-65. http://dx.doi.org/10.2166/ws.2009.768

[12] Vieira, F. and Ramos, H.M. (2008) Hybrid Solution and Pump-Storage Optimization in Water Supply System Efficiency: A Case Study. *Energy Policy*, **36**, 4142-4148. http://dx.doi.org/10.1016/j.enpol.2008.07.040

[13] E-VALUE (2011) Energy and CO2 Emissions—Technical Report (in Portuguese).

[14] Gonçalves, F.V., Costa, L.H. and Ramos, H.M. (2011) Best Economical Hybrid Energy Solution: Model Development and Case Study of a WDS in Portugal. *Energy Policy*, **39**, 3361-3369.

[15] Ramos, H.M., Kenov, K.N. and Vieira, F. (2011) Environmentally Friendly Hybrid Solutions to Improve the Energy and Hydraulic Efficiency in Water Supply Systems. *Energy for Sustainable Development*, Elsevier, **15**, 436-442.

[16] Ramos, H.M. (2012) Pumped-Storage and Hybrid Energy Solutions towards the Improvement of Energy Efficiency in Water Systems. INTECH. http://dx.doi.org/10.5772/50024

[17] Wood, L. (2011) Manage Renewable Risk: Assessing Offshore Margins. Renewable Energy World Magazine. http://library.certh.gr/libfiles/E-JOURS/FULL-TXT/REW-V-14-I-6-PP-124-Y-ND-2011.pdf.

[18] Ramos, H.M., Mello, M. and De, P.K. (2010) Clean Power in Water Supply Systems as a Sustainable Solution: From Conceptual to Practical Analysis. IWA Publishing, *Water Science & Technology*: *Water Supply—WSTWS*, **10**, 39-49. http://dx.doi.org/10.2166/ws.2010.720

[19] Ramos, H. (2000) Guidelines for Design of Small Hydropower Plants. WREAN (Western Regional Energy Agency and Network) and DED (Department of Economic Development-Energy Division), Belfast, N. pages: 205.

[20] EDP (2010) New Hydropower Plants. Technical Report. www.a-nossa-energia.edp.pt

[21] Hey, C. (2012) EU Governance for a Sustainable Energy Mix. Advisory Council on the Environment, Berlin.

[22] Kimmins, J.P. (2001) The Ethics of Energy: A Framework for Action. In: Kimmins, J.P., Eds., *Chairperson of the COMEST Sub-Commissionon the Ethics of Energy*, UNESCO, Paris.

[23] Brecher, A. (2011) Assessment of Needs and Research Roadmaps for Rechargeable Energy Storage System Onboard Electric Drive Buses. Federal Report No. FTA-TRI-MA-26-7125-2011.1.

[24] Deane, J.P., Gallachóir, B.P. and Mckeogh, E.J. (2010) Techno-Economic Review of Existing and New Pumped Hydro Energy Storage Plant. *Renewable and Sustainable Energy Reviews*, **14**, 1293-1302. http://dx.doi.org/10.1016/j.rser.2009.11.015

[25] Tam, S.W., Blomquist, C.A. and Kartsounes, G.T. (1979) Underground Pumped Hydro Storage—An Overview. *Energy Sources*, **4**, 329-351. http://dx.doi.org/10.1080/00908317908908068

[26] EDP (2012) The Alqueva II and SalamondeII Upgrade Projects in Portugal. Technical Report.

[27] Zuber, M. (2011) Renaissance for Pumped-Storage in Europe. HRW-Hydro Review Worldwide. http://www.hydroworld.com/articles/print/volume-19/issue-3/articles/new-development/renaissance-for-pumped-storage-in-europe.html

[28] ECOPROG (2011) Ecoprog GmbH Consulting Group. www.ecoprog.com

[29] FEPC (2010) Electricity Review Japan. The Federation of Electricity Companies of Japan. http://www.fepc.or.jp/english/library/electricity_eview_japan/index.html

[30] Fujihara, T., Imano, H. and Oshima, K. (1998) Development of Pump Turbine for Seawater Pumped-Storage Power Plant. *Hitachi Review*, **47**, 199-202.

[31] Seawater Pumped-Storage Power Plant. Electric Power Development Co., Ltd. (J-Power) http://www.kankeiren.or.jp/kankyou/en/pdf/en108.pdf

[32] Yang, C.J. and Jackson, R. (2011) Opportunities and Barriers to Pumped-Hydro Energy Storage in the United States. *Renewable and Sustainable Energy Reviews*, **15**, 839-844. http://dx.doi.org/10.1016/j.rser.2010.09.020

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