Applied Energy 88 (2011) 466–472

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Increasing the penetration of renewable energy resources in S. Vicente, Cape Verde

Raquel Segurado [a,*], Goran Krajačić [b], Neven Duić [a,b], Luís Alves [a]

[a] Department of Mechanical Engineering, Instituto Superior Técnico, Lisbon, Portugal

[b] Department of Energy, Power Engineering and Environment, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia

ARTICLE INFO

Article history:
Received 9 September 2009
Received in revised form 1 July 2010
Accepted 6 July 2010
Available online 1 August 2010

Keywords:
Renewable energy
Renewable Islands
H_2RES model
Pumped hydro storage
Desalination
Energy system analysis

ABSTRACT

In this article different scenarios are analysed with the objective of increasing the penetration of renewable energies in the energy system of S. Vicente Island in Cape Verde. An integrated approach is used to analyse the electricity and water supply systems. The H_2RES model, a tool designed to simulate the integration of renewable sources and hydrogen in the energy systems of islands or other isolated locations, is applied.

There is no other source of fresh water available to supply the population of S. Vicente, apart from desalinated seawater. The electricity supply system of this Island is based on fossil fuel and wind. S. Vicente has important wind resources that are not fully used because of its intermittent nature. The topography of this Island is relatively uniform, with the exception of Mont Verde, a 774 m high mountain located in its centre, which could be suitable for pumped hydro storage.

The present analysis incorporates the possibility of using pumped hydro as a storage technique to increase the penetration of renewable energy sources, using desalinated seawater.

The results show that is possible to have more than 30% of yearly penetration of renewable energy sources in the electricity supply system, together with more than 50% of the water supplied to the population produced from wind electricity.

1. Introduction

Most islands depend mainly on the importation of fossil fuels for energy production and, at the same time, present a considerable potential in renewable energies. The use of this potential in the production of electricity and fresh water (usually very scarce in islands) could represent a large fraction of the total energy distribution [1].

One of the major challenges of increasing the penetration of renewable energy in a system is to integrate a high share of intermittent resources into the electricity supply system [2,3].

The intermittent nature of some renewable energy sources as well as the small energy systems of islands introduce barriers to their penetration, like the struggle to match the demand with the supply and the problems related with the integration in the network. Hence, the integration of intermittent renewable energy sources in energy systems requires the development of energy storage technologies, energy management technologies and a greater sophistication of these systems.

The integration of renewable energy sources in energy systems of small islands presents several advantages, namely at economical level, their high technological cost is compensated by the high cost of the conventional sources of energy due to the small dimension of the energy systems and because of a very expensive security of supply. In order to achieve sustainable development, the integration of renewable energy sources for the production of electricity, together with suitable policies and regulations regarding rational use of energy, are very important. The conventional electricity production technologies are rarely adapted to the conditions of isolated areas and can seriously damage the vulnerable ecosystems and natural habitats. There is the need to develop an energy supply infrastructure that takes into consideration the seasonal variations caused by the tourist activity, without destroying the local environment or producing avoidable emissions.

Due to the several available renewable energy sources, the increasing number of technologies for their use and the different options for energy storage, the planning and modelling of energy systems are complex and demanding. Specialized models were developed to help in solving that problem [4].

To date, a number of analyses have been carried out on the feasibility of integrating renewable energy resources in islands. Many of them consider the possibility of using hydrogen as energy storage, in order to increase the penetration of intermittent renewable energy sources in the energy systems of islands [4–9].

In many places there is already an excellent storage potential in the local water supply system. By merging the energy and water supply systems, where there is sufficient elevation difference, it

* Corresponding author. Tel.: +351 218417592; fax: +351 21 847 5545.
E-mail address: raquelsegurado@ist.utl.pt (R. Segurado).

0306-2619/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2010.07.005

is possible to use pumped hydro storage in order to increase the penetration of intermittent renewable energy sources, as for example wind, even in case where there is not much hydro potential.

In Duić et al. [10], the possibility of using pumped hydro storage in the Island of Corvo, in Azores, is analysed. In this case, with the integration of the water supply system with pumped hydro, adding storage to energy and resources systems, it is possible to significantly increase the penetration of locally available resources and thus increase the security of supply and decrease the import dependence.

A wind-powered pumped hydro system is proposed in Bueno and Carta [11] for the Island of El Hierro, Canary Islands, in order to increase the renewable sourced energy penetration of the Island grid. The results indicate that an annual renewable energy penetration of 68% can be achieved.

S. Vicente has very important and stable wind resources. The Island also has Mont Verde, a 774 m high mountain located in its centre. These features make S. Vicente suitable for the use of pumped hydro as a storage technique. As there is no fresh water available in the Island, the proposed solution considers the use of desalinated water in the pumping and hydro station to later be supplied to the population.

The installation of desalination units is a common solution throughout the world in areas with water scarcity [12]. However, desalination is a process that requires a significant amount of energy [13], thus, renewable energy driven desalination plays a vital role in the application of this technology.

There are several studies that analyse renewable energy powered desalination systems [12–21].

The purpose of this study is to couple these two issues: the integration of renewable energy sources in the electricity supply system and the water scarcity problems of S. Vicente, using the intermittent excess to supply the desalination and the pumping units.

The innovation of this study lies on the analysis of the combination of these two supply systems (energy and water) in order to increase their efficiency.

In this article different scenarios are analysed for increasing the penetration of renewable energy in the energy system of S. Vicente Island. The tool used is H_2RES, a model designed to simulate the integration of renewable energy sources and hydrogen in islands or other isolated locations.

There are two types of scenarios. Scenarios with 30% hourly intermittent energy penetration, that is considered the limit of the current conversion technology that is installed on the Island, and scenarios without this limit, where it is assumed that the conversion technologies can also provide output control and auxiliary services [8].

It is shown that is possible to have more than 30% of yearly penetration of renewable energy sources in the electricity supply system, together with more than 50% of the water supplied to the population produced from wind electricity. The penetration of renewable energy sources can reach 70%, when 100% hourly intermittent energy penetration is considered.

2. Methodology

2.1. H_2RES model

In Connolly et al. [22], a review is made of the different tools than can be used to analyse the integration of renewable energy. H_2RES is classified as a simulation tool, as it simulates the operation of a given energy system to supply a given set of energy demands; a scenario tool, as it combines a series of years into a long term scenario; a bottom-up and an operation optimisation tool.

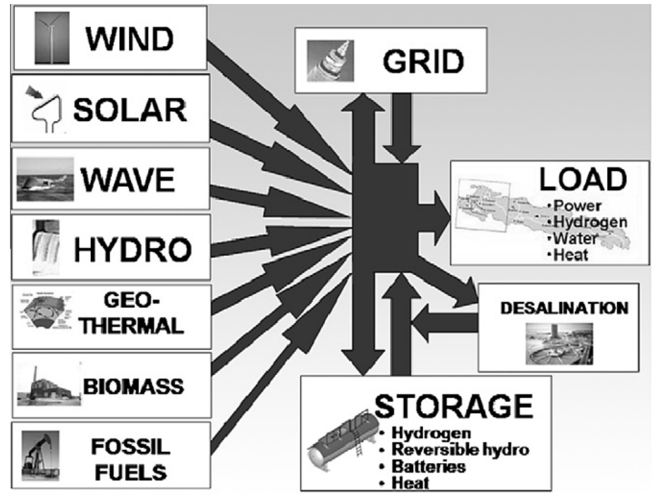

Fig. 1. H_2RES computer model v2.8.

The H_2RES model (Fig. 1) simulates the integration of renewable sources and hydrogen in the energy systems of islands or other isolated locations. It is based on hourly time series analysis of demand (water, electricity, hydrogen, heat); storage (pumped hydro, batteries, hydrogen, heat) and resources (wind speed, solar radiation, precipitation). The main purpose of this model is energy planning of islands and isolated regions which operate as stand-alone systems, but it can also serve as a planning tool for single wind, hydro or solar power producer connected to a central power system. Throughout time, the model is evolving and several new modules have been developed such as wave, biomass, solar heat and desalination.

Several articles describe H_2RES model with details of its operation [1,4–8,10]. The version that has been used for calculating Portugal case study has been updated with a wave module. The main characteristic of H_2RES model is that it uses technical data of equipment, hourly meteorological data for intermittent sources and, according to description in [6,7], energy balancing is regulated by equations.

Wind velocity, solar radiation and precipitation data obtained from the nearest meteorological station are used in the H_2RES model. The wind module uses the wind velocity data at 10 m height, adjusts them to the wind turbines hub level and, for a given choice of wind turbines and converts the velocities into the output.

The load module, based on a given criteria for the maximum acceptable renewable electricity in the power system, puts a part or all of wind and solar output into the system and discards the rest of the renewable output. The hourly load of the power system is obtained from the local utility.

The excess renewable electricity is then stored either as hydrogen, pumped water or electricity in batteries. The energy that is stored can be retrieved later, and supplied to the system as electricity. The rest is covered by diesel blocks.

A comparative study between H_2RES and EnergyPLAN, a model designed for the analysis of different regulation strategies of complex energy systems, is made in Lund et al. [23].

2.2. Desalination module

The desalination module uses the electricity produced from excess wind to supply the desalination units, that produce drinkable water and put it on the lower reservoir, this reservoir is then used to supply the population. This module takes into account the total capacity of these units (m^3 of water produced per hour) and their electricity consumption per unit of water produced. At each hour, the desalination module verifies if the lower reservoir has at least 1 day of water demand, if it does not, and if the user allows this option, the desalination units are supplied with electricity from the fossil fuel blocks.

2.3. Optimisation criteria

According to Østergaard [24], many different optimisation criteria might be applied to the design of environmentally benign energy systems and no unequivocal answer can be found to the question of how to design an optimal energy system.

The optimisation criteria used in this study is the maximization of the penetration of renewable energy sources in the electricity system of S. Vicente, keeping the rejected intermittent electricity close to 10% in the scenarios with 30% hourly intermittent energy penetration. In scenarios with 100% hourly intermittent energy penetration, the rejected intermittent electricity is kept under 30% [1].

3. Results

3.1. The Island of S. Vicente

S. Vicente is the second most crowed Island in the Archipelago of Cape Verde, which is composed of 10 Islands and is situated at about 450 km of the West African coast, in the Atlantic Ocean (Fig. 2). This Island had about 74,031 inhabitants in 2005 [25], mostly concentrated in its capital, Mindelo.

S. Vicente has about 228 km^2 of area and its topography is relatively uniform, having just one high point – Mont Verde – located at 774 m of altitude.

The Island is extremely dry; all of the fresh water provided to the population is obtained by seawater desalination. The desalination units installed in S. Vicente are showed in Table 1.

The reverse osmosis unit of 1200 m^3 per day is the most recent unit, installed in 2007.

In 2005 the total fresh water production was about 17 m^3 per capita.

The electricity production in the Island is based in fossil fuel and wind technologies. There are two conventional thermal fossil fuel power plants, the Matiota and the Lazareto plants. The total fossil fuel power installed in 2005 was about 20,170 kW. There are also three Nordtank wind turbines of 350 kW each [27].

Table 1
Desalination installed capacity in S. Vicente [27,28].

Technology	Number of units	Nominal capacity (m^3/day)
Reverse osmosis	3	1000
Mechanical vapour compression	1	1200
Multiple effect distillation	1	2400
Reverse osmosis	1	1200
Total	6	7800

The electricity production in this year was about 57 GWh and the peak power was 10,200 kW.

The electricity demand is relatively stable throughout the year, as there are not large climate variations, as can be seen in Fig. 3, with the hourly load of January 15th and August 15th 2005.

The Island has important wind resources. The hourly wind speed of 2005 was collected from the local meteorological station. In this year, the average wind speed was about 8 m/s.

3.2. Energy scenarios for S. Vicente

In order to apply the H_2RES model to the Island of S. Vicente, five scenarios were elaborated, having all 2005 as base year.

The first scenario is the Business As Usual, as it only considers the projects that are already foreseen for the Island.

Regarding the evolution of the electricity and water demand, study made by the Research Group on Energy and Sustainable Development in the scope of the National Energy Plan for Cape Verde [29], was considered. This study considered the forecast of the evolution of the Gross Domestic Product and of the resident population in order to forecast the growth in the consumption of electricity in the different Islands of Cape Verde (Table 2), the growth in the consumption of water was considered the same.

Currently, wind energy can be considered economic viable in islands, as long as it does not surpasses a certain limit of penetra-

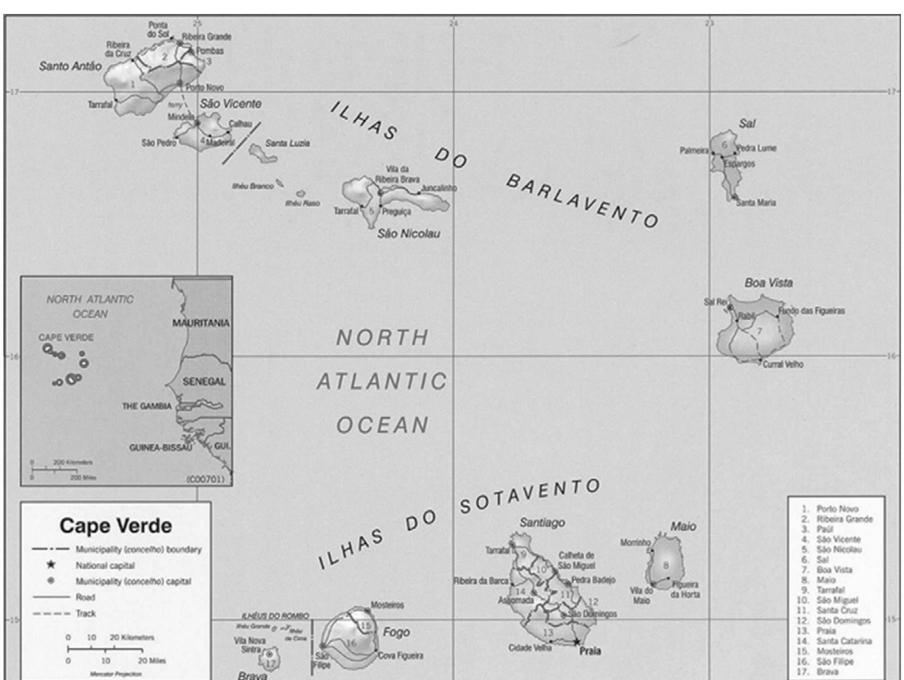

Fig. 2. Map of Cape Verde [26].

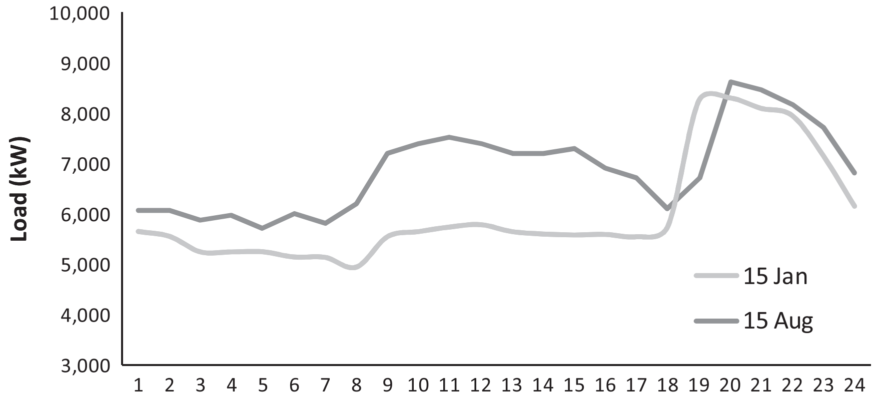

Fig. 3. Hourly electricity load of 1 day in the summer and 1 day in the winter in 2005, in S. Vicente.

Table 2
Forecast of the annual demand growth of electricity in the Island of S. Vicente [29].

Period	Annual growth (%)
2006–2009	7.92
2010–2014	6.40
2015–2019	4.20
2020–2024	3.36
2025–2030	3.08

tion. The base scenario is then defined delimiting 30% of the hourly renewable energy penetration, which means that only 30% of the load of 1 h can be covered by electricity generated from wind.

According to ELECTRA, the local utility, it is foreseen the installation of more 6800 kW of wind-power in the Island, in this study it is considered that it will be 8 turbines V52 of 850 kW each, from Vestas.

The second scenario considers the supply of electricity produced from wind to the desalination plants already installed on the Island. This scenario considers the construction of a 30,000 m^3 reservoir, at low altitude, where the water that comes out of the desalination plant will be stored before being supplied to the population. It is believed that S. Vicente has several reservoirs of smaller dimension spread through the Island. When the excess electricity from wind is not enough to desalinate all the water needed the diesel blocks are used to supply the remaining required electricity.

The succeeding scenario maximizes the desalination from wind electricity.

Scenario four considers the storage of the excess wind production through pumping of the desalinated water. This scenario contemplates the construction of a dam or water reservoir with about 50,000 m^3 at 500 m of altitude. Thus, the wind park would supply electricity to a desalination plant and to a pumping station that puts desalinated water in the upper reservoir. When it is necessary to supply water and electricity to the population, the water is turbinated from the upper to the lower reservoir (Fig. 4).

The fifth scenario is similar to the previous one, but aims to maximize the renewable energy sources (RES) penetration in this energy supply system.

All of these scenarios were modelled once more, but allowing an hourly intermittent energy penetration of 100% (scenarios 6–9).

3.3. Results of the modelled scenarios

3.3.1. Scenario 1 – BAU

Regarding the first scenario, the electricity production in S. Vicente from 2005 to 2030 is stated in Fig. 5. It was considered the above mentioned installation of 6800 kW of wind energy by 2010 and the addition of diesel blocks to satisfy the growth of the demand.

It is clear that the penetration of the wind electricity production increases from 2005 to 2010, due to the installation of the new wind turbines, it increases from 6% to 22%. However, from then on, it decreases, as no more wind turbines are added to satisfy the demand growth, only diesel blocks.

In this scenario, the electricity produced from wind has a large amount that is rejected, especially in 2010, with 45% of wind electricity rejected. As the years go by, this rejection decreases due to the growth of demand and the non installation of more wind turbines, in 2030 it reaches about 9% (Fig. 6).

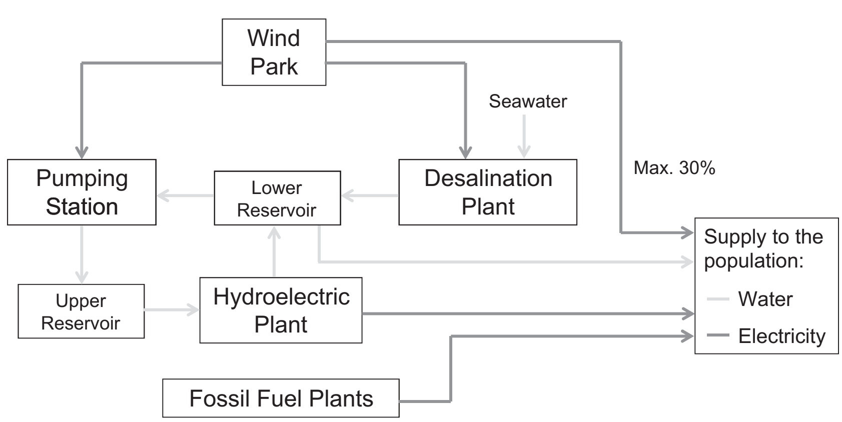

Fig. 4. Scheme of scenario 4.

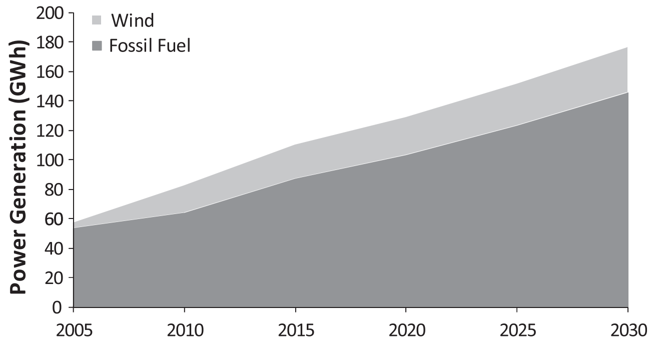

Fig. 5. Power production in S. Vicente for the BAU scenario.

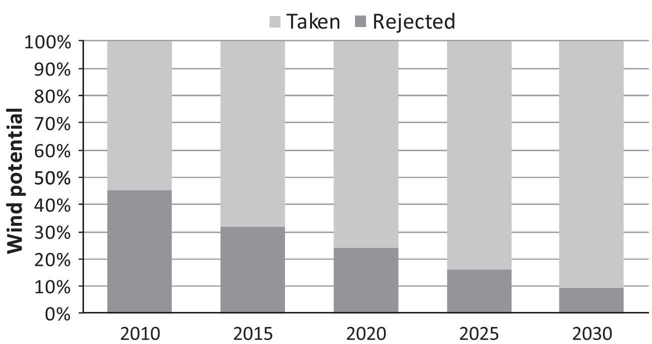

Fig. 6. Wind potential taken and rejected in S. Vicente for the BAU scenario.

3.3.2. Scenarios 2 and 3 – desalination from wind

An excellent way to decrease the wind electricity rejected is to supply the desalination plant with this excess electricity. However, when modelling this scenario, the first conclusion reached was that the wind produced was not enough to desalinate all the water needed. Hence, it was considered the supply of electricity from the diesel blocks, when the electricity from wind was not enough.

The evolution of the water demand was considered to be the same as the electricity demand.

These calculations considered desalination units already installed in the Island, and the addition of desalination units to satisfy the growth of the demand over the years.

The load considered in the first scenario included the electricity needed to desalinate water to be supplied to the population, thus, there was the need to subtract the electricity used for desalination. According to [27], 14% of the electricity produced in S. Vicente in 2005 was to supply the desalination units. Hence, and because hourly consumption of water does not vary very much, as there are not large water storages, this percentage was deducted from the hourly load.

Regarding the supply of electricity from wind, although there is a 30% hourly limit for the supply of the population, there is no limit for the supply to the desalination units.

A reservoir of 30,000 m^3 was considered, in order to have water storage with a capacity of about 5 days of the demand of 2010.

In this scenario, the penetration of wind electricity reaches higher levels than in the previous one. The proportion of wind electricity rejected in this scenario is much lower, reaching its higher value, about 23%, in 2010.

In order to maximize the desalination from wind (scenario 3), the influence of the wind turbines installed, of the capacity of the desalination units and of the capacity of the lower reservoir was studied. Although the most important factor was the power of the wind turbines installed, the increase of this value leads to an increase of the wind electricity rejected. To avoid this, the capacity of the desalination units needs also to increase. Hence, as mentioned above, the number of wind turbines and desalination units was optimised so that yearly wind desalination was maximized while keeping the rejected wind electricity close to 10% [1].

With the installation of wind turbines throughout the year, it is possible to increase the penetration of wind electricity and keep it more or less constant along the years.

The production of desalinated water, by electricity from wind and from the fossil fuel blocks is stated in Fig. 7.

The fraction of desalinated water produced from wind reaches 57% in 2020, and although it decreases slightly in the following years, it never goes below 47%.

3.3.3. Scenarios 4 and 5 – desalination and pumped hydro

Scenario 4 considers the pumping of desalinated water to an upper reservoir with 500,000 m^3 of capacity, at 500 m of altitude, and its later supply to the population producing also electricity from the hydroelectric plant. It was considered that the hydroelectric plant is used for peak shaving, about 80% of the weekly peak. The load factor of the hydraulic turbines was kept above 20%.

In scenario 5, the RES penetration in the energy supply system of the Island of S. Vicente was maximized with the installation of more wind turbines. When modelling this scenario, there was the need to verify, when testing all the possibilities, if none of the reservoirs overflowed. This is a very important issue, especially in an island as arid as S. Vicente. Thus, the two restrictive factors in maximizing RES penetration were the prevention of overflow of the reservoirs and the control of the intermittent rejected.

The electricity production along the years for this scenario is indicated in Fig. 8.

In 2020, the hydroelectric plant produces about 3% of the total electricity produced in the Island, 30% is produced from wind, totalizing 33% of RES electricity.

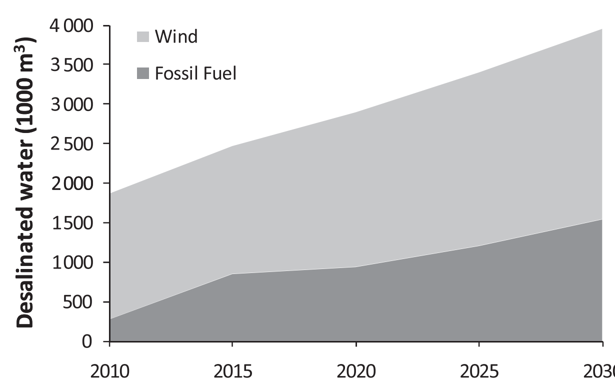

Fig. 7. Production of desalinated water in S. Vicente for scenario 3.

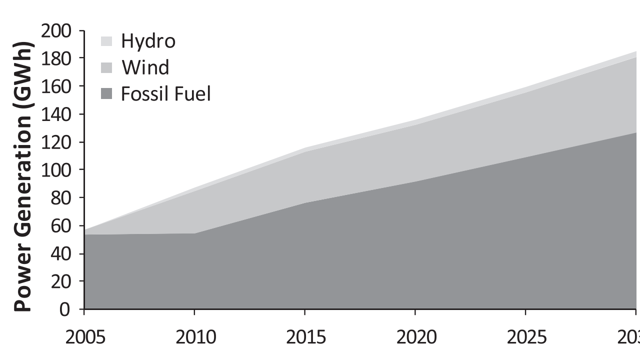

Fig. 8. Power production in S. Vicente for scenario 5.

3.3.4. 100% hourly intermittent energy penetration scenarios

These scenarios allow the hourly intermittent energy penetration rate to reach 100%. The number of wind turbines was optimised so that yearly wind penetration was maximized while keeping the rejected wind electricity close to 30% [1].

Unsurprisingly, in these scenarios the penetration of wind electricity is much higher. In scenario 7, where the desalination from wind is maximized, this value reaches 75% in 2020. The electricity produced from wind is about 70%.

In scenario 9, where the RES penetration is maximized, the hydroelectric plant produces about 6% of the total electricity produced in the Island in 2020, 65% is produced from wind, totalizing 71% of RES electricity.

3.3.5. Comparison between scenarios

In Fig. 9 the power generated to supply the Island of S. Vicente in the year 2020 in stated for four different scenarios.

It is clear that in scenario 9 the renewable energy sources have a higher fraction. In this scenario, the avoided electricity production from fossil fuel reaches 62.2 GWh. Using an overall electricity emission factor of diesel generators of 0.75 kg CO_2 per converted kWh [17], the avoided greenhouse gas emissions are 46,671 ton CO_2.

Considering the 30% of hourly penetration limit (scenario 5), the avoided electricity production from fossil fuel reaches 11.8 GWh which corresponds to 8860 ton CO_2 of avoided greenhouse gas emissions.

Fig. 10 illustrates the amount of desalinated water produced from wind and from fossil fuel in the different scenarios.

In scenarios 3 and 4, the desalination from wind is always balanced with the desalination from fossil fuel. In 2020, these scenarios present a fraction of desalinated water produced from wind of 53% and 56% respectively. Scenarios 7 and 9 have a higher fraction of desalinated water produced from wind, 75% and 59% respectively.

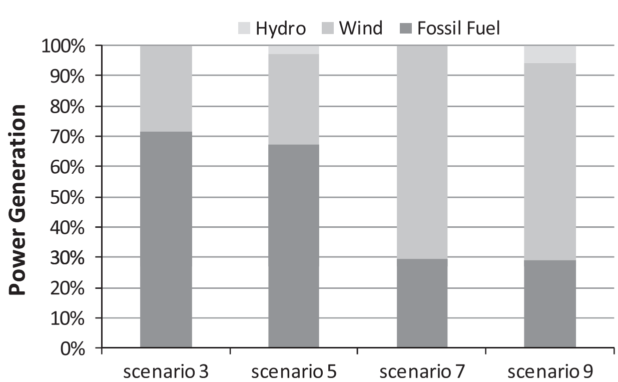

Fig. 9. Power production in S. Vicente in 2020, for four different scenarios.

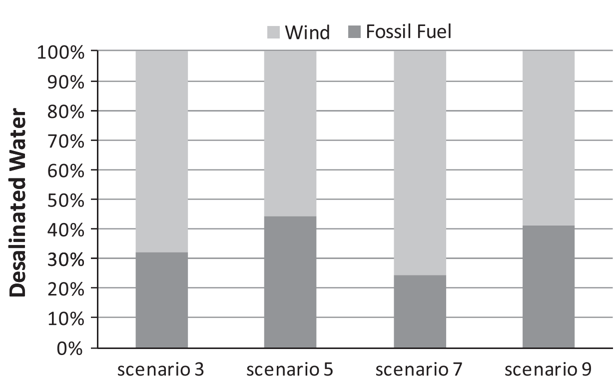

Fig. 10. Production of desalinated water in S. Vicente in 2020, for four different scenarios.

4. Conclusions and future developments

This article analyses the way to increase the penetration of renewable energy sources in the Island of S. Vicente, in Cape Verde, coupling the energy and water supply systems. Based on existing load data and meteorological data, several scenarios were built and modelled using the H_2RES model. The scenarios considered wind, pumped hydro storage and desalination technologies.

The maximization of desalination from wind resulted in fractions of desalinated water produced from wind of about 57% in 2020, but from the following years, this value decreased to around 50%.

The maximization of renewable energy sources in this supply system resulted in a penetration of about 33% of these technologies, with a major fraction from wind and a much lower contribution from hydroelectricity.

If an hourly intermittent energy penetration rate of 100% is allowed, the percentage of desalinated water produced from wind can reach 75% and 59% in 2020 for the scenarios 7 and 9, respectively, but for the following years, this value decreases. Regarding the maximization of renewable energy sources, the penetration of these technologies in this supply system reached 71%, with 65% of wind and 6% of hydroelectricity.

These scenarios need to be analysed in environmental and financial terms. There is also the need to examine the sites were the reservoirs can be built and the wind turbines installed, for instance to determine if it is possible to install reservoirs with this dimension, and what is the impact on the local environment.

In order to improve the input data of the first scenario and the baseline year, an update of the forecast of the demand growth will be carried out, together with an assessment of the demand in water and energy of the tourist projects foreseen for the Island.

Later work will be done on modelling the occurrence of fog in Mont Verde, and consider its collection to the upper reservoir, having this way more water stored in the upper reservoir, increasing the amount of water that can be turbinated to generate electricity and supplied to the population.

Acknowledgments

The authors acknowledge the contribution of the Portuguese National Foundation of Science and Technology of the Ministry for Science and Technology by supporting Raquel Segurado with a PhD grant (SFRH/BD/31663/2006). The authors would like to thank the company ELECTRA S.A., namely Eng. Rui Paisana for its availability in supplying the necessary data for this study. Finally, the authors would also like to thank the reviewers for their valuable comments to the article.

References

[1] Duić N, Krajačić G, Carvalho MG. Renew Islands methodology for sustainable energy and resource planning for Islands. Renew Sust Energy Rev 2008;12(4):1032–62.
[2] Mathiesen BV, Lund H, Karlsson K. 100% Renewable energy systems, climate mitigation and economic growth. Appl Energy 2010. doi:10.1016/j.apenergy.2010.03.001.
[3] Lund H, Mathiesen BV. Energy system analysis of 100% renewable energy systems – the case of Denmark in years 2030 and 2050. Energy 2009;34(5):524–31.
[4] Krajačić G, Duić N, Carvalho MG. H_2RES, Energy planning tool for Island energy systems – the case of the Island of Mljet. Int J Hydrogen Energy 2009;34(16):7015–26.
[5] Duić N, Carvalho MG. Increasing renewable energy sources in Island energy supply: case study Porto Santo. Renew Sust Energy Rev 2004;8(4):383–99.

[6] Duić N, Lerer M, Carvalho MG. Increasing the supply of renewable energy sources in Island energy systems. Int Sust Energy 2003;23(4):177–86.
[7] Lerer M, Duić N, Alves LM, Carvalho MG. H_2RES, energy planning tool for increasing the penetration of renewable energy sources in Island energy supply. In: Proceedings of the international conference on new and renewable energy technologies for sustainable development. Évora, Portugal; 2004.
[8] Krajačić G, Martins R. Busuttil, Duić N, Carvalho MG. Hydrogen as an energy vector in the Islands' energy supply. Int Hydrogen Energy 2008;33(4): 1091–103.
[9] Ntziachristos L, Kouridis C, Samaras Z, Pattas K. A wind-power fuel–cell hybrid system study on the non-interconnected Aegean Islands grid. Renew Energy 2005;30(10):1471–87.
[10] Duić N, Fonseca JP, Carvalho MG. Increasing the penetration of renewable energy by merging energy and water supply systems: case study Corvo Island, Azores. In: Proceedings of the 3rd Dubrovnik conference on sustainable development of energy, water and environment systems. Dubrovnik, Croatia; 2005.
[11] Bueno C, Carta JA. Technical-economic analysis of wind-powered pumped hydro storage systems. Part II: model application to the Island of El Hierro. Sol Energy 2005;78(3):396–405.
[12] Spyrou ID, Anagnostopoulos JS. Design study of a stand-alone desalination system powered by renewable energy sources and a pumped storage unit. Desalination 2010;257(1–3):137–49.
[13] Fadigas EAFA, Dias JR. Desalination of water by reverse osmosis using gravitational potential energy and wind energy. Desalination 2009;237(1–3):140–6.
[14] Henderson CR, Manwell JF, McGowan JG. A wind/diesel hybrid system with desalination for Star Island, NH: feasibility study results. Desalination 2009;237(1–3):318–29.
[15] Setiawan AA, Zhao Y, Nayar CV. Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remote areas. Renew Energy 2009;34(2):374–83.
[16] Folley M, Whittaker T. The cost of water from an autonomous wave-powered desalination plant. Renew Energy 2009;34(1):75–81.
[17] Corsini A, Rispoli F, Gamberale M, Tortora E. Assessment of H_2- and H_2O-based renewable energy-buffering systems in minor Islands. Renew Energy 2009;34(1):279–88.
[18] Udono K, Sitte R. Modeling seawater desalination powered by waste incineration using a dynamic systems approach. Desalination 2008;229(1–3):302–17.
[19] Ipsakis D, Voutetakis S, Seferlis P, Stergiopoulos F, Elmasides C. Power management strategies for a stand-alone power system using renewable energy sources and hydrogen storage. Int Hydrogen Energy 2008;34(16): 7081–95.
[20] Koschikowski J, Heijman B. Renewable energy drives desalination processes in remote or arid regions. Membr Technol 2008;8:8–9.
[21] Bermudez-Contreras A, Thomson M, Infield DG. Renewable energy powered desalination in Baja California Sur, Mexico. Desalination 2008;220:431–40.
[22] Connolly D, Lund H, Mathiesen BV, Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. Appl Energy 2010;87(4):1059–82.
[23] Lund H, Duić N, Krajačić G, Carvalho MG. Two energy system analysis models: A comparison of methodologies and results. Energy 2007;32(6):948–54.
[24] Østergaard PA. Reviewing optimisation criteria for energy systems analyses of renewable energy integration. Energy 2009;34(9):1236–45.
[25] National Statistics Institute of Cape Verde. Demographical predictions by geographical code and year (Projecções Demográficas por Código Geográfico e Ano). <http://www.ine.cv> [in Portuguese].
[26] World maps and city plans. <http://webcarta.net>.
[27] Electricity and Water Company (ELECTRA – Empresa de Electricidade e Água S.A.R.L.). Annual report 2005 (Relatório e Contas – Exercício de 2005); 2006. <http://www.electra.cv> [in Portuguese].
[28] Electricity and Water Company (ELECTRA – Empresa de Electricidade e Água S.A.R.L.). Annual report 2007 (Relatório e Contas – Exercício de 2007); 2008 <http://www.electra.cv> [in Portuguese].
[29] Ministry of Economy, Growth and Competitivity of Cape Verde. National energy plan – energy policy plan for Cape Verde (Plano Energético Nacional – Plano de Política Energética da República de Cabo Verde); May 2003 [in Portuguese].