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Integration study of a reverse osmosis desalination plant in a hydroelectric pumping station

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ABSTRACT

The archipelagos of Macaronesia (Canary Islands, Azores, Madeira and Cape Verde) have isolated energy systems (IES). This makes the island systems dependent on themselves for energy production. In the case of an island like Gran Canaria, energy production is mainly obtained from: a) Wind and solar energy, 19 % of the total energy produced, b) Energy obtained from the burning of fossil fuels in the energy production equipment of the existing power plants. Thermal power plants, 81 % of the total energy produced. It is necessary to find a solution to the current production system, which is already partially obsolete and must be renewed and/or dismantled, in order to avoid "Zero Energy", which implies a change in the production cycle. In addition, the incorporation of the "Chira-Soria" pumped-storage hydroelectric power plant into the Gran Canaria electricity system represents another, even more important, change in the dynamics followed up to now. Basically, this plant, hydraulically stabilized by means of a seawater desalination plant, incorporates energy storage by storing water at high altitude to be turbined under the right conditions. The new situation with this incorporation will be analysed and the option of integrated operation in the overall energy system of Gran Canaria will be assessed.

1. Introduction

It is considered the pumped hydroelectric power plants (PHEs) as one of the most widely used renewable energy production systems in the world. [1–10]. The need for decarbonization, the penetration of renewable energies and the broader vision of the management of our resources could be obtained with these technologies by improving their storage capacity [11–15]. Moreover, this is not indifferent to island energy systems, [5,7,8,16] for instance in the Canary Islands [2,4,9,17,18] and specifically in Gran Canaria, which faces a fourfold challenge in the coming years:

a) To meet the energy production objectives to satisfy a growing demand, using the current production plants that will be replaced with the progressive incorporation of new production technologies and to satisfy the needs opened by these obsolete units to be dismantled plus the increase in demand that is foreseen. [1,4,19–23]. It is currently covering a growing demand of 3350 GWh (demand in 2021), supported by an installed capacity of 1278.45 MW.
b) Avoiding the collapse of the system, a possible "Energy zero" or “blackout”, due to the incapacity and obsolescence of the energy system, which requires an action plan that addresses with technical solvency the incorporation of systems capable of satisfying the current growing demand. Renovating the partially obsolete energy production plant in Gran Canaria is the great challenge, which is already in the process of being renovated and/or dismantled. This plant is more than 30 years old, and its technological standards in terms of the current demanded requirement of minimum fuel consumption, maximum energy production and minimum emissions are far from the desired expectations for such production [3,24–30]. All of this is aggravated by the types of fuel used, fuel oil, and diesel oil, ignoring other alternatives that are environmentally better and even energetically more efficient [24–26]. Gran Canaria’s energy production depends 79,4 % on imported fossil fuels for electricity generation [26,27]. In the year 2021, this has a direct impact on the increase of electricity costs and CO emissions [2,9,23].
c) To achieve a progressive decarbonization of the generation system by incorporating more renewables or environmentally neutral systems. [23,28]. Currently, in the year 2021, the penetration of renewable energies in Gran Canaria stands at 20,6 %, [23,29] but is still the great challenge [1,4]. Environmental awareness has

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increased, this has led to the mobilization of island governments, promoting wind farms and encouraging the installation of solar panels, etc. Synthetic fuels with neutral CO_{2eq} emissions, could be one of the solutions, it is a question of promoting this use [2,18,30,31].

d) Similarly, and due to the scarcity of water resources [32], it is necessary to optimize and integrate alternative water resource systems into the island's energy system by means of a reverse osmosis desalination plant (SWRO), to stabilize the water levels required by the PEHS. SWROs have proven their suitability, currently representing 65 % of those implemented in the world [33,34]. In addition, these SWRO systems have implemented energy consumption reduction systems to minimize their carbon emission [33,35–37]. On the other hand, we find the adjustment and integration of the operating dynamics of the PEHs within an energy system [38–40]. All of this represents a change in the dynamics of the island's energy system to date, as it provides energy storage that can be used under appropriate conditions to pump water to the upper level, improve the penetration of energy from renewable and neutral sources and reduce greenhouse gases (GHG) emissions.

The aim of this article is to analyze the proposed incorporation of the new "Chira-Soria" PHEs into the global energy system of Gran Canaria, considering whether their integration into this energy system is effective and helps to alleviate the current shortcomings, and evaluating their operation, their virtues and shortcomings. Likewise, a study of the stabilization of water levels in the face of losses in the dams is proposed to guarantee the operation of the system, studying the capacity of the SWRO to satisfy the losses associated with the operation of the hydroelectric system, considering that variations in rainfall would not affect the operation of the PHEs.

2. Materials and methods

2.1. Methodology

The methodology adopted to analyses the system and propose the best integration solution in the face of the new energy situation, after the imminent incorporation of the Chira-Soria Pumped Hydroelectric Power Plant scheduled for 2030, has been detailed in Fig. 1 of the document. This methodology not only follows the guidelines of previous research, but also incorporates significant advances adapted to the specific characteristics of the new energy context. One of the highlights of this methodology is the development of an advanced computational algorithm, specifically designed to optimize the integration of this hydroelectric power plant into the existing system. The main objective of this algorithm is to maximize energy efficiency, minimize operating costs and minimize greenhouse gases, thus ensuring optimal management of available hydroelectric resources. This tool becomes a crucial component to facilitate real-time strategic decisions and to dynamically adapt system operations to fluctuating energy demands and offers.

2.2. Current energy production situation in Gran Canaria

The analysis data of the anon 2021 is taken, as it is the last official data available. Based on such data, Gran Canaria's current energy production in 2021 is supported by four steam turbines, five diesel units, five gas turbines, two combined cycles with double gas turbine and steam turbine, all of which represents 80,1 % of the installed power (1024.06 MW), with the percentage of installed power from renewables being 19.9 % (254.39 MW), which brings the total installed power to 1278.45 MW. The total energy demand was 3350,094 MWh of which 2661,453 MWh (79.4 %) were produced in thermal power plants by fossil fuel combustion and 668,641 MWh (20.6 %) by wind and photovoltaic systems of which 55,823 MWh are produced by photovoltaic panels (1.7 %) and 632,818 MWh by wind generation (18.9 %), as can be seen in Table 1.

As can be seen, from the data from the average daily usage, Appendix 1, the operation of the equipment is below the recommended level, this is due to its age which leads to difficulty in its use, more breakages, more hours in repairs, more hours of maintenance, in short, increasing variable operating costs, and the solution that is finally given is to have a lot of equipment in reserve ready for use when breakages occur. This leads to excess power due to an excess of equipment close to the limit of its useful life. From the data extracted from the average daily usage, in Appendix 1, we obtain the average daily use data (hours/day) for all the technologies, which is 7.30 h/day for combustion equipment, representing an average use of 30.41 %. The highest figure is for the Combined Cycle with a use of 10.41 h/day, which represents an average use of 43.46 %.

The study of the day of highest energy demand is a good indicator of the situation that the energy system of Gran Canaria must face in the immediate future, 17 August 2021 at 14:53, with 529.0 MW of instantaneous power. This day and time of peak power is the maximum since 2007. At that peak time, the point demand was met with 138.7 MW of renewables and 390.3 MW of non-renewables. The behavior of energy supply in response to this peak demand, distinguishing

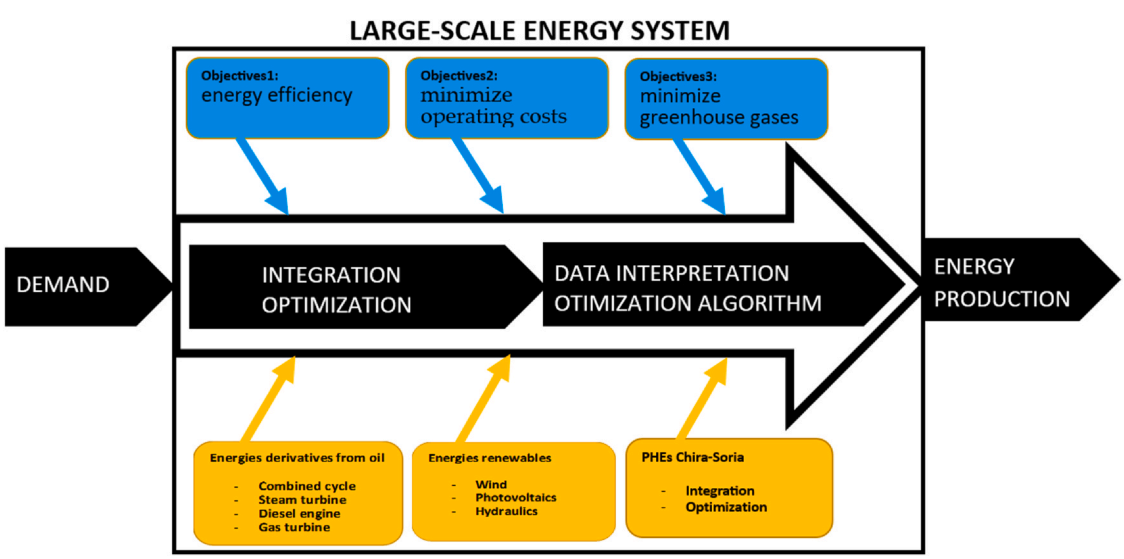

Fig. 1. Methodology.

Table 1
Installed Capacity (MW) and Demand Coverage (MWh). Gran Canaria, year 2021 [18].

Type Energy	Type Technology	Installed Power		Demand Coverage	
		MW	%	MWh	%
Energies derivatives from oil	Thermal power plants. Steam turbine	280.00	21.9 %	647,519	19.3 %
	Thermal power plants. Diesel engine	84.00	6.6 %	199,206	5.9 %
	Thermal power plants. Gas turbine	173.45	13.6 %	60,853	1.8 %
	Thermal power plants. Combined cycle	461.73	36.1 %	1753,875	52.4 %
	Cogeneration. Steam turbine	24.20	1.9 %	0	0.0 %
	Cogeneration. Diesel engine	0.68	0.1 %	0	0.0 %
	Cogeneration. Gas turbine	0.00	0.0 %	0	0.0 %
	Sum	**1024.06**	**80.1 %**	**2661,453**	**79.4 %**
Energies Renewables	Wind	205.24	16.1 %	632,818	18.9 %
	Photovoltaics	49.15	3.8 %	55,823	1.7 %
	Sum	**254.39**	**19.9 %**	**668,641**	**20.6 %**
TOTAL		**1278.45**	**100.0 %**	**3350,094**	**100.0 %**

Source: Canary Islands Energy Yearbook 2021.

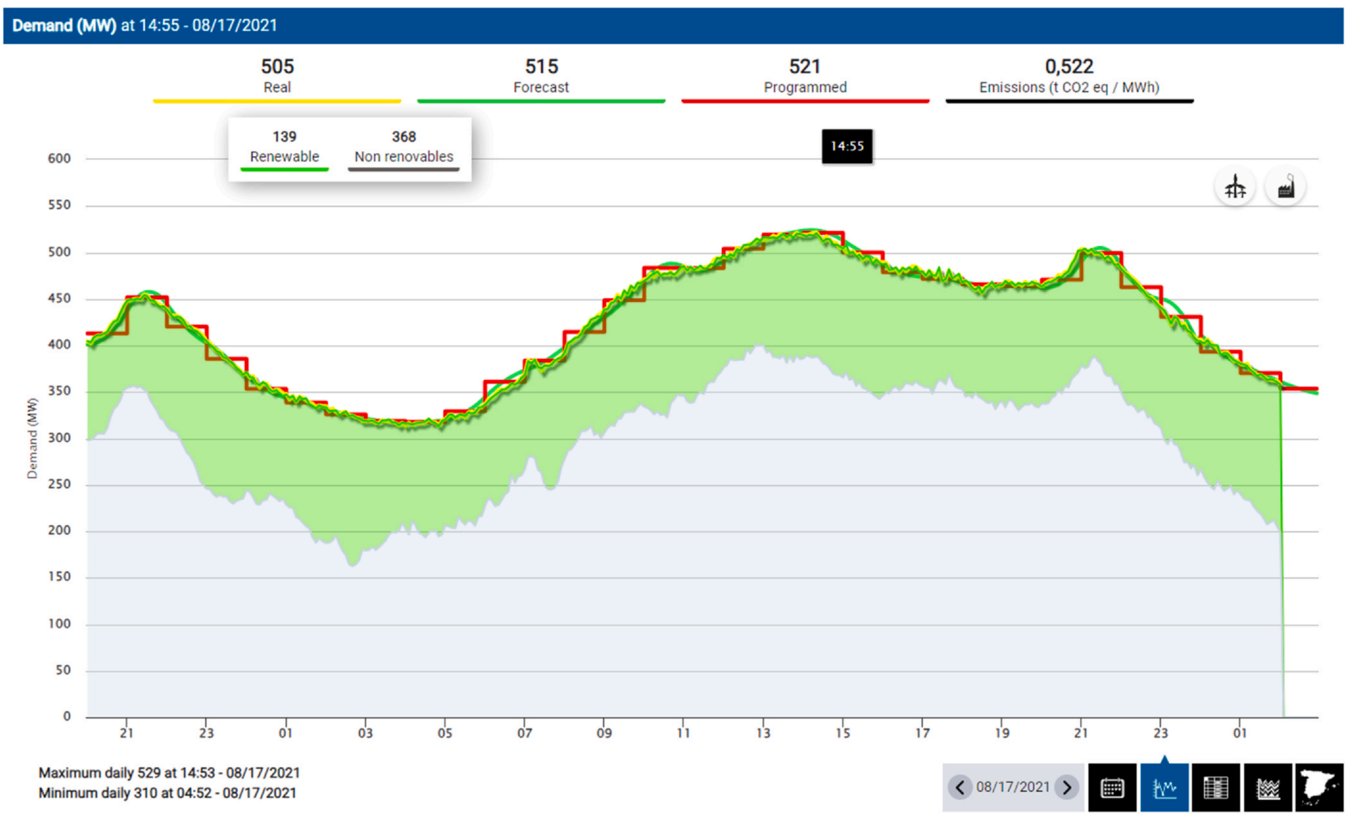

Fig. 2. Response to peak demand in 2021. Distinction between renewables and non-renewables. [31].

between renewables and non-renewables, is shown in Fig. 2. In Fig. 3, all the production equipment is differentiated. At the time of highest annual demand, the equipment that contributed the most was the combined cycle with 218.2 MW (43.09 %), followed by the steam turbine with 115.0 MW (22.69 %), wind with 112.4 MW (22.18 %), solar with 26.3 MW (5.19 %), diesel engines with 22.0 MW (4.34 %) and the one that contributed the least was the gas turbine with 12.9 MW (2.55 %).

Table 2 shows the type of fuel burned by technology and the type of GHG emitted. The total tons of fuel consumed in energy production in 2021 amounted to 555,811 t and the total tons of GHGs in 2021 as a result of their combustion amounted to 1782,561 tCO_{2eq}, with the final energy supplied, net of losses, being 3076,109 MWh and the GHG emissions 1782,561 tCO_{2eq}, the emission factor on the island of Gran Canaria for the year 2021 was 0.579 tCO_{2eq} /MWh.

2.3. “Chira- Soria” PHEs analysis

"Chira-Soria" is a new pumped hydroelectric power plant, PHEs, designed and thought several years ago and currently being built on the island of Gran Canaria, it is about taking advantage of the unevenness of two existing dams to produce energy through turbines. It is estimated that it will be operational in 2026 and will be the first facility of its kind on the island, and together with the rest of Gran Canaria's energy production equipment, it will serve a population of approximately one million inhabitants. This facility is located in the municipality of Tejeda, in the center of the island, as shown in Fig. 4.

2.3.1. Expectations of the Chira-Soria pumped-storage hydroelectric power station (PHEs)"

The wind power installed of Gran Canaria in 2021 is 205.24 MW in an electricity system whose valley demand in 2021 was 257 MW and

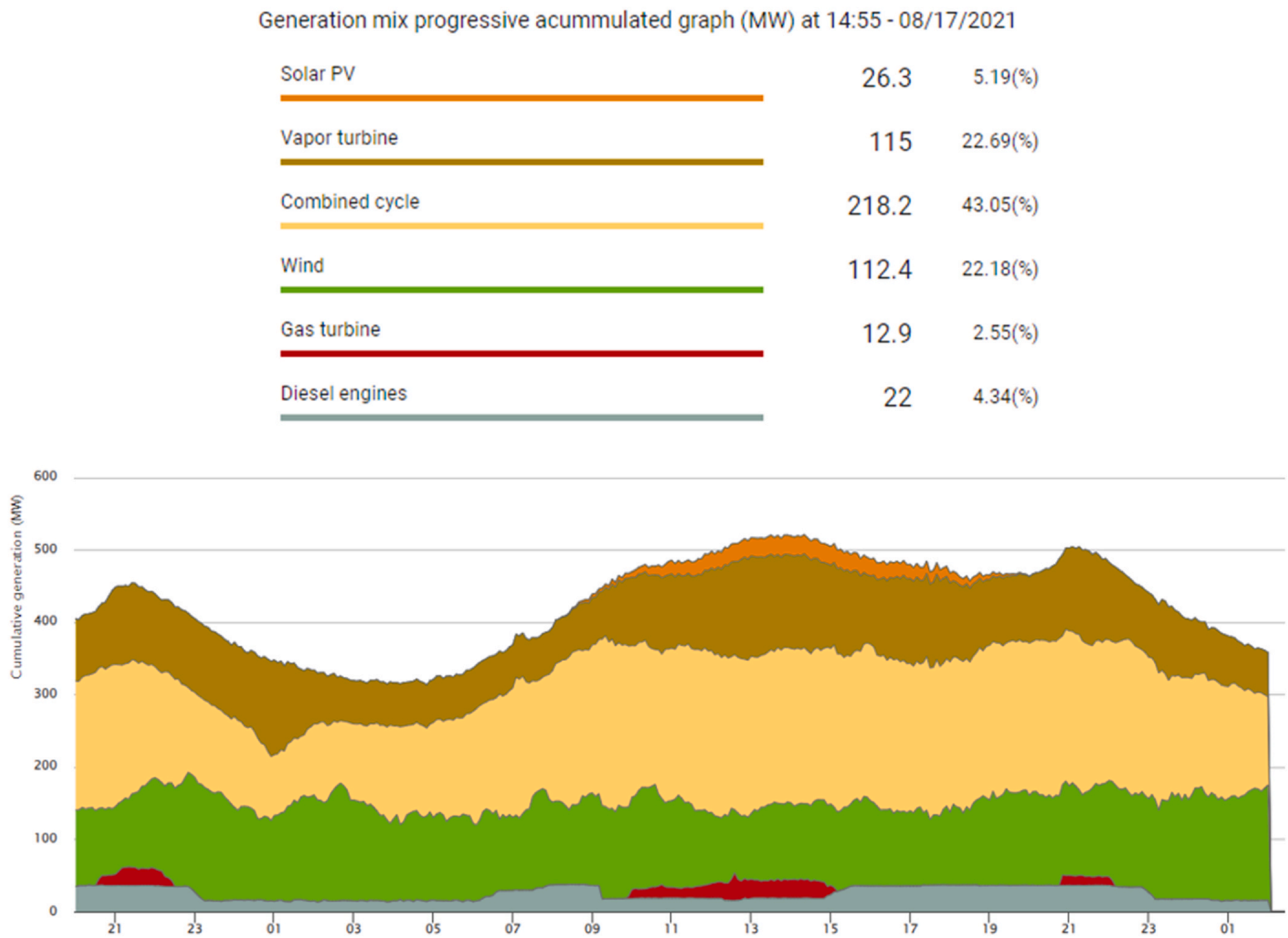

Fig. 3. 2021 peak demand response. Distinction between all renewable and non-renewable technologies. [31].

where there is a contingent of new installation projects (wind and photovoltaic) with a potential of 725 MW that have at least authorization for access to the grid.

The objective of the PHEs "Chira-Soria" would be to provide security of supply, ensuring the integration of the non-manageable renewable energy system. The high variability of the already installed wind generation introduces rapid frequency changes in the electricity system. These changes will continue to increase as installed wind power capacity increases. Frequency changes negatively affect consumers and could even lead to market disruptions. In this respect, the PHEs "Chira-Soria" would help mitigate the increasing degradation of frequency quality, making the system more stable, robust, and secure. It would also enable the penetration, under safe and quality of service conditions, of the expected large contingent of renewable energy. In this way, it would be possible to store surplus renewable energy that cannot be directly integrated into the system, making power balances viable and minimizing surpluses of renewable energy.

Because of the greater integration of renewables using an energy storage system, there would be a displacement of thermal generation in favor of renewable energy, with the consequent reduction of emissions, CO_2 and NO_x, which would bring economic and environmental advantages. It will allow adding flexibility to the energy system where the existing thermal generation park, designed for another energy context, lacks the necessary features for the adequate integration of renewable energies for the energy transition. The PHEs "Chira-Soria" would be characterized by a massive energy storage capacity, as well as by using a technology that would allow, depending on its operating mode, to maintain the synchronous characteristic of the electricity system, necessary for its operation, providing inertia, short-circuit power, etc.

Table 2
Fuels used (t) and GHGs produced (tCO2eq) in Gran Canaria in 2021.

Type Technology	**Fuels**			GHGs		
	Fuel (t)	**Diesel (t)**	**Diesel oil (t)**	**CO_2 (tCO_{2eq})**	**CH_4 (tCO_{2eq})**	**NOx (tCO_{2eq})**
Steam turbine	160.119,0	129,0	0,0	524.382	427,0	1.260,0
Diesel engine	37.852,0	1.561,0	0,0	128.793	105,0	310,0
Gas turbine	0,0	21.781,0	0,0	68.710	58,0	172,0
Combined cycle	0,0	334.369,0	0,0	1.054.799	897,0	2.648,0
Total	**197.971,0**	**357.840,0**	**0,0**	**1.776.684,0**	**1.487,0**	**4.390,0**

Source: Canary Islands Energy Yearbook 2021 [18].

Fig. 4. Location: Chira-Soria PHEs.

In addition, a desalination plant would be incorporated to produce sufficient water to compensate for the losses associated with the operation of the hydroelectric system, and variations in rainfall would not affect the operation of the PHEs. At present, the productive uses linked to the crops that supply the Chira and Soria reservoirs are subject to the availability of resources, an aspect that depends on the rainfall regime in the south of Gran Canaria. The desalination plant would keep the water in the reservoir within the appropriate volume limits.

2.3.2. Technical characterisation of the PHEs 'Chira-Soria'

2.3.2.1. Description of units. A simplified schematic of the hydraulic network of this installation is shown in Fig. 5 and Fig. 6 shows the general plan of the hydraulic circuit, with the Chira reservoir on the right and the Soria reservoir on the left (image oriented south instead of north).

The turbomachines that make up the PHEs Chira-Soria pumped-storage hydroelectric power station are listed in Table 3, as well as the operating characteristics for turbining and pumping.

The capacity of the Chira dam is 5640,000.00 m^3 and that of Soria dam is 32,300,000.00 m3, with a maximum transfer capacity of 4080,000.00 m^3.

The seawater reverse osmosis plant, it will keep the reservoir water within the proper volume limits, its production figures are negligible compared to those of pumping and turbining, produce 7900.00 m^3 in 24 h compared to turbine, 3939,840.00 m^3 in 16 h and pumping 1537,920.00 m^3 in 8 h. This seawater desalination plant, installed in the system as a complement to the natural inputs of the system, consists of an open intake seawater intake, a collection tank, raw water pipes, an outfall with Venturi diffuser and a product water pumping tank with capacity of 1000 m^3.

2.3.2.2. Stabilization of the water resource. A detailed study has been carried out to determine the needs for industrial water supply to the Soria reservoir, and therefore to the hydroelectric power plant. The inflows must allow the hydroelectric system to operate at full capacity at any time during the operating period. For the analysis of industrial water production needs, three different calculations have been carried out. The annual losses due to the evaporation and filtration processes corresponding to the own water were determined, resulting in a total of 1.63 hm3/year, sensitivity to the climate change scenario was analysed, in accordance with the conclusions of the Paris Climate Summit, which set the objective of limiting the increase in the average annual temperature to 1.5 °C by 2010, it is found that the annual losses would amount to a maximum of 1.68 hm3/year.

The basic capacity data of the seawater reverse osmosis plant that resulted from this was 1.80 hm3/year.

SWRO's surplus production will also be used to supply the town of Arguineguín, close to the installation, as shown in Fig. 7.

2.3.3. Operational description

As established in the PHEs "Chira-Soria" Project, the power plant's groups would operate in pumping mode when there is excess energy, due to excess non-manageable generation, mainly wind, or due to low consumption, which would force the large thermal groups to operate in modes of poorer performance or below their technical minimum. Turbinating would occur at peak demand times, replacing the energy that would have been produced by thermal technologies with higher variable system costs and greater environmental impact. Thus, the plant will operate with a daily cycle in which:

– Turbomachines in pumping mode. The groups will consume energy to pump water from the lower basin (Soria) to the upper basin (Chira) in the off-peak period of the night demand (typically from 0.00 h to 7.00 h). This will allow, on the one hand, the use of renewable energy generated at night that is not consumed, as well as the base groups that will be able to operate with better performance

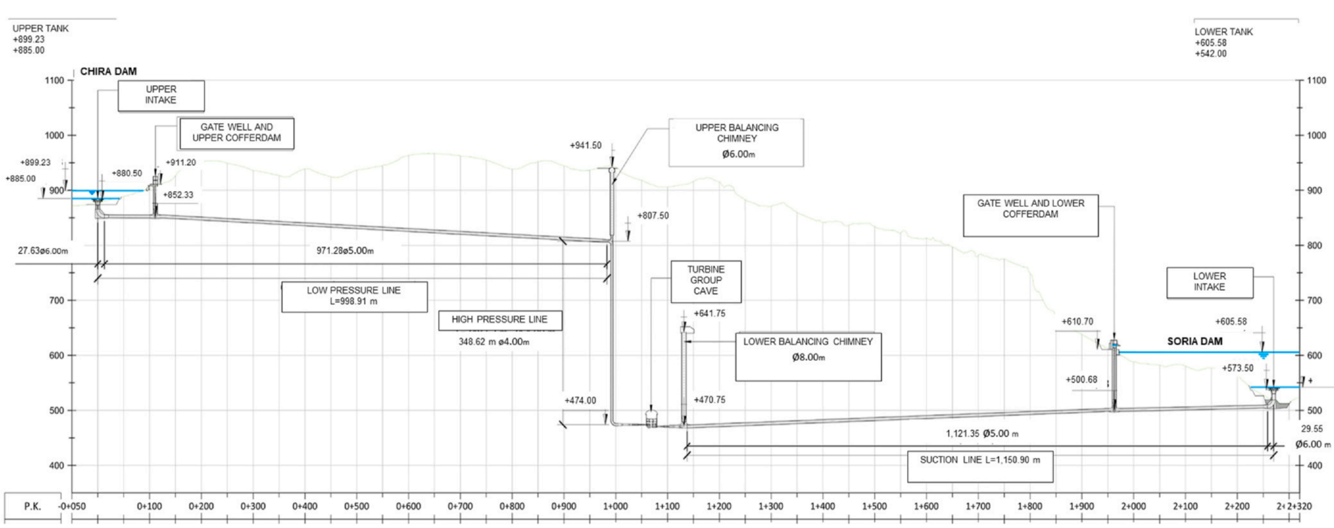

Fig. 5. General diagram of the PHEs "Chira-Soria" pumped-storage hydroelectric power station (PHEs) hydraulic network. [31].

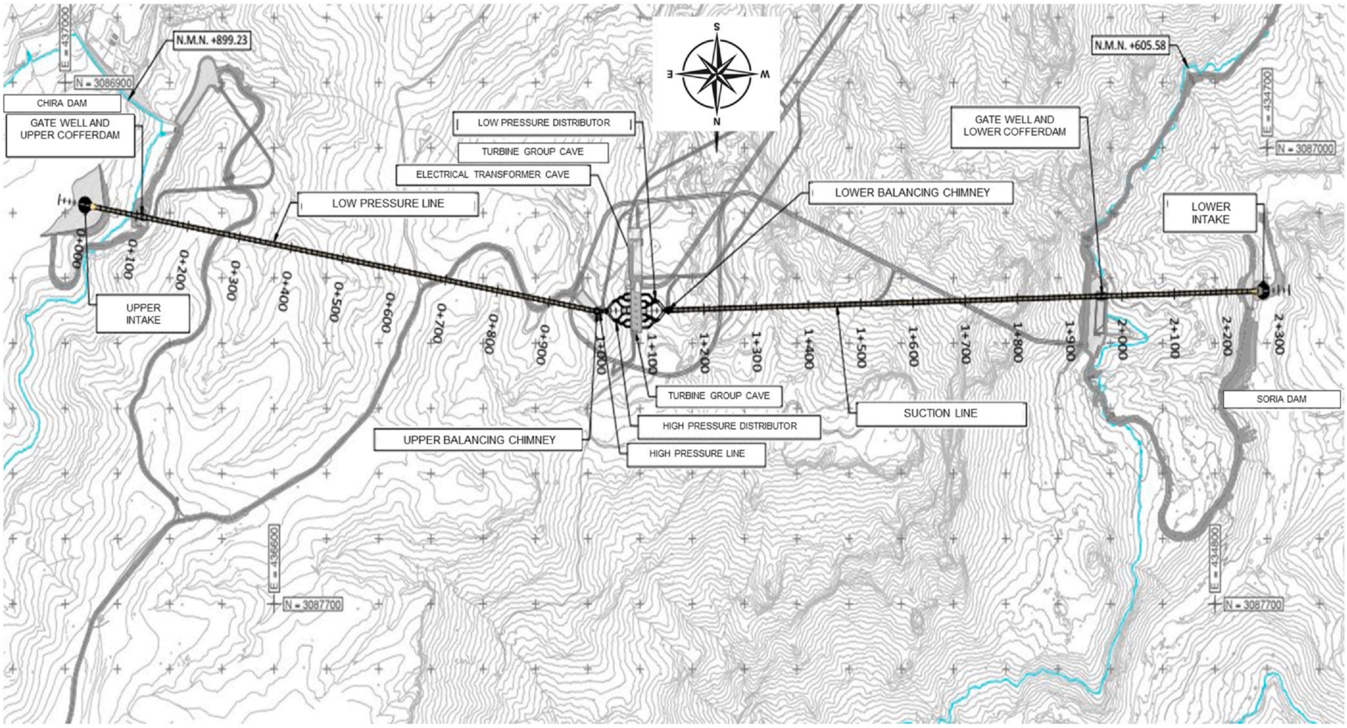

Fig. 6. General plan of the Hydraulic Circuit, with the Chira reservoir on the right and the Soria reservoir on the left in this image (image oriented south instead of north). [31].

during the night and, consequently, reduce the specific CO_2 emissions of the whole. It will also avoid shutting down certain units for a few hours, and thus the subsequent start-up, which is costly. On the other hand, in cases where there is excess wind energy production in the system, pumping will make it possible to "artificially" increase demand, making it possible to integrate the electricity production corresponding to this excess.

- Turbomachines in turbined mode. The units will produce energy by turbining the water conveyed from the upper basin to the lower basin, during peak demand hours (typically from 9.00 to 23.00) and the morning (typically from 10.00 to 13.00) and evening (19.00 to 21.00) peaks. They will thus replace, during the year, higher variable cost technologies (gas turbines running on diesel).

On the other hand, hydroelectric power is very fast in its start-up and power variation, allowing it to respond quickly to failures of grid or system elements. In the event of a total power failure (zero electricity) on the island, the Chira-Soria plant could initiate the recovery of supply in a few minutes, 10–20 min, given its enormous flexibility, being the generating equipment that will initiate the process of replenishing the system. The generation power is 200 MW, the pumping power consumed is 220 MW and the cumulative energy is 3,2 GWh (turbining for 16 h). The transferable volume from the Chira reservoir to the Soria reservoir is 4.08hm^3. The sedimentation study shows that the calculated volume of diversion water will not be affected by the increase in sedimentation and therefore the decrease in the capacity of the dam for at least 50 years, after which it will have to be dredged, which gives us an initial useful life of 50 years of PHEs.

2.3.4. Data analysis. Search for strengths and weaknesses

2.3.4.1. Pumping-turbine balancing operation. As indicated in the previous section, the plant's units would operate in pumping mode and in turbine mode at certain times of the day, and this situation is analysed first. The Table 4 shows the electricity demand required in both modes for the different operating hours, as well as the amount of water pumped and turbined.

If we want to maintain the transfer level, we cannot turbine without having first replenished the water levels. Consequently, it is always necessary to follow a balance between turbining and pumping in the unit of time that is valued and always without exhausting the transfer capacity. This balance is:

This means that if 43.84 % of the time (10 h and 31 min) we run the turbines, 56.16 % of the time (13 h and 28 min) we need to pump. Obtaining 2104.43 MWh/day with turbine and need 2965.12 MWh/day for pumping.

2.3.4.2. Estimated power and renewable energy production. As mentioned above, the PHEs "Chira-Soria" project will maximize the integration of renewable energies, avoiding the discharges that would otherwise occur and enabling the development and installation of this type of energy.

There is a contingent of new installation projects (wind and photovoltaic) with a potential of 725 MW that have at least grid access

Table 3
Turbine characteristics according to their operation.

Type Operation	Ud	Stipulated Hours of Work	Power Unit	Total	Flow rate	Volume of water displaced	Energy/day
	Ud	hours	MW	MW	m^3 /s	m^3	MWh
(T1) Turbinating	6	16	33.33	200.00	68.40	3939,840.00	3200.00
(B1) Pumping	6	8	36.67	220.00	53.40	1537,920.00	1760.00

Source: PHEs Project "Chira-Soria".

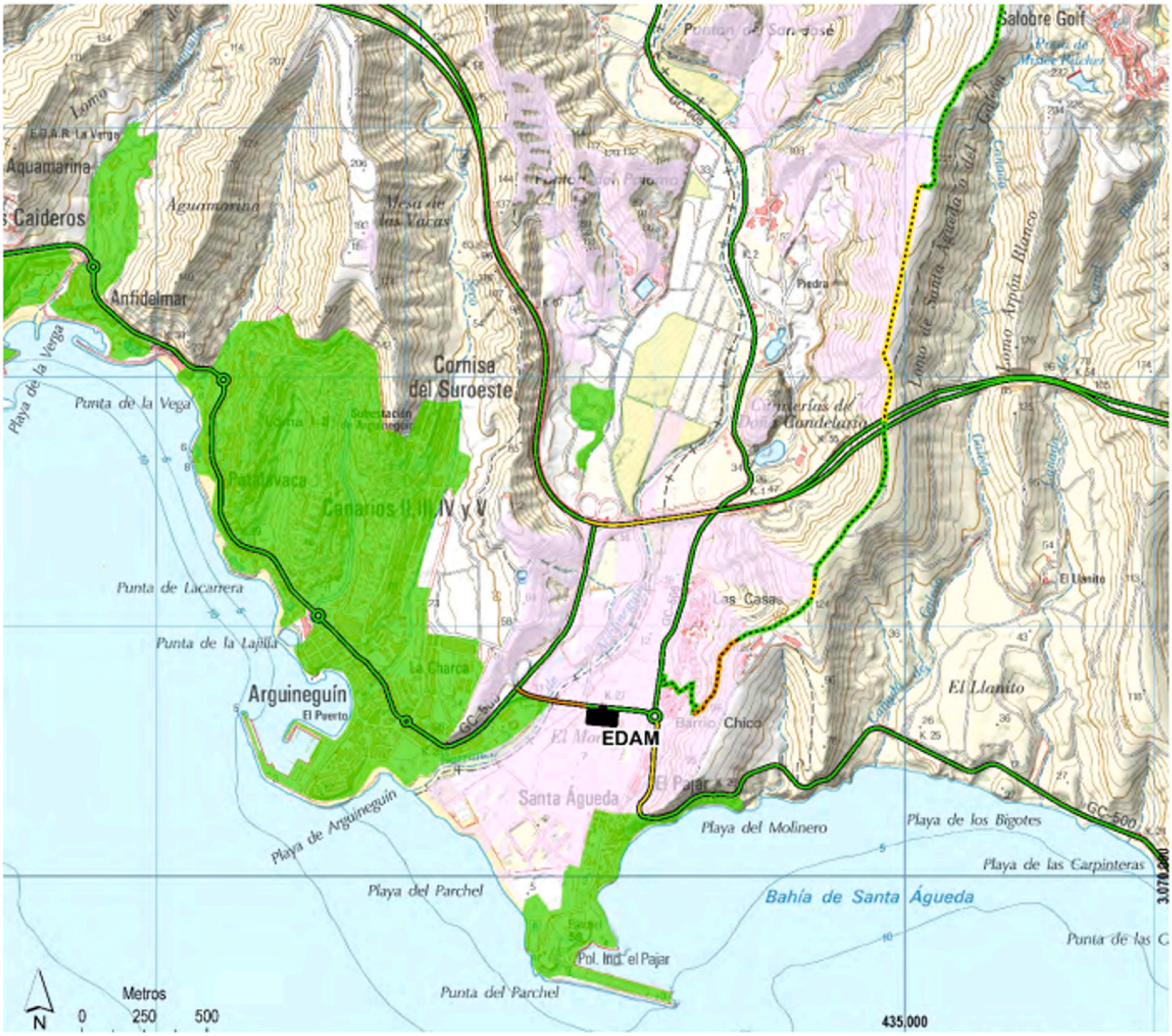

Fig. 7. Location SWRO and city of Arguineguin.

authorization, the current reality is show in Appendix 5, although currently only 400.97 MW are confirmed (Situation with Final registration).

The forecast growth of energy produced in renewables is shown in Table 5, taking as a reference the data for 2021 on the average operating hours of renewable sources. For wind power, the average annual capacity factor for twelve-month operation is 36.76 %, i.e. 8.82 equivalent hours/day (3220 equivalent hours per year). Considering the hours available to work, 24 h a day, 365 days a year, for photovoltaic, the Annual Average Capacity Factor is 24.27 %, i.e. 2.91 equivalent hours/day, (1063 equivalent hours per year), considering the hours available to work, 12 h a day, 365 days a year.

2.3.4.3. Study of installed power in the island electricity system with the incorporation of the PHEs "Chira-Soria". Based on the above analysis, the following energy-producing facilities would be as shown in Table 6:

The installed capacity has increased by 13.53 %, with total installed capacity in renewables accounting for 30.73 % of total capacity.

2.3.4.4. Study of the energy demand and production in the Gran Canaria system with the incorporation of the PHEs "Chira-Soria". In terms of demand, with the incorporation of the PHEs project, it should be borne in mind that the plant needs to pump water from Soria to Chira to achieve balance, which means an increase in demand due to pumping

Table 4
Equilibrium pump-turbine operation.

Operating Mode	Operation		Power	Energy/day	Flow rate	Volume of water displaced
	Hours/day	%	MW	MWh	m /s^{3}	m^{3}
Equilibrium Turbinado	10.522	43.84 %	200.0	2104.43	68.40	2590,978.53
Balance pumping	13.478	56.16 %	220.0	2965.12	53.40	2590,978.52
Sum	**24.000**	**100.00 %**				

Table 5
Forecast growth of energy produced in renewables.

Type renewable	Chira-Soria Project Estimate MWh year	Situation year 2021 MWh year	Situation year 2023 MWyear	Situation with Final registration MWyear
Wind	1829,629.76	641,990.72	955,572.72	1001,585.60
Photovoltaic	148,905.04	52,246.45	77,769.08	85,858.51
Sum	**1978,534.80**	**694,237.17**	**1033,341.80**	**1087,444.11**

of 2965.12 MWh per day on average, or 1082,268.8 MWh per year on average for maximum pumping use, i.e. 56.16 % of the annual average time, which means that the demand with the incorporation of the PHEs project will increase from 3350,094.00 MWh per year to 4432,362.80 MWh per year as a maximum.

In terms of energy production, there is an increase due to turbine of 2104.43 MWh per day on average, or 768,118.23 MWh per year on average for maximum turbine use, i.e. 43.84 % of the annual average time, with the incorporation of the Chira-Soria hydroelectric pumping station project, electricity production would increase from 3350,094.0 MWh per year to a maximum of 4118,212.23 MWh per year, generating a deficit in demand of 314,151,72 MWh per year. Table 7 shows different hypotheses for the increase in demand and electricity production due to the different percentages of pumping and turbine use in the PHEs.

2.3.4.5. Calculation of the new needs for renewable wind power production in the Gran Canaria system with the incorporation of the " PHEs "Chira-Soria. To compensate for the new energy production, need to cover the new demand, two scenarios are considered, a) to cover the difference between pumping and turbining, b) to cover all pumping. For this purpose, we calculate the wind power requirements for different capacity factors. As indicated above, the average annual capacity factor for twelve-month operation is 36.76 %, i.e. 8.82 equivalent hours/day (3220 equivalent hours/year).

For the first scenario, Table 8, it turns out that we would need 97.56 MW to cover the net difference in consumption and running pumping and turbining for as long as possible, i.e. 56.16 % and 43.84 % of the time, and assuming a wind capacity factor of 36.76 %, (8.82 h/day) which is the figure achieved in 2021. For the second scenario, Table 9, we would need 336.11 MW to cover pumping for the maximum possible time, i.e. 56.16 % of the time, and assuming a wind capacity factor of 36.76 % (8.82 h/day), which is the figure achieved in 2021.

On the other hand, these data on installed power and wind energy production versus pumping operating hours must be compared. The operating hours of pumping must be coordinated with the operating hours of wind power. To do this, let us consider the most extreme case, that is, when the entire transfer capacity from Chira to Soria has been turbined and must be pumped back to Chira. The volume that can be transferred from the Chira reservoir to the Soria reservoir is 4.08hm^3.

As shown, Table 10, the maximum pumping capacity is produced by pumping for 21 h and 13 min. In this case, it is possible to obtain the power shown in the table depending on the capacity wind factor.

Therefore, for the extreme case that concerns us, working the pumping for 21 h and 13 min, we would need 529.27 MW, which could demand 1703,878.91 MWh per year, assuming a wind power capacity factor of 36.76 % (8.82 h/day), as shown in Table 11.

2.3.4.6. Calculation of the volume of volume of water transferred in the Soria reservoir. The number of water renewals in the dam per year to obtain the maximum annual power with the turbine is estimated as follows, i.e. 768,118.23 MWh per year.

As determined above, it takes 16 h and 34 min to empty the dam and 21 h and 13 min to refill it, for a total renovation time of 37 h and 47 min, requiring 231.8 annual renovations to produce the maximum annual turbine power.

2.4. Integration of the Chira-Soria hydroelectric pumping station into the overall energy system of Gran Canaria

2.4.1. Contribution to the current energy system of Gran Canaria

As shown, where the day of highest electricity demand in 2021 is analysed, among others, the wind energy contribution remains almost constant during the 24 h (Fig. 8), instantly disposing of an average of 119.21 MW out of a total of 205.24 MW installed, with its maximum average per hour being 147.5 MW and its minimum average per hour being 91.1 MW. But these are one-off events as it is practically constant. The following graph, Fig. 8, shows the average hourly values of wind power during 24 h.

This behavior is repeated annually. This corroborates what we know about installed wind power production: it is far below what is desirable. Therefore, there is still no possibility of waste due to excess wind power production.

The increase in wind power, in addition to that currently existing, to cover the maximum pumping operation (MW) of the PHEs "Chira-Soria" (Table 11), assuming a wind power capacity factor of 36.76 % (8.82 h/day), results in 529.27 MW. There is currently 205.24 MW of wind power installed, so the integration and commissioning of the Chira-

Table 6
Estimated Installed Capacity (MW) including the PHEs "Chira-Soria".

Type Energy	Type Technology	Installed Power	
		MW	%
Energies Derivatives from oil	Thermal power plants. Steam turbine	280.00	18.94 %
	Thermal power plants. Diesel engine	84.00	5.68 %
	Thermal power plants. Gas turbine	173.45	11.73 %
	Thermal power plants. Combined cycle	461.73	31.23 %
	Cogeneration. Steam turbine	24.20	1.64 %
	Cogeneration. Diesel engine	0.68	0.05 %
	Cogeneration. Gas turbine	0.00	0.00 %
	Sum	**1024.06**	**69.72 %**
Energies renewables	Wind	205.24	13.88 %
	Photovoltaics	49.15	3.32 %
	Hydraulics	200.00	13.53 %
	Sum	**454.39**	**30.73 %**
Total		**1478.45**	**100.00 %**

Table 7
Increase in electricity demand and production with the incorporation of the PHEs "Chira-Soria".

Increase in energy demand with the incorporation of the PHEs "Chira-Soria".							
Percentage Pumping performance (%)	56.16 %	50.00 %	40.00 %	30.00 %	20.00 %	10.00 %	0.00 %
Hours per day Pumping (h/day)	13.48	12.00	9.60	7.20	4.80	2.40	0.00
Increase Demand (MWh year)	1082,269.95	963,600.00	770,880.00	578,160.00	385,440.00	192,720.00	0.00
Pre-existing demand (MWh year)	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00
Sum (MWh year)	4432,363.95	4313,694.00	4120,974.00	3928,254.00	3735,534.00	3542,814.00	3350,094.00
Increased energy production with the incorporation of the Chira-Soria Turbine.							
Percentage Turbined Operation (%)	43.84 %	39.04 %	31.23 %	23.42 %	15.61 %	7.81 %	0.00 %
Hours per day Turbined (h/day)	10.52	9.37	7.49	5.62	3.75	1.87	0.00
Production increase (MWh year)	768,118.23	683,894.74	547,115.79	410,336.84	273,557.90	136,778.95	0.00
Pre-existing production (MWh year)	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00	3350,094.00
Sum (MWh year)	4118,212.23	4033,988.74	3897,209.79	3760,430.84	3623,651.90	3486,872.95	3350,094.00
Demand-Production Difference (MWh year)	**-314,151.72**	**-279,705.26**	**-223,764.21**	**-167,823.16**	**-111,882.10**	**-55,941.05**	**0.00**

Soria hydroelectric plant could be carried out, but this would be at the cost of subtracting installed capacity and energy production from the system. In the average that more wind power is installed and we get closer to the proposed, the PHEs "Chira-Soria" will be closer to the objective for which it has been designed.

Another analysis carried out for better integration looks for daily production differences, Fig. 9. The weekly energy production-energy demand has been analyzed to study the possible variations in demand on days when there is less work activity and to take advantage of the lower energy production from combustion in that period for use in pumping, thus helping to comply with the minimum technical operating requirements of the groups, almost exclusively in the Combined Cycle. This situation would be a good transitional contribution until the expected demand in the plant is covered by wind turbines and would be usable on days of less work activity.

2.4.2. Contribution to the immediate-future energy system of Gran Canaria

The case for which the PHEs "Chira-Soria" has been designed is studied, i.e., according to the results of this study, a minimum additional wind power of 529.27 MW, bringing the total wind renewable energy to 734.51 MW.

Table 12 shows the new power table for this scenario. The total installed capacity is 2007.72 MW, if 49.0 % of the capacity comes from renewable sources. In terms of generation, it should be noted that the possible generation includes generation from the hydro turbine and new wind renewables, and that a new demand appears, which is from pumping from the power plant, as shown in Table 13.

This means that there is an increase of 1389,727.64 MWh per year over the current situation of over-production in renewables. This production can be used, among other things, to mitigate the demand covered by non-renewable production, which is 2661,453 MWh, and for pumping. It would mean a reduction of almost 47.78 % in polluting generation and therefore in emissions and would mean that renewable electricity production would be 71.31 %.

3. Results and discussions

During the analysis process, it has been determined what the incorporation of the PHEs "Chira-Soria" in the energy production system in Gran Canaria entails and the stabilization of the water levels of the dams for their guaranteed operation has been exposed. The results obtained are as follows:

3.1. Associated with the characteristics of the installation

- The use of turbo hydraulic machines that operate in pumping have a worse performance (more power demanded for lower hydraulic consumption), generate a deficit of 20 MW and a lower pumping flow than the turbine.
- As a consequence, more time is required in the pumping phase and more energy than that obtained in the turbine to restore the normal operating levels of the reservoirs. Out of a maximum of 24 h of operation, 13.5 h of pumping are required versus 10.5 h of turbinating. Under these conditions, an annual energy deficit of 314,152 MWh would be obtained.
- The capacity of the Chira reservoir with 5.64 hm^3, allows a transfer capacity of 4.08 hm^3, this being the limiting value for the determination of the maximum energy delivery in the planned power plant. This maximum value would be obtained in the continuous turbine phase for 16 h and 34 min to deliver 3313.84 MWh that must be compensated with 21 h and 15 min of pumping, requiring 4669.16 MWh.

3.2. Associated with the stabilization of water resources

The exhaustive analysis carried out to assess the industrial water supply needs of the Soria reservoir and, consequently, the associated hydroelectric plant, highlights the importance of maintaining adequate inflow flows to allow the optimal operation of the hydroelectric system at any time during the operation cycle. Within the framework of this study, as indicated, three different evaluations were carried out to specify the demands of industrial water production, quantifying the annual losses attributable to the processes of evaporation and percolation in the stored water, which amounted to 1.63 cubic hectometers per year (hm / year), performing a sensitivity analysis considering a climate change scenario aligned with the objectives established during the Climate Summit of Paris, which aims to limit the increase in average annual temperature to 1.5 °C by 2100. According to this scenario, annual losses could increase to 1.68 hm / year and finally, to determine the average annual consumption of industrial water, a simulation of the operation of the reservoirs was carried out in the period between 1972 and 2019.

The results of this simulation are detailed in Table 14, which shows the water consumption scenarios based on the annual and seasonal variations observed during the period analyzed. This methodological approach allows for more precise planning adapted to future needs, thus ensuring the sustainability of water resources in the context of progressive climate change.

Finally, the time needed to have a volume of own water of 5hm3 was analyzed, which, according to the requirements of the Concession, must be less than 60 months (5 years). The results obtained were as follows:

- In the case of not having the natural inputs to the Soria reservoir and filling it only with the industrial water produced in the ROS plant, a total of 43 months would be required, and the flow to be produced would amount to 6396,160.62 m3.

Table 8
Increase in wind power capacity to cover the difference in demand with the incorporation of the Chira-Soria Hydroelectric Pumping Station.

Percentage Pumping performance (%)		56.16 %	50.00 %	40.00 %	30.00 %	20.00 %	10.00 %	0.00 %
Hours pumping operation per day (h/day)		13.48	12.00	9.60	7.20	4.80	2.40	0.00
Capacity factor Wind	**Equivalent operating hours/day Wind**	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)
25.00 %	6.00	143.45	127.72	102.18	76.63	51.09	25.54	0.00
29.17 %	7.00	122.96	109.47	87.58	65.68	43.79	21.89	0.00
33.33 %	8.00	107.59	95.79	76.63	57.47	38.32	19.16	0.00
35.71 %	8.57	100.43	89.42	71.54	53.65	35.77	17.88	0.00
36.76 %	**8.82**	**97.56**	**86.86**	**69.49**	**52.12**	**34.75**	**17.37**	**0.00**
37.50 %	9.00	95.63	85.15	68.12	51.09	34.06	17.03	0.00
41.67 %	10.00	86.07	76.63	61.31	45.98	30.65	15.33	0.00
45.83 %	11.00	78.24	69.67	55.73	41.80	27.87	13.93	0.00

Table 9
Increase in wind power to cover exclusively the increase in total pumping demand with the incorporation of the Chira-Soria hydroelectric pumping station.

Percentage Pumping performance (%)		56.16 %	50.00 %	40.00 %	30.00 %	20.00 %	10.00 %	0.00 %
Hours pumping operation per day (h/day)		13.48	12.00	9.60	7.20	4.80	2.40	0.00
Capacity factor Wind	**Equivalent operating hours/day Wind**	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)	**Power** (MW)
25.00 %	6.00	494.19	440.00	352.00	264.00	176.00	88.00	0.00
29.17 %	7.00	423.49	377.14	301.71	226.29	150.86	75.43	0.00
33.33 %	8.00	370.64	330.00	264.00	198.00	132.00	66.00	0.00
35.71 %	8.57	345.99	308.06	246.45	184.83	123.22	61.61	0.00
36.76 %	**8.82**	**336.11**	**299.25**	**239.40**	**179.55**	**119.70**	**59.85**	**0.00**
37.50 %	9.00	329.46	293.33	234.67	176.00	117.33	58.67	0.00
41.67 %	10.00	296.51	264.00	211.20	158.40	105.60	52.80	0.00
45.83 %	11.00	269.56	240.00	192.00	144.00	96.00	48.00	0.00

Table 10
Maximum Turbinating and Pumping capacity limited by maximum racking capacity.

Operating Mode	Operation		Flow rate	Volume of water displaced
	Hours	%	m /s^3	m^3
Equilibrium Turbinado	16 h 34 min	43.84 %	68.40	4080,000.00
Balance pumping	21 h 13 min	56.16 %	53.40	4080,000.00
Sum		**100.00 %**		

Table 11
Wind power increase to cover maximum pumping operation (MW).

Pumping operating hours (h)		13.48 h 13 h 28 min	21.22 h 21 h 13 min
Capacity factor Wind	**Operating hours equivalents/day Wind**	**Power** (MW)	**Power** (MW)
25.00 %	6.00	494.19	778.19
29.17 %	7.00	423.49	667.02
33.33 %	8.00	370.64	583.65
35.71 %	8.57	345.99	544.84
36.76 %	**8.82**	**336.11**	**529.27**
37.50 %	9.00	329.46	518.80
41.67 %	10.00	296.51	466.92
45.83 %	11.00	269.56	424.47

– With 20 % of the natural water reaching the Soria reservoir, as indicated in the Concession, the filling process would produce the following scenarios:

Unlikely scenario (5 % chance of occurrence): 24 months.
Medium scenario (50 % chance of occurrence): 38 months.
Worst-case scenario (100 % chance of occurrence): 43 months.
The basic capacity data of the resulting seawater reverse osmosis plant is shown in Table 15.

3.3. Associated with the integration of renewables

– According to the PHEs "Chira-Soria", an installed renewable energy capacity forecast of 725 MW is indicated.
– The need to re-establish the level of the Chira reservoir may eventually require an increase in renewable power of 529.22 MW, to reach 734.51 MW, data obtained because of our study, which, considering the required operating time (21 h and 15 min), will have to be used in the field of wind energy.
– With the above result (734.51 MW), the installed wind power capacity in the island's energy park would account for 49 % of the total.
– If the maximum power production per turbine is sought, 768,118.23 MWh per year, 231.8 annual renewals of the maximum volume of transfer of the reservoir would be needed.

3.4. Associated with beneficial contributions to the system

The PEHS, confirming the final installation of 725.00 MW-734.51 MW, would achieve great benefits:

– It would maximize the integration of renewable energies, avoiding spills that would otherwise occur and enabling the development and installation of this type of energy.
– It would provide security to the electrical system and guarantee of supply.

✓ It would stabilize the frequency, the quality of which worsens as the installation of non-dispatchable renewables increases.
✓ It would increase the flexibility of the electrical system, improving its response and making it safer in the face of disturbances.

– It would reduce the costs of the electricity system.
– It would reduce energy dependence on the outside world.

3.5. Associated with greenhouse gas (GHG) emissions

It is shown in the following graph for the average day of the total emissions produced and compared with those produced with the integration of the Chira-Soria Pumped Hydroelectric Power Plant.

It is verified that the average daily emissions were 6145.61 tCO2eq/day, which means 2243,202.21 tCO2eq/year annually and with the incorporation of the Chira-Soria Pumped Hydroelectric Power Plant, which in the pumping phase the emissions increase, but in the turbine phase decrease, there would be a net result of reduction in emissions of 1432.98 tCO2eq/day, or 523,038.12 tCO2eq/year, which represents a decrease of 23.32 %. A summary table of the most significant parameters of the integration of the Chira-Soria Pumped Hydroelectric Power Plant is shown, highlighting the decrease in emissions due to its integration.

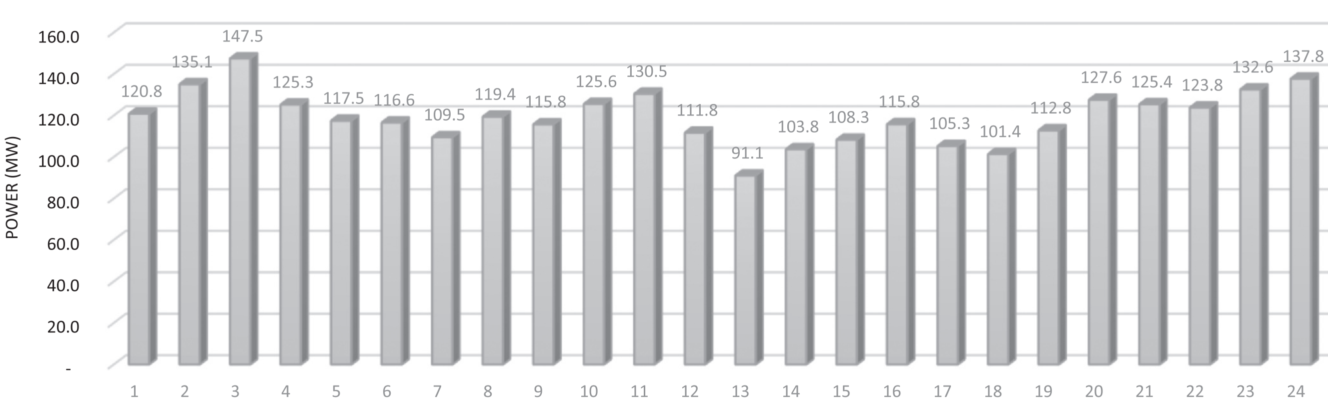

Fig. 8. Instantaneous wind power production (MW) on 17 August 2021 [18].

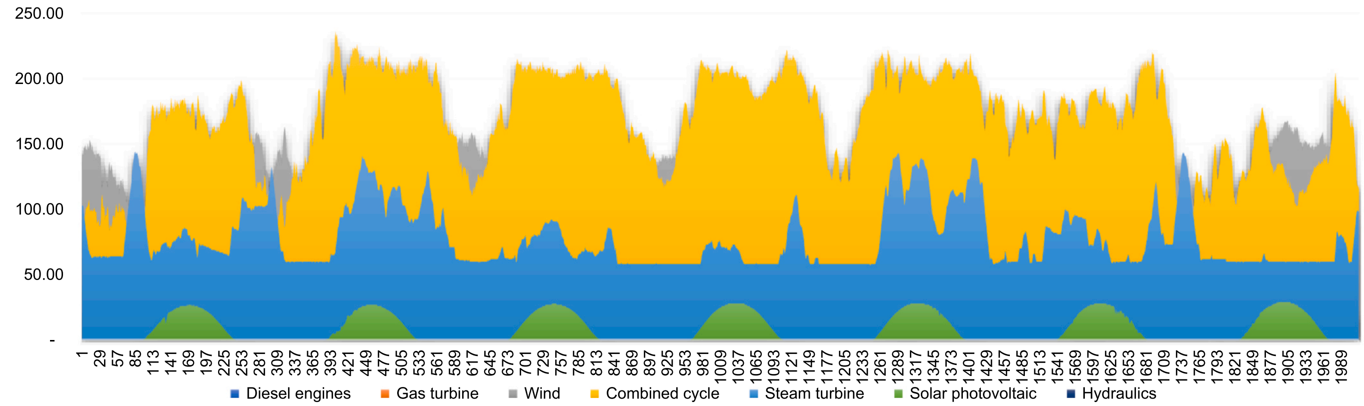

Fig. 9. Instantaneous production (MW) from 16 to 22 August 2021 [18].

For this ideal integration, it is necessary to have an average annual power in the pumping period of 175.46 MW of wind power, from this amount the accumulated average renewable discharges would have to be subtracted, which represents a cumulative 6.58 % (25.45 MW), of annual average of discharges, establishing the need for power used at 133.82 MW. In terms of the installed capacity of renewables and new needs, the existing ones would have to be increased by 483.13 MW on average and occasionally by 609.91 MW, which brings us on average to 788.62 MW.

Extrapolating the average annual data to the year, the annual data would be as follows.

3.6. Challenges

The PHEs "Chira-Soria" would bring new challenges to the system. As proposed by the project, this PHEs would cooperate with wind energy to make better use of it.

- To make up for this deficit in wind energy production, it is certain that future wind energy production in Gran Canaria will reach 725 MW.
- As has been shown, the Chira-Soria Pumped Hydroelectric Power Plant would need a maximum of 529.27 MW of wind power in addition to the installed capacity to cover pumping.
- Until wind energy production does not reach the expected 725 MW, and during the transition, pumping can be encouraged on days of less working activity to comply with the technical minimums of the combined cycle and due to the absence of the necessary wind power quota. It cannot yet be properly exploited due to the shortfall in installed wind power.

Its immediate commissioning would result in an installed power deficit of 97.56 MW in the Gran Canaria electricity system. As more wind power is installed, up to an increase of 529.27 MW and we get closer to the proposed 734.51 MW, the PHEs "Chira-Soria" will get closer to the objective for which it was designed.

4. Summary of applied methods

4.1. Hydraulic stabilization requirements

Regarding hydraulic stabilization, the results of this simulation are detailed in Fig. 11, which shows the water consumption scenarios based on the annual and seasonal variations observed during the period analyzed.

From the analysis of the time needed to have a volume of own water of 5hm3, with 20 % of the natural water reaching the Soria reservoir, as indicated in the Concession, the filling process would produce the following scenarios:.

In the case of not having the natural inputs to the Soria reservoir and filling it only with the industrial water produced in the ROS plant, a total of 43 months would be required, and the flow to be produced would amount to 6396,160.62 m3.

Table 12
Estimated Installed Capacity (MW).

Type Energy	Type Technology	Installed Power	
		MW	%
Energies Derivatives from oil	Thermal power plants. Steam turbine	280.00	13.9 %
	Thermal power plants. Diesel engine	84.00	4.2 %
	Thermal power plants. Gas turbine	173.45	8.6 %
	Thermal power plants. Combined cycle	461.73	23.0 %
	Cogeneration. Steam turbine	24.20	1.2 %
	Cogeneration. Diesel engine	0.68	0.0 %
	Cogeneration. Gas turbine	0.00	0.0 %
	Sum	**1024.06**	**51.0 %**
Energies Renewables	Wind	734.51	36.6 %
	Photovoltaics	49.15	2.4 %
	Hydraulics	200.00	10.0 %
	Sum	**983.66**	**49.0 %**
TOTAL		**2007.72**	**100.0 %**

Table 13
Estimated increase in production and demand (MWh).

Type Technology	Powers	Situation 2021	Increase Production	Increase Demand	Proposal Demand – Equilibrium production	
	MW	MWh	MWh	MWh	MWh	%
Current non-renewable generation	1024.06	2661,453.00	2661,453.00	2661,453.00	1271,725.36	28.69 %
Current photovoltaic renewable generation	49.15	55,823.00	55,823.00	55,823.00	55,823.00	1.26 %
Current wind renewable generation	205.24	632,818.00	632,818.00	632,818.00	632,818.00	14.28 %
Generation by new wind renewables	529.27	-	1703,878.91	-	1703,878.91	38.44 %
Hydro turbine generation	200.00	-	768,118.23	-	768,118.23	17.33 %
Demand Pumping	-220.00	-	-	1082,269.50	-	-
		3350,094.00	5822,091.14	4432,363.50	4432,363.50	100.00 %

Table 14
Simulation of reservoir exploitation during the period 1972–2019.

Scenario	Description	Annual Average Industrial Water Requirement in “Chira” (m^3/year)
Lousy	Associated with a 10 % probability of occurrence during the concession period.	1574,872.91
Medium	Associated with a 50 % probability of occurrence during the concession period.	1104,571.81
More likely	Associated with a 90 % probability of occurrence during the concession period.	615,389.27

Source: PHEs Project "Chira-Soria".

Table 15
Water resource and impulsion.

Concept	Value
Capacity	1.80 hm^3 /year
Availability Factor	0.95
Reverse Osmosis Conversion	45.0 %
Total Production	5200.00 m^3 /day
Reverse Osmosis Feed Flow	11,644.50 m^3 /day

Source: Chira-Soria Hydroelectric Pumping Plant Project.

4.2. Wind requirements

Table 17 shows that we would definitely need 336.11 MW to cover pumping for as long as possible, i.e. 56.16 % of the time, and assuming a wind capacity factor of 36.76 % (8.82 h/day), which is the figure reached in 2021.

These data are highlighted in the figure below, Fig. 13, which also reflects other capabilities for comparison.

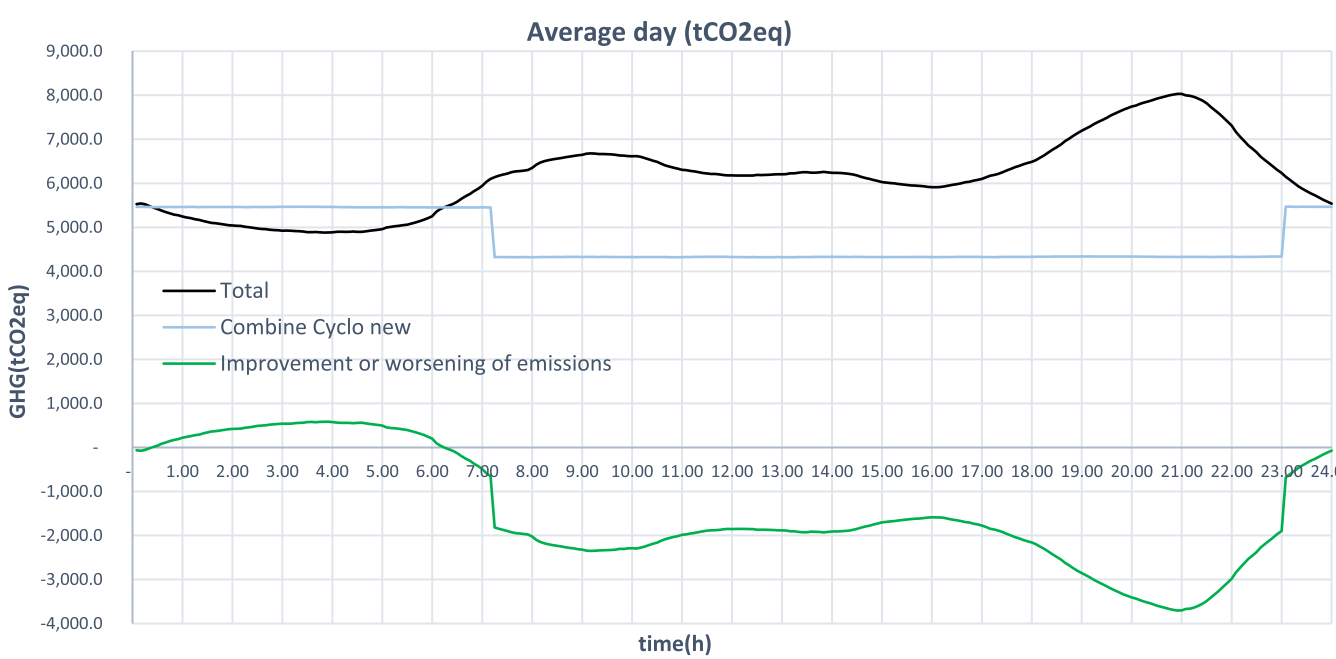

Fig. 10. Comparison of tCO2eq/MWh emissions with and without the integration of the Chira-Soria Pumped Hydroelectric Power Plant. (average annual day).

Table 16
GHG data with the energy integration of the Chira-Soria Pumped Hydroelectric Power Plant. Day.

	Average daily production (MWh)		Average Daily Power Used (MW)		Installed power (MW)		Installed power GHG Daily Average (tCO_{2eq})	
	2023	2023 - CH-S	2023	2023 - CH-S	2023	2023 - CH-S	2023	2023 - CH-S
Combined Cycle	4913.02	6206.24	204.71	258.59	433.10	433.10	3804.69	4712.78
Steam Turbine	1651.40	-	68.81	-	259.60	-	1915.69	-
Gas Turbine	109.26	-	4.55	-	147.00	-	158.12	-
Diesel Engines	305.22	-	12.72	-	66.55	-	267.11	-
Wind	1742.89	3211.67	72.62	133.82	305.49	788.62	0.00	-
Solar	379.11	386.64	15.80	16.11	73.16	73.16	0.00	0.00
Suma	9100.91	9804.55	379.20	408.52	1284.90	1294.88	6145.61	4712.78

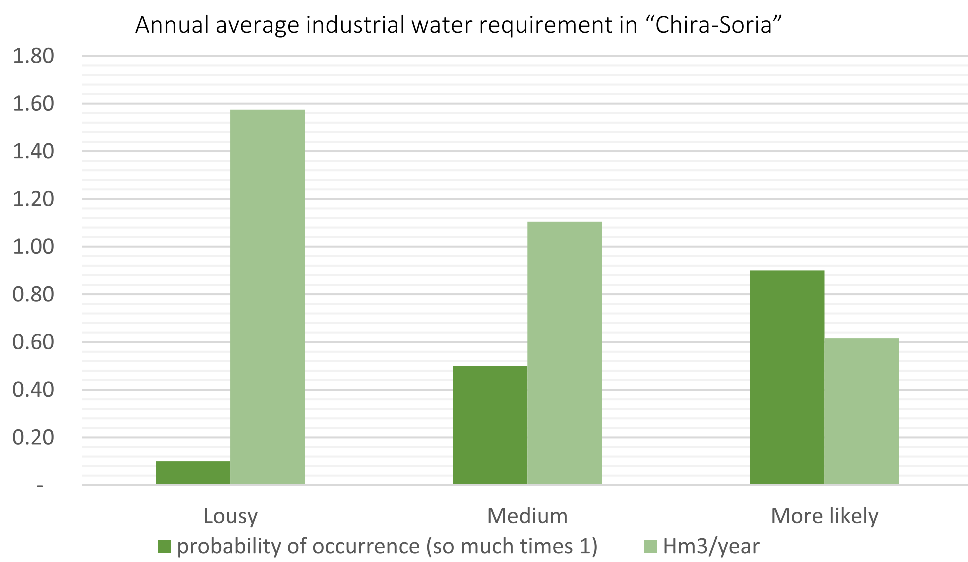

Fig. 11. Result of the simulation of reservoir exploitation during the period 1972–2019.

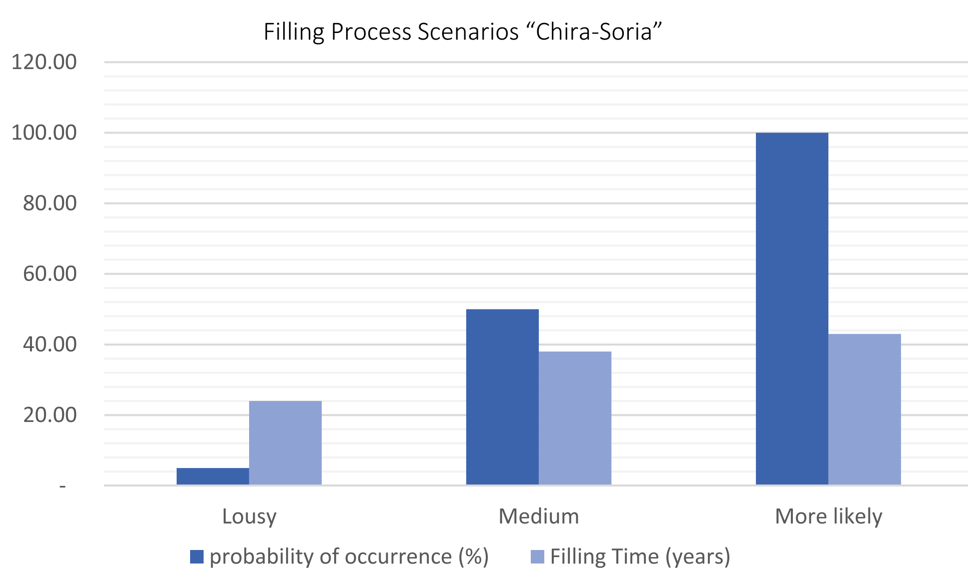

Fig. 12. Time needed to have your own water volume.

Table 17
GHG data with the energy integration of the Chira-Soria Pumped Hydroelectric Power Plant. Year.

	Producción media anual (MWh)		Average annual power Used (MW)		Installed power (MW)		GHG Annual Average (tCO_{2eq})	
	2023	2023 - CH-S	2023	2023 - CH-S	2023	2023 - CH-S	2023	2023 - CH-S
Combined Cycle	1793,253.17	2265,277.60	74,718.88	94,385.35	433.10	433.10	1388,767.77	1720,164.09
Steam Turbine	602,761.73	-	25,115.07	-	259.60	-	699,226.41	-
Gas Turbine	39,881.20	-	1661.72	-	147.00	-	57,712.66	-
Diesel Engines	111,406.43	-	4641.93	-	66.55	-	97,495.37	-
Wind	636,155.75	1172,259.55	2653,339.82	48,844.30	305.49	788.62	-	-
Solar	138,373.60	141,123.60	5765.57	5880.15	73.16	73.16	-	-
Suma	3321,827.95	3578,660.75	138,409.50	149,109.80	1284.90	1294.88	2243,202.21	1720,164.09

Table 18
Final determination of the most likely wind need for pumping with the incorporation of the Chira-Soria pumped-storage hydroelectric power plant.

Percentage Pumping performance (%)		56.16 %	50.00 %	40.00 %	30.00 %	20.00 %	10.00 %	0.00 %
Capacity factor Wind	Equivalent operating hours/day Wind	Power (MW)	Power (MW)	Power (MW)	Power (MW)	Power (MW)	Power (MW)	Power (MW)
36.76 %	8.82	336.11	299.25	239.40	179.55	119.70	59.85	0.00

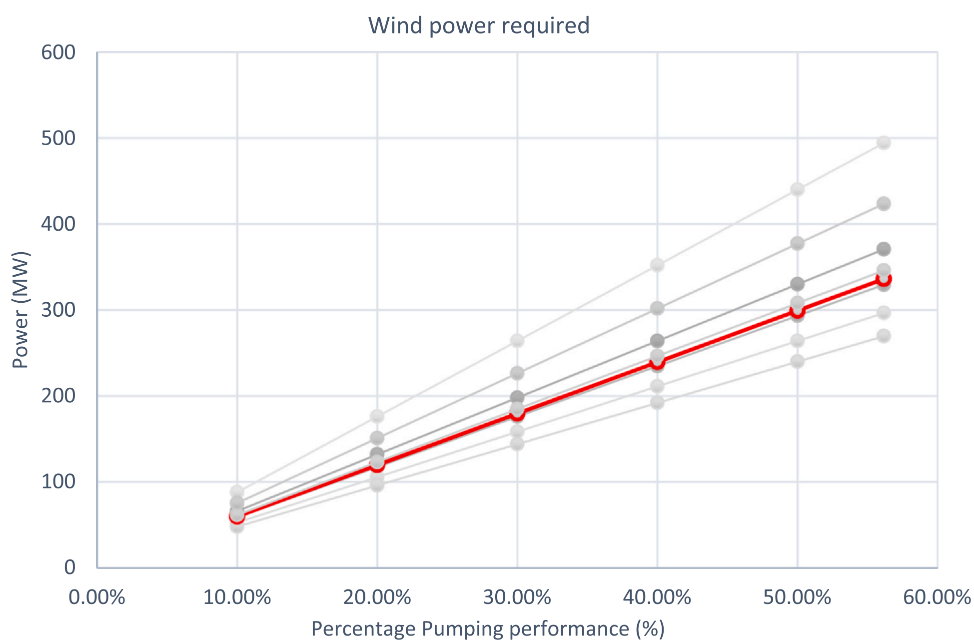

Fig. 13. Increase in wind power capacity to cover exclusively the increase in total pumping demand.

5. Conclusions

The use of turbohydraulic machines that operate in pumping have a worse performance (more power demanded for a lower hydraulic consumption), generate a deficit of 20 MW and a lower pumping flow than the turbine, this means that, for the maximum operating value, (continuous turbine phase for 16 h and 34 min) it could produce 3313.84 MWh that must be compensated with pumping, (21 h and 15 min), requiring 4669.16 MWh. A deficit of 1355.32 MWh.

For maximum production, 231.8 annual renewals of the maximum transfer volume of the reservoir would be required.

PEHs would maximize the integration of renewable energies, avoiding spills that would otherwise occur and enabling the development and installation of this type of energy and would provide security to the electricity system and guarantee of supply.

On the other hand, greenhouse gas (GHG) emissions will decrease, giving a net emission reduction result of 1432.98 tCO2eq/day, or 523,038.12 tCO2eq/year, representing a decrease of 23.32 %.

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CRediT authorship contribution statement

Vicente Henríquez Concepción: Writing – original draft, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Juan Carlos Lozano Medina:** Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carlos Alberto Mendieta Pino:** Writing – original draft, Validation, Supervision, Software, Investigation, Formal analysis, Conceptualization. **FEDERICO ANTONIO LEON ZERPA:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Appendix 1
Average daily use (h). Gran Canaria, year 2021 [18].

Type Energy	Type Technology	Average daily usage	
		(h/day)	(%)
Non-renewable Energies	Thermal power plants. Steam turbine	6.34	26.40%
	Thermal power plants. Diesel engine	6.50	27.07%
	Thermal power plants. Gas turbine	0.96	4.01%
	Thermal power plants. Combined cycle	10.41	43.36%
	Cogeneration. Steam turbine	-	-
	Cogeneration. Diesel engine	-	-
	Cogeneration. Gas turbine	-	-
	Media	**7.30**	**30.41%**
Renewable Energies	Wind	8.45	35.20%
	Photovoltaics	3.11	12.97%
	Media	**7.42**	**30.90%**
Total average		**7.32**	**30.51%**

This table, Appentix1 shows the average daily use of each electricity production technology on the island of Gran Canaria during the year 2021.

Appendix 2
. SWRO plant and annexes.

Installation	Flow rate of Design	Range operation	Length	Diameter
	m^3 /day	m^3 /day	m	mm
Seawater SWRO plant	5200.00	5200.00 - 7900.00	-	-
Catchment tower	17,468.00	11,643.50 - 17,468.00	-	-
Open-take catchment inmisario	17,459.00	11,643.50 - 17,468.70	994.93	560.0
Raw water impulsión	11,643.50	11,643.50 - 17,468.70	839.56	450.0
Brine discharge outfall. With Venturi type diffuser	9668.70	6443.50 - 9668.70	1485.49	450.0
Product water pumping. Pumping1 to Pumping II	5200.00	-	17,592.94	400.0
Product water pumping. Pumping II to Lower Platform	5200.00	-	4129.07	400.0
Product water impulsion. Lower Platform to Soria Reservoir	5200.00	-	402.00	-

Source: PHEs Project "Chira-Soria".

This table, Appentix2 shows the salient features of the SWRO plant, necessary for our analysis.

Appendix 3
. Turbine operation.

Operating Mode	No. Units Ud	Distribution Operating time Timetable
(T2) Theoretical continuous turbining	6	9.00 h-23.00 h
(T3) Theoretical tip turbinate	6	10.00 h-13.00 h and 19.00 h-21.00 h
(B2) Theoretical pumping	6	0.00 h-7.00 h

Source: PHEs Project "Chira-Soria".

The table shows the theoretical operating hours foreseen for the start-up of the PHEs Project "Chira-Soria, in the year 2030.

Appendix 4
Turbine characteristics.

Operating Mode	Operation Hours	Power MW	Energy/day MWh	Flow rate m^3/s	Volume of water displaced m^3
(T1) Maximum daily turnover	16	200.0	3200.0	68.4	3939,840
(T2) Theoretical continuous turbining	14	200.0	2800.0	68.4	3447,360
(T3) Theoretical continuous turbining	5	200.0	1000.0	68.4	1231,200
(B1) Maximum daily pumping	8	220.0	1760.0	53.4	1537,920
(B2) Theoretical pumping	7	220.0	1540.0	53.4	1345,680

Source: PHEs Project "Chira-Soria".

The table, Appentix4 shows different technical characteristics of the turbines, operating in the different modes, as well as their theoretical and maximum operations.

Appendix 5
. Forecast growth in installed capacity in renewables.

Type renewable	Chira-Soria Project Estimate MW	Situation year 2021 MW	Situation year 2023 MW	Situation with Final registration MW
Wind	584.92	205.24	305.49	320.20
Photovoltaic	140.08	49.15	73.16	80.77
Sum	**725.00**	**254.39**	**378.65**	**400.97**

In the Table, Appentix5 shows the growth forecast of the installed capacity in renewables necessary for the start-up of the PHEs Project "Chira-Soria, in the year 2030.

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