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Gran Canaria energy system: Integration of the chira-soria pumped hydroelectric power plant and analysis of weekly daily demand patterns for the year 2023

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A R T I C L E I N F O

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A B S T R A C T

Due to its insular condition, Gran Canaria operates an isolated energy system that requires high self-sufficiency in energy generation and that covers its energy need, 3,327,872.76 MWh/year. The future integration of the Chira-Soria Pumped Hydroelectric Power Plant, scheduled for 2030, is expected to radically transform the energy dynamics of Gran Canaria's electricity system, facing different challenges and opportunities. Challenges include the need for greater flexibility due to growing renewable energy sources, going from 381,000 MW of renewables today to an increase of more than 750,000 MW, environmental commitments, and the operation must address potential operational constraints related to downstream hydrological effects. On the other hand, the opportunities lie in the ability of the reversible hydropower plant to provide balancing services during off-peak hours, improving the integration of intermittent energy sources such as wind and solar power, in addition, the Pumped Hydroelectric (PHES) technology is recognized as mature and efficient for large-scale energy storage, contributing significantly to the integration of renewable energy sources. Implementing innovative approaches such as integrating Big Data into construction projects can also improve efficiency and decision-making in the project delivery process. This facility will facilitate energy storage through the pumping of water at high levels, allowing it to be subsequently turbined in periods of high demand, which will be essential to improve the management and efficiency of the island's energy system. This energy demand will be studied, which follows certain patterns according to the day of the week and, continuing with the line of research established in previous works, a detailed analysis of the existing system, simulation and algorithmic optimization of the integration of the Chira-Soria Pumped Hydroelectric Power Plant into the energy system of Gran Canaria in the year 2023 will be carried out, providing the expected results of such optimal integration by differentiating the demand patterns of each day of the week, previously establishing these annual representative days.

1. Introduction

This work continues the research on optimizing and improving energy systems in isolated areas, specifically studying the future installation of the Chira-Soria pumped hydroelectric power plant on the island of Gran Canaria. Previous studies have provided complementary results that are useful for this new one. In a first work, *"Algorithmic optimization of the integration of the Chira-Soria pumped hydroelectric power plant into the energy system of Gran Canaria",* the integration of this facility was optimized on the worst day of 2023, three operating scenarios were proposed and the renewable energy needs were determined. During the rigorous analysis process carried out in this article, the impact that the integration of the Chira-Soria Pumped Hydroelectric Power Plant into the energy network of Gran Canaria would entail has been clarified, based on the study of the most unfavorable day. In summary, the implementation of this plant would entail a series of benefits, generic to this type of system that were specified in the conclusions. (see Tables 1–8)

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Table 1
Theoretical planning of turbine operation. Schedules.

Operating Mode	No. of turbines	Operating Mode Time	
	Ud	Hours of Operation	Total hours
(T2) Continuous turbine	6	9:00–23:00 h	14
(T3) Maximum turbine	6	10:00–13:00 h and 19:00–21:00 h	5
(B2) Pumping	6	0:00–7:00 h	7

Source: Chira-Soria Pumping Hydroelectric Power Plant Project.

Table 2
Turbine operating characteristics.

Operating Mode	Operation	Power	Energy/ Day	Flow Rate	Volume of Water Displaced
	Total hours	MW	MWh	m^3/s	m^3
(T1) Maximum daily turbine	16	200.0	3200.0	68.4	3,939,840
(T2) Continuous turbine	14	200.0	2800.0	68.4	3,447,360
(T3) Maximum turbine	5	200.0	1000.0	68.4	1,231,200
(B1) Maximum daily pumping	8	220.0	1760.0	53.4	1,537,920
(B2) Pumping	7	220.0	1540.0	53.4	1,345,680

Table 3
Balance between pumping and turbination in operation.

Operating Mode	Operation		Power	Energy/ Day	Flow Rate	Volume of Water Displaced
	h/day	%	MW	MWh	m/s^3	m^3
Turbine balance	10.522	43.84 %	200.0	2104.43	68.40	2,590,978.53
Pumping balance	13.478	56.16 %	220.0	2965.12	53.40	2,590,978.52

- It would strengthen the security of the electrical system, ensuring a reliable supply.
- It would stabilize the frequency, the stability of which is affected by the increasing presence of non-dispatchable renewable energies.
- It would improve the flexibility of the system, optimizing its response and strengthening it in the event of possible contingencies.
- It would promote the incorporation of renewable sources into the system, avoiding unnecessary discharges and promoting the expansion of these clean energies.
- It would reduce the costs of the electricity system as a whole.
- It would reduce energy dependence on the outside world.

However, the integration of the Chira-Soria Pumped Hydroelectric Power Plant would also pose new challenges.

- It would generate an installed capacity deficit of 20 MW compared to the current situation.
- Turbine energy production must be balanced with pumping, resulting in a potential production shortfall of up to 314,151.72 MWh per year in the plant's continuous operation scenario.
- The turbine would only be viable for a maximum of 16 h and 34 min, generating a maximum of 3313.84 MWh during that period (considering the maximum energy storage).
- To compensate for the turbine and replenish the transferred water, the pumping station will have to operate for 21 h and 13 min, consuming 4669.16 MWh.
- The maximum energy production through turbines (768,118.23 MWh per year) is reached with 231.8 complete transfers from Chira to Soria.

In a second paper, *"Analysis and Optimization of the Integration of the Chira-Soria Pumped Hydroelectric Power Plant in the Energy System of Gran Canaria: Perspectives and Projections for the Year 2023",* the integration of this facility in 2023 was optimized, based on the representation of the electricity production of 2023 in a single day, Average annual day 2023 representative, using actual electricity production readings read every 5 min and for each type of electricity production technology. Three operating scenarios were proposed and renewable energy needs were identified. In summary, the implementation of this plant would entail a series of benefits, generic to this type of system that were specified in the conclusions.

- The energy production per turbine required for the most optimal solution is estimated at 465.42 GWh per year and the pumping demand is set at 655.78 GWh per year.
- The usage times for the year 2023 to achieve such an optimal solution would be 2980.33 h per year for pumping and 5799.17 h per year for turbines.

Table 5
Dam capacities.

Reservoir	Total Capacity	Racking Capacity
	m^3	m^3
Chira Reservoir (upper reservoir)	5,640,000.00	4,080,000.00
Soria Reservoir (lower depot)	32,300,000.00	
Difference	26,660,000.00	

Source: Chira-Soria Hydroelectric Pumping Plant Project

Table 6
Projected power and production of renewable energies.

Type Renewable	Chira-Soria Project Estimate	Situation Year 2021	Situation Year 2023	Situation with Final Registration
	MW	MW	MW	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

Table 4
Operation of the turbines at the Chira-Soria Hydroelectric Pumping Station.

Type Operation	Ud	Stipulated Hours of Work	Power Unit Total		Flow Rate	Volume of Water Displaced	Energy/Day
	Ud	horas	MW	MW	m^3/s	m^3	MWh
(T1) Turbinating	6	16	33.33	200.00	68.40	3,939,840.00	3200.00
(B1) Pumping	6	8	36.67	220.00	53.40	1,537,920.00	1760.00

Source: Chira-Soria Pumping Hydroelectric Power Station Project

Table 7
Discharges of renewable energy in Gran Canaria 2023.

	January	February	March	April	May	June	July	August	September	October	November	December	Running total
Wind	3.85 %	0.70 %	8.50 %	11.18 %	15.44 %	0.33 %	8.72 %	8.63 %	2.73 %	0.73 %	6.39 %	2.76 %	7.27 %
Photovoltaic	0.51 %	0.06 %	1.47 %	5.84 %	8.39 %	0.01 %	6.59 %	6.04 %	1.23 %	0.14 %	3.11 %	0.52 %	3.08 %
Total	3.41 %	0.51 %	7.38 %	10.16 %	14.46 %	0.25 %	8.51 %	8.33 %	2.47 %	0.55 %	5.86 %	2.24 %	6.58 %

This represents a cumulative annual average of 6.58 % (25.45 MW) of discharges.
Source: Red Eléctrica de España

Table 8
Chira-Soria Pumped-storage hydroelectric power station integration data according to proposed hypotheses. Daily average.

Day	Daily production (MWh)			Average power used (MW)			Factor availability	Hours/day operation		Necessary power renewables (MW))		Production flat	
	pumping	turbine	total	pumping	turbine	total	%	pumping	turbine	mean	maximum	loud	casualty
Monday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	458.98	608.05	307.50	253.79
Tuesday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	455.50	604.57	308.70	253.79
Wednesday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	481.74	611.85	299.60	243.99
Thursday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	468.68	611.58	297.50	235.13
Friday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	471.17	607.98	302.50	238.42
Saturday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	533.11	608.35	281.50	232.75
Sunday	1778.33	1262.13	3040.47	74.10	52.59	126.69	59.98 %	8.08	15.92	549.06	610.97	272.10	219.27

- The Chira-Soria Pumped Hydroelectric Power Plant would work in the most optimal way, providing stability to combustion production, establishing two levels of production, high production, which is set at 299.50 MW for 8.17 h per day on average, and low production, which is set at 237.49 MW for 15.83 h per day on average.

In this new work, based on the representation of electricity production in 2023 according to the different patterns followed by the different days of the week and, using real readings of electricity production read every 5 min and for each type of electricity production technology, the best integration into the system is sought in an optimal way for the future installation of the Chira-Soria pumped hydroelectric power plant. resulting in actual average integration data and establishing three integration hypotheses.

1.1. Current context

Numerous specialists emphasize the urgent need to move towards decarbonization [1–8], Increase the presence of renewable energy sources [9–13], Take a holistic approach to the management of energy resources, optimizing the use of existing technologies [14–19] applied at the island level [20,21], solving insularity [22,23], as well as seeking a new perspective on resource management. [24–26], making the most efficient use of available technologies. This imperative is particularly relevant for the energy systems of the Canary Islands, especially Gran Canaria, which faces multiple challenges in the coming years. [27], particularly that of Gran Canaria [28], with a tourism sector that represents 20 % of GDP [29,30] highly energy demanding [30,31] or an increasing reliance on desalinated water [32,33] and which also requires mitigation strategies [34,35], and that it faces many challenges in the coming years.

- **Alignment with Energy Production Targets:** Electricity demand in Gran Canaria was 3268 GWh in 2022 and is projected at 3321 GWh by 2023, with an installed capacity of 1287.00 MW forecast for the same year. To meet this growing demand, it is imperative to continue operating existing facilities, which will be progressively replaced by more advanced technologies as obsolete units are decommissioned, [28].
- **Prevention of Energy System Collapse:** Gran Canaria's energy system faces the risk of co-lapse due to the obsolescence and incapacity of current infrastructures, which requires an action plan to partially renew energy plants, some of which are over 30 years old. Current standards for energy efficiency, maximum output and minimum emissions are insufficient. In addition, dependence on imported fossil fuels, which accounted for 70.40 % in 2023, significantly raises electricity costs and CO_2 emissions, [28,36–39].
- **Environmental Sustainability:** The aim is to increase the penetration of renewable energies, which currently stands at 29.60 % in Gran Canaria, through government promotion of wind farms and the installation of solar panels, as well as adopting environmentally neutral systems for CO_2 emissions, [6,28].
- **Optimization of the Chira-Soria pumped-storage hydroelectric power plant:** The integration of this plant into the energy system represents a significant change in the island's energy dynamics, with commissioning scheduled for 2030. The plant facilitates energy storage by pumping water to higher altitudes, allowing its subsequent turbination during peaks of high demand, and the reuse of water in periods of excess renewable production, [20,40].
- **Role of Artificial Intelligence for sustainable.** As defined by Refs. [41,42], green artificial intelligence (AI) emphasizes environmental sustainability and inclusivity, enabling researchers to achieve accurate results without high computational costs or expensive cloud servers. In this paper define AI solutions promoting eco-friendly practices in various fields, some strategies for designing energy-efficient machine learning (ML) algorithms and models and methods for measuring and optimizing energy consumption accurately. On the other hand [43,44], in these study explores data-driven probabilistic machine learning (ML) techniques and their real-time applications in smart energy systems, emphasizing the urgency of this research area work such us, ML in Core Energy Technologies (advanced energy materials, energy systems and storage devices, energy efficiency, smart energy material manufacturing, strategic energy planning, renewable energy integration, and big data analytics within the smart grid paradigm) and ML for Energy Distribution Utilities (Applications such as energy consumption and price forecasting, energy price merit order, and consumer lifetime value).

The analysis of energy demand in 2023 will differentiate daily patterns, establishing annual averages by day of the week. A detailed analysis, simulation and algorithmic optimization of the integration of the Chira-Soria hydroelectric pumping station will be carried out, providing results of the optimal integration and comparing consumption

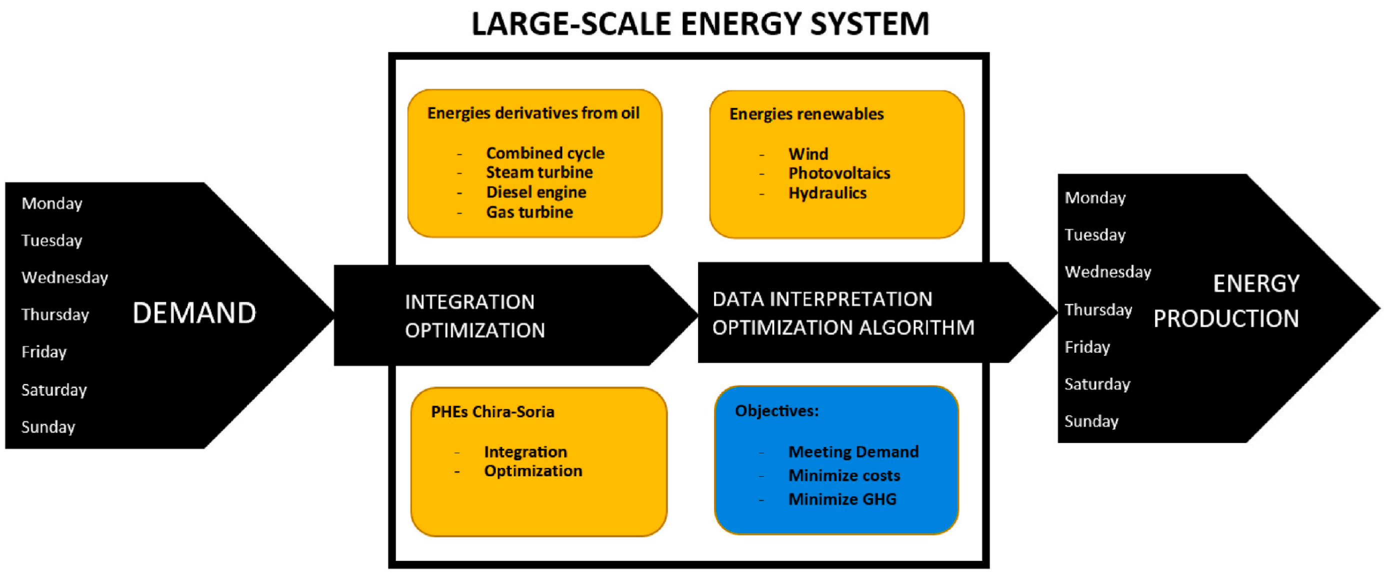

Fig. 1. Methodology.

patterns. This research continues the line established in previous studies, focusing on an efficient and sustainable implementation of the energy system of Gran Canaria.

2. Materials and methods

2.1. Current overview of energy production in Gran Canaria

The energy production infrastructure in Gran Canaria incorporates a wide range of technologies, including four steam turbines, five diesel units, five gas turbines and two combined cycle plants, each consisting of a double gas turbine and a steam turbine. These installations account for 70.40 % of the total installed power on the island, which amounts to 906.00 MW, the other 29.60 % of the installed capacity, equivalent to 381.00 MW and comes from renewable sources. Therefore, the total installed power in Gran Canaria reaches 1287.00 MW. As for energy production in Gran Canaria, that due to renewables in 2023 was 22.87 % (761,084.5 MWh/year) and by non-renewable equipment 77.13 % (2,556,788.26 MWh/year). Gran Canaria currently has no massive energy storage solutions; the Chira-Soria pumped-storage hydroelectric power plant will be the first major installation of this type.

In 2023, total energy demand in the Canary Islands was 3321 GWh. A highlight of that year was the recording of the historical maximum daily energy demand on October 9, reaching 1455.3 MWh. Other significant peaks were also recorded that same day: at 20:00 h a maximum hourly demand of 558.80 MWh was reached and at 20:28 h a historical maximum instantaneous power of 563.40 MW was recorded.

2.2. Methodology

Fig. 1 details the methodology used for system analysis, study, and formulation of the optimal integration proposal in response to the incorporation of the Chira-Soria Pumped Hydroelectric Power Plant, scheduled for 2030.

This methodology follows the line of research previously established in previous works. The starting database of electricity production in 2023 according to the different patterns followed by the different days of the week and, for this purpose, real electricity production readings are taken every 5 min and for each type of electricity production technology, as well as the development of a computational algorithm designed to achieve the maximum optimization of the integration system. This method analyses all the energy production technologies by combustion, renewable energy production and its randomness, availability factors, energy demand according to days of the week, etc., and proposes the best integration for the system.

2.3. Chira-Soria hydroelectric pumping station. Analysis

The Chira-Soria pumped-storage hydroelectric power plant is primarily designed to secure electricity supply and facilitate the efficient integration of intermittent renewable energy sources. Given the high variability of wind generation, rapid and significant fluctuations in power system frequency are observed, a phenomenon that tends to increase with the continued expansion of installed wind capacity, a pattern that is likely to persist in the future. These frequency variations can be adverse to consumers and can even lead to power outages. The Power Plant plays a crucial role in mitigating frequency quality degradation, thus contributing to a more stable, resilient and secure electricity system. In addition, this facility promotes the safe and efficient penetration of a significant volume of renewable energy into the system, allowing the storage of surplus energy that cannot be directly integrated, thus facilitating a balance between supply and demand and the reduction of surplus renewable energy. The intensification of the integration of renewable energies through energy storage systems favours a gradual transition from thermal to renewable generation, resulting in a significant reduction of CO_2 and NOx emissions, with both economic and environmental advantages. This adds greater flexibility to the energy system, compensating for the limitations of the existing thermal generation units, which were designed for a different energy context and lack the necessary capacities for an effective integration of renewable energies in the framework of the energy transition. The Chira-Soria pumped-storage hydroelectric power plant stands out for its massive energy storage capacity and for maintaining the synchronous characteristics of the electricity system through specific technologies, providing inertia and short-circuit power, among other crucial benefits for its optimal operation.

2.3.1. Operation of the hydroelectric pumping station

The Chira-Soria pumped-storage hydroelectric power plant project is designed to operate optimally by adapting to fluctuations in energy demand and production. It will use the pumping mode at times of energy surplus, generally derived from intermittent renewable sources such as wind, or during periods of low consumption. In contrast, the turbine will be activated during peak demand to supply energy, thus substituting

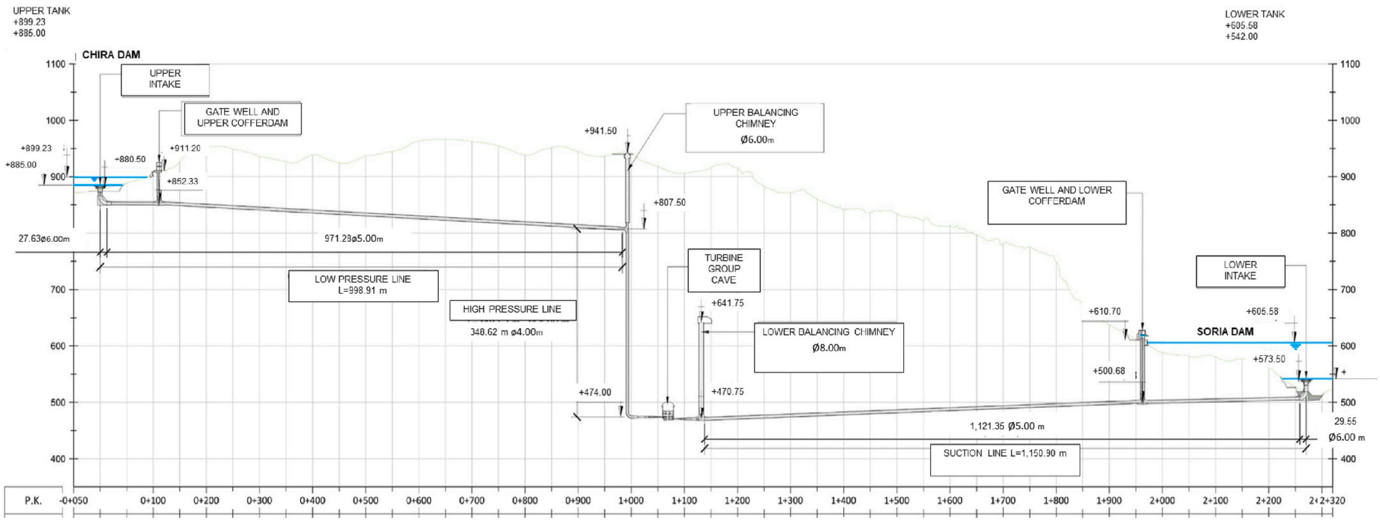

Fig. 2. Diagram of the hydraulic network of the Chira-Soria pumping hydroelectric power station.

generation from more costly thermal sources with a higher environmental impact.

Daily Operating Cycle of the Plant:

Pumping Mode: activated mainly during low night-time demand, from 0:00 to 7:00, where energy is used to lift water from the lower reservoir (Soria) to the upper reservoir (Chira). This not only takes advantage of the renewable energy generated during the night but also optimises the performance of the thermal groups, reducing CO2 emissions and avoiding the costs associated with frequent start-up of these groups. Increased pumped demand helps to integrate any excess wind production.

Turbine Mode: At peak demand times, from 9:00 to 23:00, and especially in the morning and evening peaks, power is generated by allowing water to flow from the upper reservoir to the lower reservoir. This process replaces power generated by thermal technologies such as gas turbines that run on more expensive fuels**.**

In addition, the plant can respond quickly to grid failures, being able to initiate supply recovery within minutes after a total blackout on the island, thanks to its fast start-up capability and operational flexibility. The plant has a generation capacity of 200 MW, consumes 220 MW in pumping mode and can store up to 3.2 GWh of energy for turbining for 16 h. The transfer capacity between the Chira and Soria reservoirs is 4.08 hm^3. Sedimentation studies indicate that the intakes will not be affected by sedimentation for the next 50 years, although dredging will eventually be required.

2.3.2. Balance between pumping and turbination in operation

In order to evaluate the operational performance of the plant in both pumping and turbine mode during different time periods of the day, the following table is provided which details the electricity demand required in each mode, together with the volume of water pumped and turbined.

Maintaining a balance between pumping and turbining is crucial for the optimal operation of the hydropower plant. It is essential to ensure that the volume of water turbined is equivalent to the volume pumped in the same time interval, thus ensuring that the water levels in the reservoirs are adequately restored before turbining. This approach prevents overexploitation of the plant's transfer capacity and ensures a constant and reliable power supply. Therefore, effective plant planning and operation requires meticulous coordination of the quantities of water pumped and turbined. Adjusting these operations according to electricity demand and system conditions is essential to preserve this balance. Doing so maximizes the efficiency and sustainability of the hydropower system, ensuring that the balance between pumping and turbining is continuously and effectively maintained.

This indicates that 43.84 % of the time (equivalent to 10 h and 31 min per day) is dedicated to turbining, while the remaining 56.16 % (13 h and 28 min) is used for the pumping process. During turbining, 2104 GWh are produced per day, and pumping consumes 2965 GWh per day. This leads to an average maximum operating power of 211.23 MW, distributed between turbining and pumping with percentages of 41.51

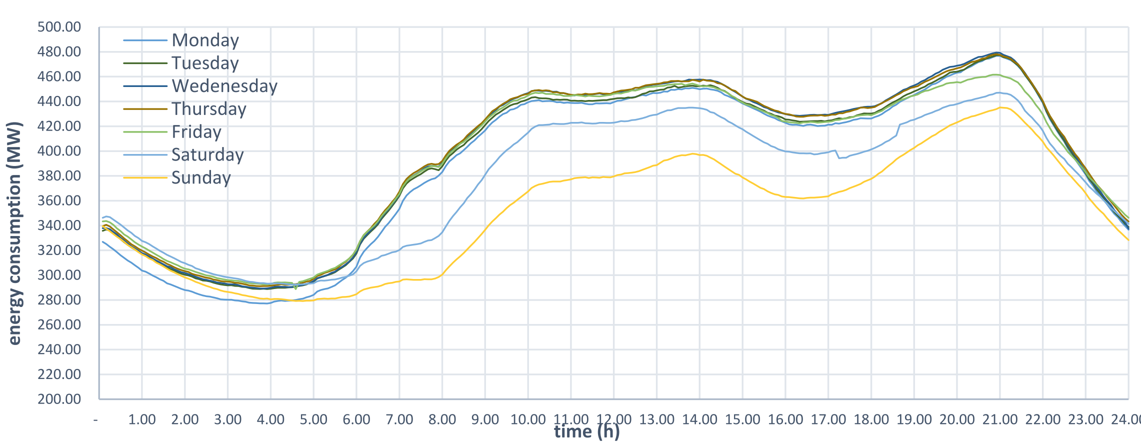

Fig. 3. Average daily demand response curve in Gran Canaria for the year 2023, differentiating the days of the week.

% and 58.49 % respectively.

2.3.3. Technical analysis of the Chira-Soria hydroelectric pumping station

Fig. 2 provides a simplified schematic diagram that gives a visual representation of the hydro network of the facility in question. This schematic is fundamental to understanding how water flow is organised within the pumped-storage hydropower plant, detailing key components such as pipes, valves, turbines, pumps and reservoirs. In the diagram, the following elements, among others, can be observed: Fig. 3

Upper and Lower Reservoir: These reservoirs are essential for the turbining and pumping process. The upper reservoir stores the water that is released during high demand hours to generate power, while the lower reservoir collects the water after it passes through the turbines.

Connecting Pipes: Connect both reservoirs allowing water to flow in both directions, depending on whether the system is in power generation mode or in pumped storage mode.

Reversible Pump-Turbine Caverns: This component acts as both a pump and a turbine. As a turbine, it generates electricity when water descends from the upper reservoir to the lower reservoir; as a pump, it lifts water from the lower reservoir to the upper reservoir during periods of low demand and high availability of renewable energy.

The turbo-machines that make up the Chira-Soria Pumping Hydroelectric Power Station are detailed in the following table, as well as the foreseen operating characteristics in turbining and pumping.

Table below shows the data referring to the characteristics of the dams, cubing them and establishing their transfer capacity.

2.3.4. Plant factor and availability factor analysis

The plant factor concept reflects the proportion of the time that the installed capacity of a power plant is actually used. A value of less than 1 indicates that the plant is not constantly operating at full capacity. In contrast, the availability factor, particularly relevant in pumped hydro power plants, denotes the fraction of time a plant is operational, either turbining or pumping, and whether it is available to operate at full or reduced capacity. It is crucial to differentiate between these two factors: the plant factor measures the actual utilization of the installed capacity, while the availability factor evaluates the operational capacity of the plant during a specific period, considering both full and reduced operations or inactivates. For example, plants of different types exhibit variations in their availability factors: Thermal plants such as coal-fired, geothermal and nuclear plants generally exhibit availability factors of 70 %–90 %, gas turbines can reach 80 %–99 %. Typical plant factors vary as follows.

- Wind farms: 10–40 %.
- Photovoltaic panels: 10–30 %.
- Hydroelectric power plants: 60 %.
- Nuclear power plants: 60%–98 %.
- Coal-fired power plants: 70–90 % Coal-fired power plants: 70-90
- Combined-cycle power plants: 60 %.

The following are specific examples of availability and plant factors for installations in Gran Canaria.

- Gran Canaria wind farm
  2021: 36.76 %, equivalent to 8.82 equivalent hours/day.
  2022: 34.5 %.
- Photovoltaic plants.
  2021: 24.27 %, equivalent to 2.91 equivalent hours/day.
  2022: 33.1 %.
- Chira-Soria pumped-storage hydroelectric power plant.
  Assumed plant factor equal to 60 % availability.

2.3.5. Estimated production of electricity and renewable energy

The Chira-Soria pumped-storage hydroelectric power plant project will maximize the integration of renewable energies, avoiding the discharges that would otherwise occur and allowing 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 authorization.

2.3.6. Optimal integration of the Chira-Soria pumped-storage hydroelectric power plant into the overall energy system of Gran Canaria

As previously mentioned, the integration must conform to certain essential guidelines for its correct execution. These include.

- Maintenance of the balance between turbining and pumping.
- Adherence to the plant availability factor.
- Implementation of the pumping process using renewable energies.

The aim of this integration is to level the energy production curve, which currently relies on combustion, thus improving equipment efficiency and maximizing the absorption of surplus renewable energy. This allows for a more efficient and sustainable management of the energy supply.

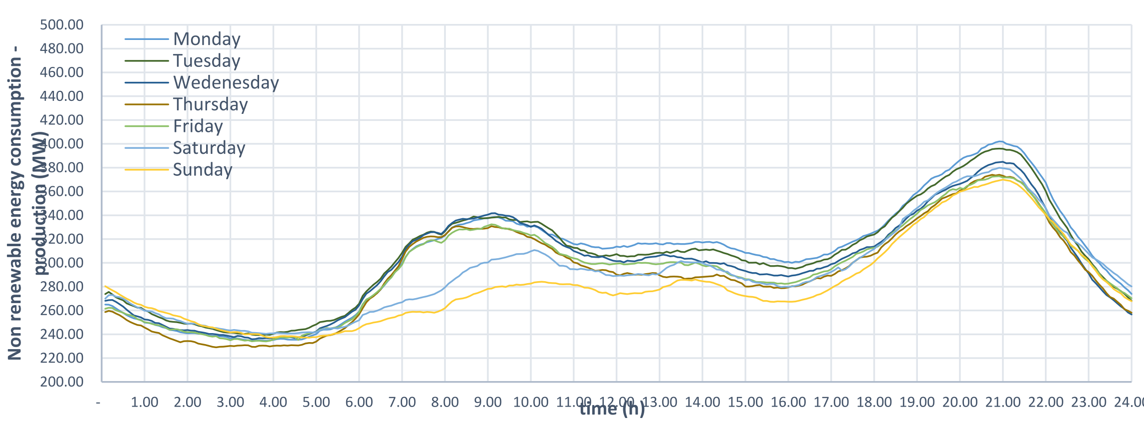

Fig. 4. Curve of response to the average daily demand in Gran Canaria in the year 2023, of the non-renewable production equipment, differentiating the days of the week.

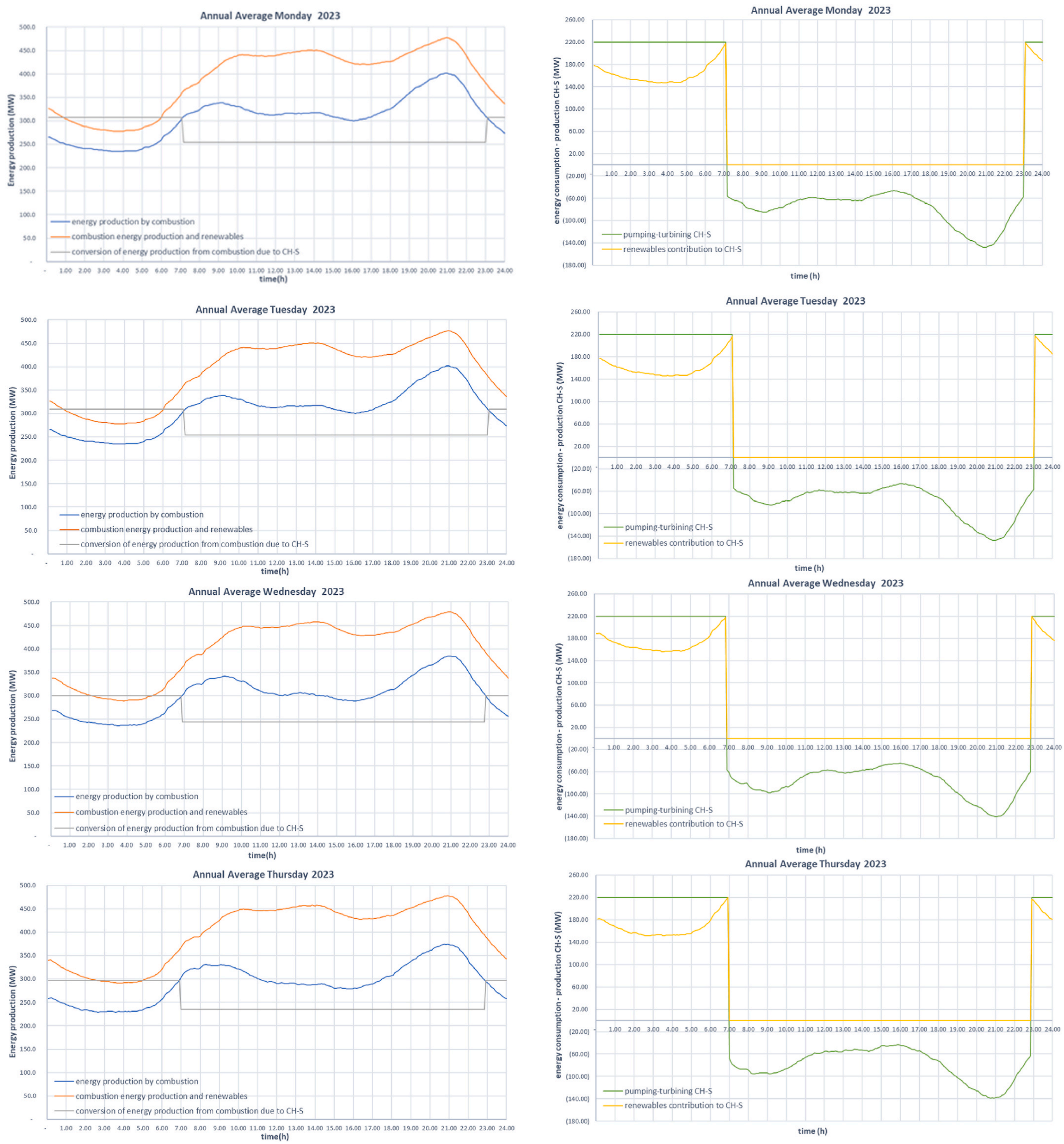

Fig. 5. For each day of the week, a) "Ideal" flattening of the energy production curve by combustion due to the integration of the Chira-Soria Pumped-storage hydroelectric power plant. Average year 2023 and b) Pumping and turbining of the Chira-Soria pumped-storage hydroelectric power plant. Average year 2023.

2.4. Estimation of the average demand curve according to days of the week for the study and estimation of the integration of the Chira-Soria pumped-storage hydroelectric power station into the Gran Canaria energy system in 2023, according to these patterns

In order to analyse the energy situation in 2023 as a whole and to serve as a basis for studying the integration of the Chira-Soria pumped-storage hydroelectric power station into the system, the average energy behavior curve of the generating equipment is needed. For this purpose, the 365 days of the year 2023 are analyzed and the annual average of these 365 days is established, differentiated by days of the week, as shown in the following figure.

It should be noted that the year 2023 consists of 52 Saturdays, 52 Mondays, 52 Tuesdays, 52 Wednesdays, 52 Thursdays, 52 Fridays and

Fig. 5. (*continued*).

53 Sundays. This curve represents the energy average for each day of the week and includes renewable and non-renewable energy.

On the other hand, we establish in the following figure the average annual non-renewable energy production of these 365 days differentiated by days of the week.

The differences in behavior patterns can be clearly seen, especially on Saturdays and Sundays compared to the rest of the week.

2.5. *Estimated renewable energy discharges 2023*

In the Canary Islands, due to the lack of storage in the Canary Islands electricity system, renewable energy discharges occur. These were estimated for the year 2023, and are set out in the following table as a % of demand.

3. Results and discussion

Theoretical integration has been carried out in order to minimize emissions and stabilize frequency with maximum use of renewables, maximizing the capacity and use of the pumped-turbine operation of the Chira-Soria pumped-storage hydroelectric power station (assuming there is no deficit of renewables for this use), differentiating each day of the week, which follow the differentiated patterns established in the previous section, using the annual average for each day of the week in the year 2023 (see Fig. 4).

These "optimal-ideal" integrations of the Chira-Soria pumped-storage hydroelectric power plant are shown in Fig. 5, as well as the operation of the Chira-Soria pumped-storage hydroelectric power plant pumping-turbine, establishing the following.

1. Plant factor: 59.98 % 2.
2. Pumping-Turbine balance: 43.84 % turbine and 56.16 % pumping.
3. Daily production (MWh): 1262.13 MWh turbined and 1778.33 MWh pumping.
4. Average power used (MW): 52.59 MW turbined and 74.10 MW pumped.
5. Hours/day of operation (h/day): 15.92 (h/day) turbined and 8.08 (h/day) pumping.

With this optimization, the energy production curve through combustion has been flattened and defined in two steps. These steps represent the average annual demand to be covered by the combustion equipment due to the integration of the Chira-Soria pumped-storage hydroelectric power plant.

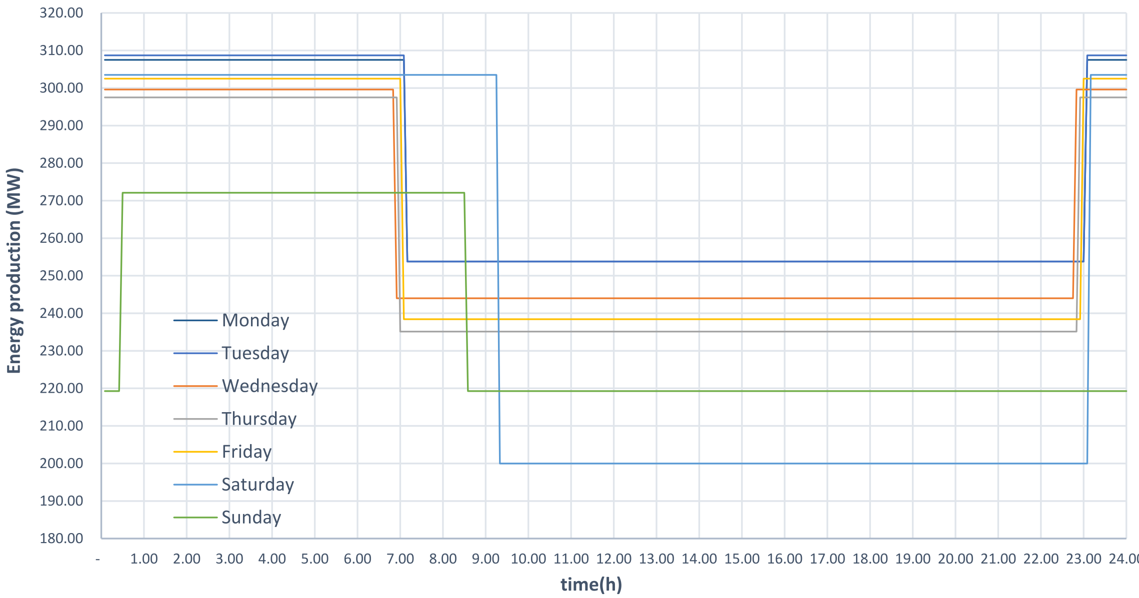

Fig. 6. Average annual non-renewable production differentiated by days of the week.

For the specific case of Monday, the highest step would be 307.50 MW and the lowest would be 253.79 MW. For this ideal integration, it is necessary to have an average annual power in the pumping period of 167.13 MW of wind power and 218.56 MW on a one-off basis, which, taking the availability factor for 12-month operation in 2022 (34.5 %), would lead to an additional renewable power installation to the existing one of 484.437 MW on average and 633.50 MW on a one-off basis. From this amount, the accumulated average renewable energy discharges would have to be subtracted, resulting in an additional renewable energy capacity of 458.98 MW on average and 608.05 MW on average and 608.05 MW on average, respectively. Fig. 5 shows the "ideal" flattening of the energy production curve through combustion due to the integration of the Chira-Soria pumped-storage hydroelectric power station for each day of the week and b) the pumping and turbining of the Chira-Soria pumped-storage hydroelectric power station for each day of the week.Fig. 6

4. Summary of applied methods

Attached is a summary table of the operating proposals according to weekday patterns for the Chira-Soria pumped-storage hydroelectric power plant, all of them complying with the necessary and argued guidelines, for an average useful installed power of 211.23 MW.

5. Conclusions

During the analysis process, the Chira-Soria hydroelectric pumping station has been integrated into the energy production system in Gran Canaria in the year 2023, and it has been technically determined at the production level what this integration into the system means according to patterns established by days of the week.

The analysis of the Chira-Soria pumped-storage hydroelectric power station, studied and integrated by days of the week, shows that the flat energy production in the high step is estimated at a maximum value of 308.70 MW on Tuesdays and a minimum value of 272.10 MW on Sundays, while the flat energy production in the low step is estimated at a maximum value of 253.79 MW on Mondays and Tuesdays and a minimum value of 219.27 MW on Sundays.

The ideal operating conditions are established in these integrations as follows.

Plant factor: 59.98 %.
Pumping-Turbine balance: 43.84 % turbine and 56.16 % pumping.
Daily production (MWh): 1262.13 MWh turbined and 1778.33 MWh pumped.
Average power used (MW): 52.59 MW turbined and 74.10 MW pumped.
Hours/day of operation (h/day): 15.92 (h/day) turbined and 8.08 (h/day) pumped.

Future research should address as a priority the massive storage of renewable energy that cannot be integrated into the system and that occurs during the turbine schedule, storage in its different forms and typologies, as well as its optimal integration into the energy system.

CRediT authorship contribution statement

Juan Carlos Lozano Medina: Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization. **Vicente Henríquez Concepción:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation. **Federico Antonio León Zerpa:** Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization. **Carlos A. Mendieta Pino:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation.

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.

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