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ORIGINAL ARTICLE

A carbon footprint: the full water cycle in the Balearic Islands

Noelia Cruz-Pérez[1] · **Jesica Rodríguez-Martín**[2] · **Celso García**[3] · **Pablo Rodríguez-Lozano**[3] · **Dolores Tirado**[4] · **Alejandro García-Gil**[5] · **Juan C. Santamarta**[1]

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Abstract

The integral urban water cycle of the Balearic Islands (Spain) is composed of desalination plants, extraction wells, water distribution networks, treatment plants and sewerage systems. This article presents the results of the carbon and water footprint of each of the islands that form the Balearic archipelago, finding differences between those islands with a greater contribution of groundwater, such as Mallorca, and those that are fed exclusively with desalinated water, such as Formentera. Water consumption on these islands is highly seasonal, which results in peaks in demand, which are mainly supplied by desalination. This article aims to be the starting point for assessing the water and energy status of the facilities related to drinking water consumption in the archipelago to be able to take measures aimed at ecological transition in this sector. The results obtained show that seawater desalination plants have the largest carbon footprint, mainly due to their high electricity consumption.

Keywords Water system · Environment · Water facilities · Desalination · Energy saving

Introduction

Four billion people in the world live under conditions of severe water scarcity at least one month of the year and half a billion people face water scarcity all year (Mekonnen & Hoekstra 2016). In addition to population and economic growth, numerous other factors intensify demands for freshwater, for example, climate change and variability (IPCC 2018), rapid urbanisation (UN 2008), and globalised energy markets (Smil 2005). Mediterranean Sea semiarid and arid regions, including part of Spain, are the most affected by water scarcity (Uche et al. 2015). These areas are commonly found close to the seashore where seawater resources are unusable for direct utilisation for human consumption and irrigation. To meet increasing water demand, some arid areas close to the seashore are already using desalination technology (Voutchkov 2012).

The concept of a *water-energy nexus* (Scott et al. 2011) refers to the fact that water production requires energy and

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✉ Noelia Cruz-Pérez
ncruzper@ull.edu.es

Jesica Rodríguez-Martín
jrodrima@ull.edu.es

Celso García
celso.garcia@uib.es

Pablo Rodríguez-Lozano
pablo.rodriguez@uib.es

Dolores Tirado
dolores.tirado@uib.es

Alejandro García-Gil
a.garcia@igme.es

Juan C. Santamarta
jcsanta@ull.es

[1] Departamento de Ingeniería Agraria y del Medio Natural, Universidad de La Laguna (ULL), Tenerife, Spain

[2] Departamento Técnicas y Proyectos en Ingeniería y Arquitectura, Universidad de La Laguna (ULL), Tenerife, Spain

[3] Department of Geography, University of the Balearic Islands, Palma, Spain

[4] Department of Applied Economics, University of the Balearic Islands, Palma, Spain

[5] Geological Survey of Spain (IGME-CSIC), C/Ríos Rosas 23, 28003 Madrid, Spain

energy production needs large amounts of water in most cases. This water-energy nexus is usually increased on islands, as they rely on seawater desalination and/or groundwater pumping (Meerganz von Medeazza & Moreau 2007). In fact, desalination technology, although indispensable for these regions, is the most expensive and energy demanding technology for water production. Indeed, energy and water are interlinked and coupled at multiple scales.

In this vein, the World Bank illustrated the enormous carbon reduction potential of combining renewable energies and desalination. It was estimated that almost all carbon dioxide equivalent (CO_2e) emissions involved in desalination could be avoided by means of renewable energy utilisation (Negewo, 2013). In this context, the carbon footprint is an environmental indicator used to quantify the greenhouse gas emissions of different activities and companies (Ledgard et al. 2020). A product water footprint assessment considers all stages of a product's life cycle, from raw material acquisition to final disposal, and an assessment of an organisation's water footprint takes a life cycle perspective based on all its activities (Morera et al. 2016). Although several studies that have addressed technical, economic or ecological issues of desalination have shown that desalination can be affordable and potentially sustainable, socioeconomic and ecological and environmental studies of desalination processes are urgently required in this critical era (Gude 2016).

In the assessment of the carbon footprint, three scopes are contemplated (Wiedmann et al. 2021), the first two being mandatory and the third optional. The first scope calculates the emissions related to the direct consumption of fossil fuels by the company, either in vehicles or in fixed installations. Scope two calculates indirect emissions from electricity consumption, which can be zero if the energy supplier uses 100% renewable energy sources. Scope 3 covers indirect activities related to the company that involve the consumption of fossil fuels or electricity, such as business trips, supplier and employee vehicles (Kucukvar et al. 2015).

This study aims to quantify the environmental sustainability of the whole water cycle of the Balearic Islands (Spain) by assessing the carbon footprint of the existing water facilities. To address the calculation of the carbon footprint, the water cycle has been divided into two parts: i) obtaining drinking water and ii) purifying wastewater. When obtaining drinking water free of pollutants, the factor that most influences the generation of greenhouse gases is the consumption of electricity (desalination, pumping, etc.) to capture the water. In the case of wastewater, it is also important to consider the generation of methane from wastewater treatment plants, since methane is also a greenhouse gas (Ma et al. 2017), whose greatest importance is in agriculture, but it is also present in these plants due to the organic load that these waters carry after being used by citizens (Wang et al. 2021). Therefore, the carbon footprint of the selected facilities was calculated to determine the environmental status of the water sector in the Balearic Islands in 2019 and 2020. The calculation of this indicator of environmental sustainability implies an organisation of energy consumption, environmental benefits and significant economic savings (Dong et al. 2014). This is the first study covering the whole water cycle, including the water distribution and sewerage systems, providing a reference scenario for the sustainable transition of European islands towards the energy transition in the European Union's *Clean Energy for EU Islands Initiative*.

Materials and methods

Study area: Balearic Islands

The Balearic Islands archipelago is made up of the islands of Mallorca (923,608 inhabitants in 2019), Menorca (96,620 inhabitants), Ibiza (50,000 inhabitants), Formentera (12,200 inhabitants), and a series of smaller, practically uninhabited islands and enjoys a Mediterranean climate (see Fig. 1). Archipelagos such as the Balearic Islands face severe water scarcity problems. A review of the regional distribution of desalination capacities worldwide shows that the installed capacity for the desalination of seawater is increasing rapidly. Spain is the largest producer in the region and represents 7% of the worldwide capacity, with 70% of the Spanish plants located on the Mediterranean coast and the Balearic Islands (Lattemann & Höpner 2008). The pressures on water resources suffered by this archipelago are mainly due to the following aspects: high tourist activity, overexploitation of aquifers and marine intrusion into them (Candela et al. 2009), urban pollution, diffuse pollution from agricultural and livestock activity, and periods of drought, amongst

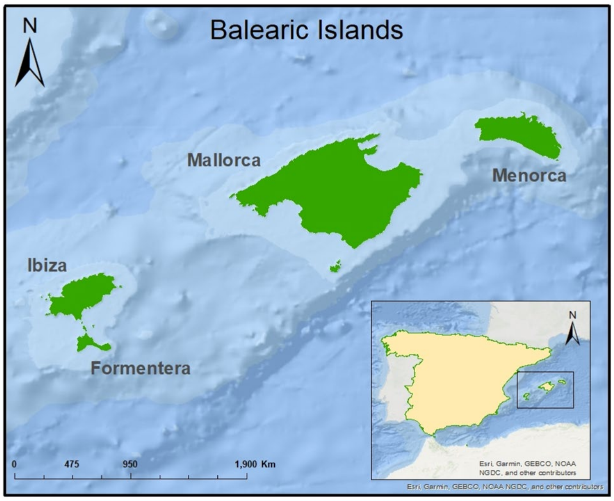

Fig. 1 Location of the Balearic Islands (Spain)

Table 1 Main characteristics of the installations studied in the Balearic archipelago (data for 2019 as they are more representative of the facility activity due to the 2020 lockdown)

Water facility			Fuel consumption	Electricity consumption	No. of workers	No. of suppliers	Flow captured 2019	Flow captured 2020
			L	kWh	[-]	[-]	[Hm^3]	[Hm^3]
Desalination	Mallorca	1	3.13	39,639.16	22	6	10.04	10
		2	1	10,683.60	11	20	6.39	1.2
		3	6	6,695.90	7	10	4.12	1.24
	Menorca	1	250	3,780.00	7	5	2.38	2.38
	Ibiza	1	264.37	11,654.29	11	150	8.39	8.34
		2	0	14,923.56	8	150	8.86	8.86
		3	1	10,920.05	8	91	6.25	6.55
	Formentera	1	0	2,749.90	5	20	0.9	1.15
Wastewater	Mallorca	1	0	242.18	3	3	0.29	0.88
		2	0	701.15	2	0	0.95	0.02
		3	0	31.11	1	0	0.02	0.05
		4	0	181.5	2	0	0.15	0.08
		5	0	33.12	2	0	0.11	0.01
		6	0	30.86	1	0	0.02	0.08
		7	0	132.9	1	0	0.08	0.99
	Menorca	1	0	128.82	1	2	0.33	0.24
		2	0	148.67	1	1	0.19	0.09
		3	0	176.84	2	2	0.39	0.36
		4	0	184.35	2	1	0.3	0.15
		5	0	1,135.29	9	6	4.36	3.4
	Ibiza	1	0	953.74	6	0	5.64	6.08
		2	0	2,358.29	6	0	3.08	2.17
		3	0	275.56	2	1	0.14	0.07
	Formentera	1	1.21	512.35	4	0	0.48	0.49
Well	Mallorca	1	1	4,084.03	2	10	5.14	3.96
		2	2	1,427.23	1	10	4.84	4.19
		3	1	1,368.54	1	10	2.33	2.84
Distribution	Mallorca	1	12	3,924.45	8	20	26.19	5.56

others (García et al. 2017). This situation may worsen or intensify the pressures in a scenario of climate change, in which we currently find ourselves (García & Rodríguez-Lozano 2020). The Balearic Islands are also supplied by a combination of groundwater, which accounts for 90% of the water resources in the Balearic archipelago (Gómez et al. 2004), surface water, and desalinated seawater. Because of the high consumption of electrical energy to obtain freshwater, the production of drinking water is one of the most important sectors in the ecological transition of islands (Papapostolou et al. 2020).

The facilities that constitute the integral water cycle in Spain are varied, and the technology utilised in each one depends on the geographical area studied. This is due to the water model and the availability of resources, which varies between the islands and the Iberian Peninsula (Custodio et al. 2019). In this regard, the Balearic Islands base their own water model on the use of groundwater resources, which are the most important in quantitative and qualitative terms. In the Iberian Peninsula, the water production model relies more on surface water resources (García & Rodríguez-Lozano 2020). Therefore, the main facilities on the islands for treating drinking and wastewater are the following: groundwater wells, desalination plants, treatment plants and artificial recharge stations for the aquifers.

Methodology

The methodology followed in this article is that proposed by the internationally recognised Green House Gas Protocol or GHG Protocol (Guallasamin Constante & Simón-Baile 2018). The GHG Protocol initiative arose from the union of various companies, nongovernmental organisations and other agents under the coordination of the World Resources

Table 2 Results of the calculation of the carbon footprint of the facilities studied in the Balearic Islands (Formentera, Ibiza, Mallorca, and Menorca islands) in 2019 and 2020

Water facility			2019				2020			
			Total Scope 1	Total Scope 2	Total Scope 3	Carbon footprint	Total Scope 1	Total Scope 2	Total Scope 3	Carbon footprint
			[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]	[tCO_2 eq]
Wastewater	Mallorca	1	2.45	189.31	6,74	198.5	2.45	134.73	6.74	143.92
		2	3.54	8.4	3,38	15.31	3.54	6.66	3.38	13.58
		3	1.82	49.01	6,74	57.56	1.82	20.63	6.74	29.18
		4	4.2	8.94	6,74	19.88	4.2	4.53	6.74	15.47
		5	0.91	8.33	3,38	12.62	0.91	3.72	3.38	8.00
		6	0.91	35.88	3,38	40.17	0.91	22.62	3.38	26.9
		7	3.63	172.8	6,74	183.16	3.63	116.46	6.74	126.83
	Menorca	1	1.66	34.78	4,5	40.94	1.6	18.13	4.5	24.23
		2	1.66	40.14	3,75	45.55	1.6	21.9	3.75	27.25
		3	2.57	47.75	7,23	57.55	2.51	34.15	7.23	43.89
		4	3.03	49.77	7,12	59.91	3.03	20.73	7.12	30.87
		5	10.35	306.53	37,79	345.67	10.35	176.29	37.79	224.43
	Ibiza	1	10.3	257.51	6,74	274.55	10.3	178.85	6.74	195.89
		2	12.83	636.74	10,1	659.67	12.83	415.9	10.1	438.83
		3	0.45	74.4	0,02	74.87	0.45	33.86	0.02	34.33
	Formentera	1	3.03	138.33	8,37	149.73	3.03	106.38	8.37	117.78
Desalination	Mallorca	1	9.88	10,665	18,501	29,176	10.57	3,140	18,494	21,645
		2	10.2	2,847	8,446	11,304	8.28	579.46	8,414	9,002
		3	31.78	1,770	7,009	8,811	25.47	391.63	7,009	7,426
	Menorca	1	1.04	810.00	5,601	6,412	4.85	756.00	5,601	6,362
	Ibiza	1	997.16	2,683	11,853	15,534	712.03	1,727	11,853	14,292
		2	1.82	3,526	7,373	10,901	1.82	2,217	7,373	9,593
		3	6.42	2,911	8,080	10,998	6.91	2,276	8,080	10,363
	Formentera	1	1.82	391.79	3,362	3,756	1.8	249.22	3,362	3,613
Well	Mallorca	1	4.8	1,332	1,687	3,024	3.22	816.81	1,687	2,507
		2	7	539.51	847.28	1,393	3.46	285.45	847.28	1,136
		3	5.28	631.19	847.28	1,483	2.38	273.71	847.28	1,123
Distribution	Mallorca	1	17.77	1,096	10,188	11,303	32.12	784.89	10,188	11,005

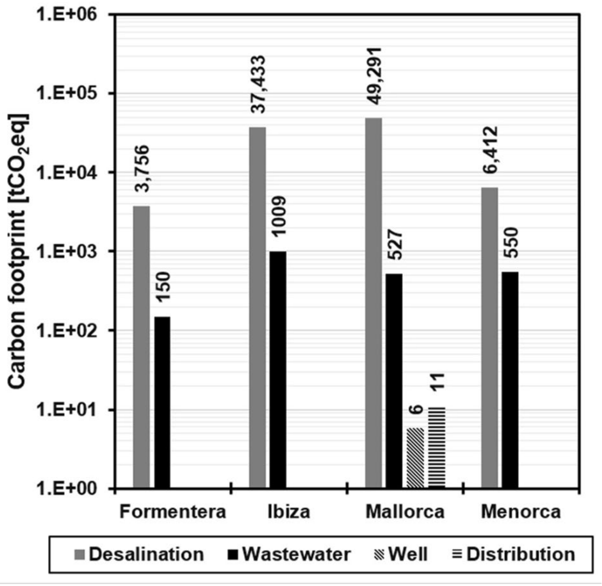

Fig. 2 Overall carbon footprint by type of facility in each of the Balearic Islands

Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The aim of this standard is to avoid heterogeneity in the methods and principles used to calculate the greenhouse gas emissions of internationally accepted companies and organisations (Guallasamin Constante & Simón-Baile 2018). Importantly, the GHG Protocol is applicable to any type of organisation and company and allows all three scopes of the carbon footprint to be calculated, making it a good fit for any carbon footprint calculation desired.

This standard makes it possible to account for the emissions of an activity using the three scopes of the carbon footprint. Scope 1 refers to direct emissions made by the company, mainly related to the burning of fossil fuels, and Scope 2 refers to indirect emissions caused by the company's electricity consumption (Azarkamand et al. 2020). The case of Scope 3 is more particular, as it accounts for indirect emissions of the company that are related to it (suppliers, business trips, purchase of materials) (Hertwich & Wood 2018). This last scope is the most complex to address due to its open nature, but in this case, it is limited to suppliers, workers and waste management. Thus, the journeys made by the main actors related to the facility have been considered, such as the workers' journeys to the workplace, those of suppliers and those due to waste management. To this end, information has been collected on the days worked by workers, how they travel to the treatment plant, the type of vehicle and the kilometres travelled to be able to make a realistic estimate of these emissions.

In this regard, it is necessary to bear in mind that in a water treatment or distribution facility, two types of emissions can be distinguished depending on the point or area of emission. Emissions from concessionary or authorised companies are emissions produced by activities carried out at the facility by concessionary or authorised companies. Emissions from the installation are those produced by the activities carried out by the operator itself. Therefore, the scope of the study of the installations includes maintenance work, the electrical transformer station, fuel station, clean point, drinking water supply installation and electrical network.

To obtain the data, a specific form was designed and sent to the managers of the selected facilities to obtain information on diesel consumption in litres and electricity consumption in kWh, as well as the number of suppliers and workers, their attendance at the company and the average distance travelled by their vehicles. After obtaining the data, the emission factors for the studied years of 2019 and 2020 were used to transform the data into tonnes of CO_2 equivalent, which is the unit of the carbon footprint.

Regarding the data on electricity consumption and diesel fuel consumption, the facilities had these data monitored for each year, meaning they were very accurate. However, there is less accuracy in terms of workers' and suppliers' vehicles, as it is very difficult to establish the exact kilometres driven by each worker to their job, as well as the possibility that they may change the type of vehicle during the years studied. This is why in Scope 3 more uncertainty arises than in Scope 1 and 2, which are more accurate as they are annual company consumption.

To calculate methane emissions from a wastewater treatment plant, the methodology proposed by the IPCC (Doorn et al. 2006) was followed, where the total organic load of the water (related to the equivalent population served by the treatment plant), the methane emission factor and the uncertainties were considered.

The facilities for which data were obtained, distributed by island, are as follows (see Table 1):

- Mallorca: three desalination plants, a drinking water distribution network, three wells to obtain drinking water from the aquifer and seven wastewater treatment plants
- Menorca: one desalination plant and five wastewater treatment plants
- Ibiza: three desalination plants and three wastewater treatment plants
- Formentera: one desalination plant and one wastewater treatment plant

Table 3 Carbon footprint by volume of water treated in 2019 and 2020

Wastewater treatment plants	Volume processed in 2019 (hm^3)	Carbon footprint in 2019 (tCO_2eq)	Carbon footprint by volume of water treated by 2019 ($kgCO_2eq/hm^3$)	Volume processed in 2020 (hm^3)	Carbon footprint in 2020 (tCO_2eq)	Carbon footprint by volume of water treated by 2020 ($kgCO_2eq/hm^3$)
Mallorca 1	0.95	198.50	0.21	0.88	143.92	0.16
Mallorca 2	0.02	15.31	0.77	0.02	13.58	0.71
Mallorca 3	0.14	57.56	0.41	0.05	29.18	0.58
Mallorca 4	0.11	19.88	0.18	0.08	15.74	0.20
Mallorca 5	0.02	12.62	0.79	0.01	8.00	0.73
Mallorca 6	0.08	40.17	0.50	0.08	26.90	0.35
Mallorca 7	1.07	183.16	0.17	0.99	126.83	0.13
Menorca 1	0.30	40.94	0.14	0.24	24.23	0.10
Menorca 2	0.19	45.55	0.24	0.09	27.25	0.32
Menorca 3	0.39	57.55	0.15	0.36	43.89	0.12
Menorca 4	0.30	59.91	0.20	0.15	30.87	0.21
Menorca 5	4.30	354.67	0.08	3.40	224.43	0.07
Ibiza 1	5.60	274.55	0.05	6.08	195.89	0.03
Ibiza 2	3.08	659.67	0.21	2.17	438.83	0.20
Ibiza 3	0.14	74.87	0.52	0.07	34.33	0.47
Formentera 1	0.48	149.73	0.31	0.49	117.78	0.24

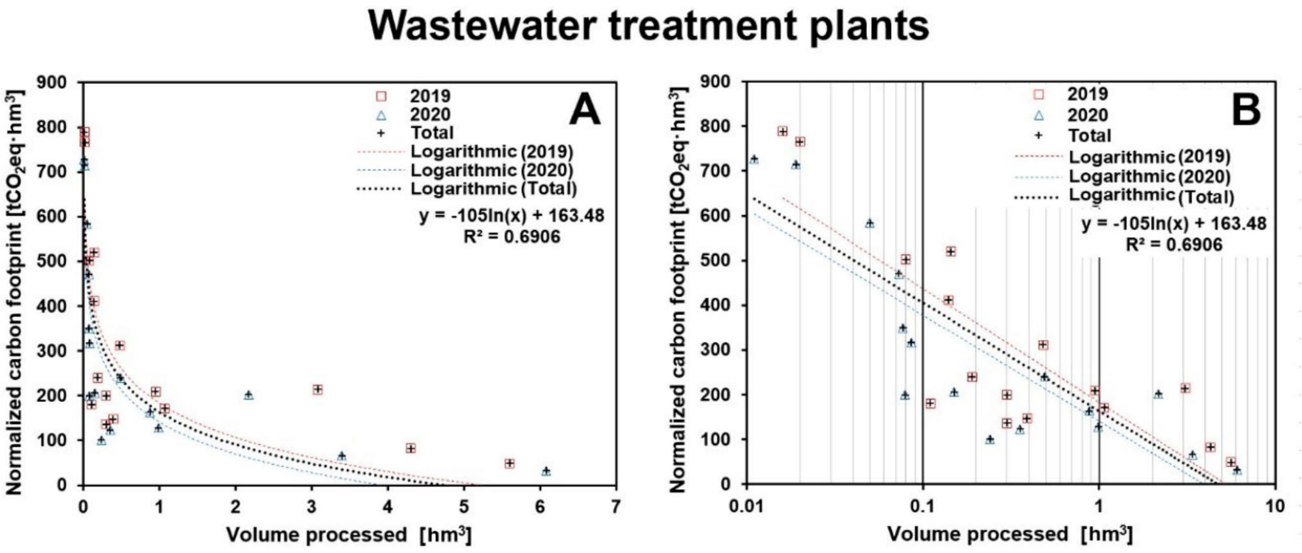

Fig. 3 CO_2 emissions per hm.^{3} of water treated in the treatment plants of the Balearic Islands for 2019 and 2020

Results and discussion

Our analysis of the carbon footprint of the facilities studied in the Balearic Islands showed that the carbon footprint was lower in 2020 than in 2019 for all facilities studied (see Table 2). This is mainly due to an increase in renewables in the electricity mix of the energy supplier, as well as a general decrease in the electricity consumption of the facilities. This is also due to the anomalous operating conditions of all companies due to the 2020 confinement caused by the COVID-19 pandemic.

In all the Balearic Islands, the desalination section produces the largest carbon footprint, mainly due to the high electricity consumption of the desalination plants (see Fig. 2).

Table 4 Carbon footprint by volume of water treated for desalination in 2019 and 2020

Desalination plants	Volume processed in 2019 (hm^3)	Carbon footprint in 2019 (tCO$_2$eq)	Carbon footprint by volume of water treated by 2019 (kgCO$_2$eq/hm^3)	Volume processed in 2020 (hm^3)	Carbon footprint in 2020 (tCO$_2$eq)	Carbon footprint by volume of water treated by 2020 (kgCO$_2$eq/hm^3)
Mallorca 1	10.30	29,917	2.83	10.00	21,645	2.16
Mallorca 2	1.85	8,811	4.76	1.20	7,426	6.19
Mallorca 3	2.73	11,303	4.14	1.24	9,002	7.26
Menorca 1	1.95	6,412	3.29	2.38	6,362	2.67
Ibiza 1	8.28	15,534	1.87	8.34	14,292	1.71
Ibiza 2	9.83	10,901	1.11	8.86	10,901	1.23
Ibiza 3	6.25	10,998	1.76	6.55	10,363	1.58
Formentera 1	0.90	3,756	4.17	1.15	3,142	3.14

Wastewater treatment plants

The three wastewater treatment plants (WWTP) of Menorca share the company vehicle; therefore, as they do not have diesel consumption for fixed installations, these three treatment plants have the lowest scope, Scope 1. With respect to Scope 2 of these three treatment plants, it should be noted that, as of September 2020, the diesel company vehicle was replaced by an electric vehicle; therefore, the carbon footprint of 2021 will not have values associated with Scope 1 in these treatment plants but with Scope 2, as the new vehicle is dependent on electric energy and not on fossil fuels. The charging point for this vehicle is located at the Menorca 3 wastewater treatment plant, which is where it remains at rest.

In the Menorca 3 WWTP, photovoltaic panels are installed in the plant, with a mode of self-consumption with surpluses, and the production of the panels is on the order of approximately 60,000 kWh per year. At the Menorca 4 WWTP, the company vehicle was also replaced by an electric vehicle in September 2020. The WWTP Menorca 5 responds to a larger population; therefore, it has the largest carbon footprint, as it has the highest electricity consumption of all. It also has the largest number of associated vehicles and the largest number of workers.

On the islands of Ibiza and Mallorca, Scope 2 is the highest in all cases. However, Scope 3 in Mallorca is higher than Scope 1, i.e. the use of fossil fuels by the facility, whilst in Ibiza, Scope 1 is higher than Scope 3 in the facilities studied.

With respect to Scope 3, all the treatment plants have suppliers and authorised waste management, mainly related to the treatment of sludge generated at the facility. The purified sludge undergoes digestion treatment and, once digested, is thickened and dewatered by means of centrifugal decanters

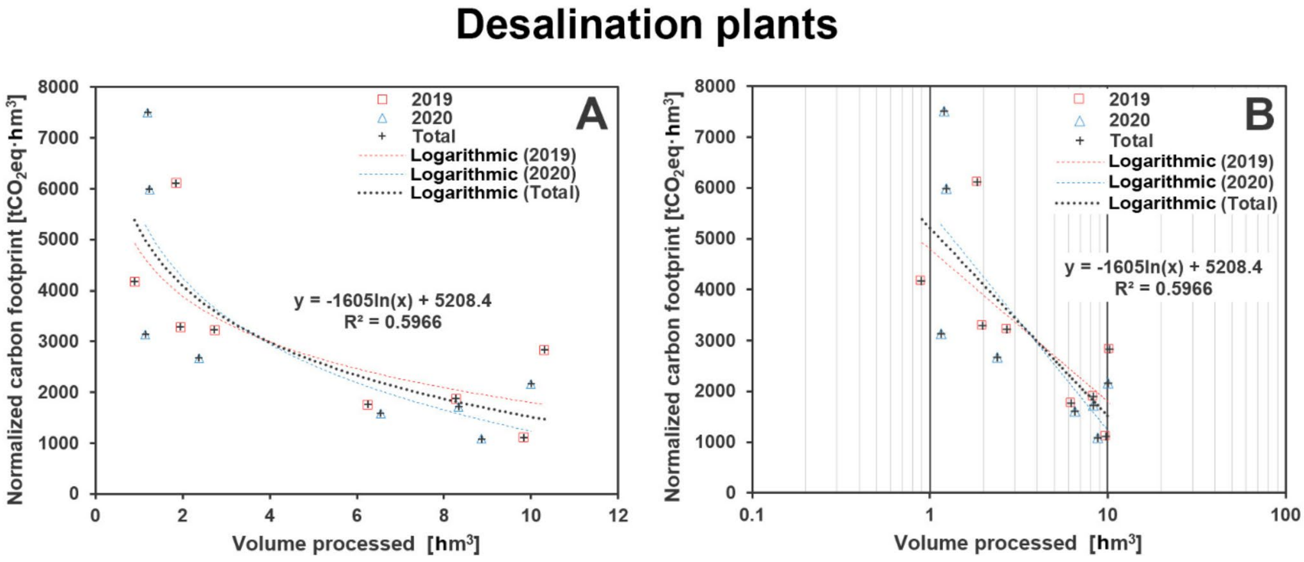

Fig. 4 CO$_2$ emissions per hm^3 of water treated in the desalination plants of the Balearic Islands for 2019 and 2020

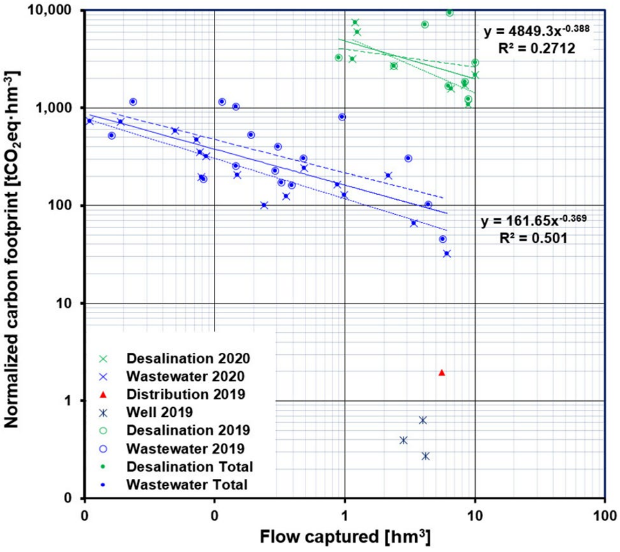

Fig. 5 Normalised carbon footprint by type of facility and year, per hm^3 of water treated

(use of polyelectrolyte for thickening). The treated effluent goes, in all cases, to a submarine outfall.

Population and BOD$_5$ also influence the methane production of each facility, the range of which in this case is between 1 and 15 tons of methane per year, depending on the type of each treatment plant. In the digestion of sludge, whether it is done at the WWTP or elsewhere, large quantities of methane are emitted, which have not been calculated in this study. In general, they account for between 0 and 40% of the total emissions generated at wastewater treatment plants and are associated with the carbon footprint (Baeten et al. 2021). In general, the sludge produced is collected by a specialised company and treated as solid waste in a facility designed for this purpose. The final destination of the treated effluent varies in each case, although most commonly it is sent to a submarine outfall and, in some cases, it is used for irrigation in agriculture, golf courses and street washing.

Our findings also demonstrate that the facilities that treat a higher flow rate are more energy efficient (see Table 3) since wastewater treatment plants have a carbon footprint that is a function of the volume treated by the facility. However, it should be borne in mind that the value that will mark the suitability of the wastewater treatment plant is its efficiency in removing pollutants from the water, and this is only achieved when operating below the design flow rate (Collivignarelli et al. 2021).

With respect to the carbon footprint results obtained in the WWTPs, we observe that their values are similar to a study carried out in China on nine WWTPs (Gu et al. 2016), where these also showed a carbon footprint range between 0.11 and 0.45 kg/m^3. In the case of the Balearic Islands, we find that this range is between 0.10 and 0.79 kg/m^3 (see Table 3). There is a logarithmic relationship between (see Fig. 3) the number of tons of CO$_2$ emissions per Hm^3 treated that are generated in each treatment plant. Therefore, in this case, the treatment plants are much more efficient the more flow they treat.

Desalination plants

The results of the carbon footprint are also divided by scopes (see Table 2). As expected, Scope 2 for desalination plants is quite high compared to the rest of the facilities studied in this report. This is because desalination plants are large consumers of electricity for their operation, and given that Scope 2 considers emissions related to electricity consumption by the company, it has yielded high results in all the desalination plants studied. In other similar studies (Ghani et al. 2021), this same trend is observed, where electricity consumption is the main contributor to emissions associated with desalination plants. In a study developed in the Canary Islands (Spain), it is shown that the tons of CO$_2$ per MWh associated with the desalination sector are between 0.5 and 0.84 (Leon et al. 2021).

One of the existing alternatives that can compensate for the carbon footprint in Scope 2 is to select supply companies with an electric mix equal to zero. The electricity mix is calculated for each electricity company, considering the sources of energy generation. If the company uses entirely renewable energy sources for electricity production, the electricity mix is zero. As it incorporates non-renewable sources, the electricity mix increases due to the emissions associated with burning fossil fuels from those sources (Gopi et al. 2019).

Scope 1 is composed of the diesel consumption of the facility, as well as the fuel consumed by the vehicles associated with the facility (staff travel and activities related to the desalination plant). Finally, in Scope 3, we have high emissions mainly due to the large number of workers at the desalination plant, the number of suppliers and waste management. The trips made by the vehicles of suppliers, workers and waste management significantly increase the carbon footprint of the facilities. This is common in all those companies that provide a service, since they generally have a large number of workers and require numerous suppliers to assist them to guarantee the service (spare parts, office material, occasional maintenance by external companies, revisions, breakdowns, etc.).

The carbon footprint per volume of water withdrawn was generally lower in 2020 than in 2019 for most of the

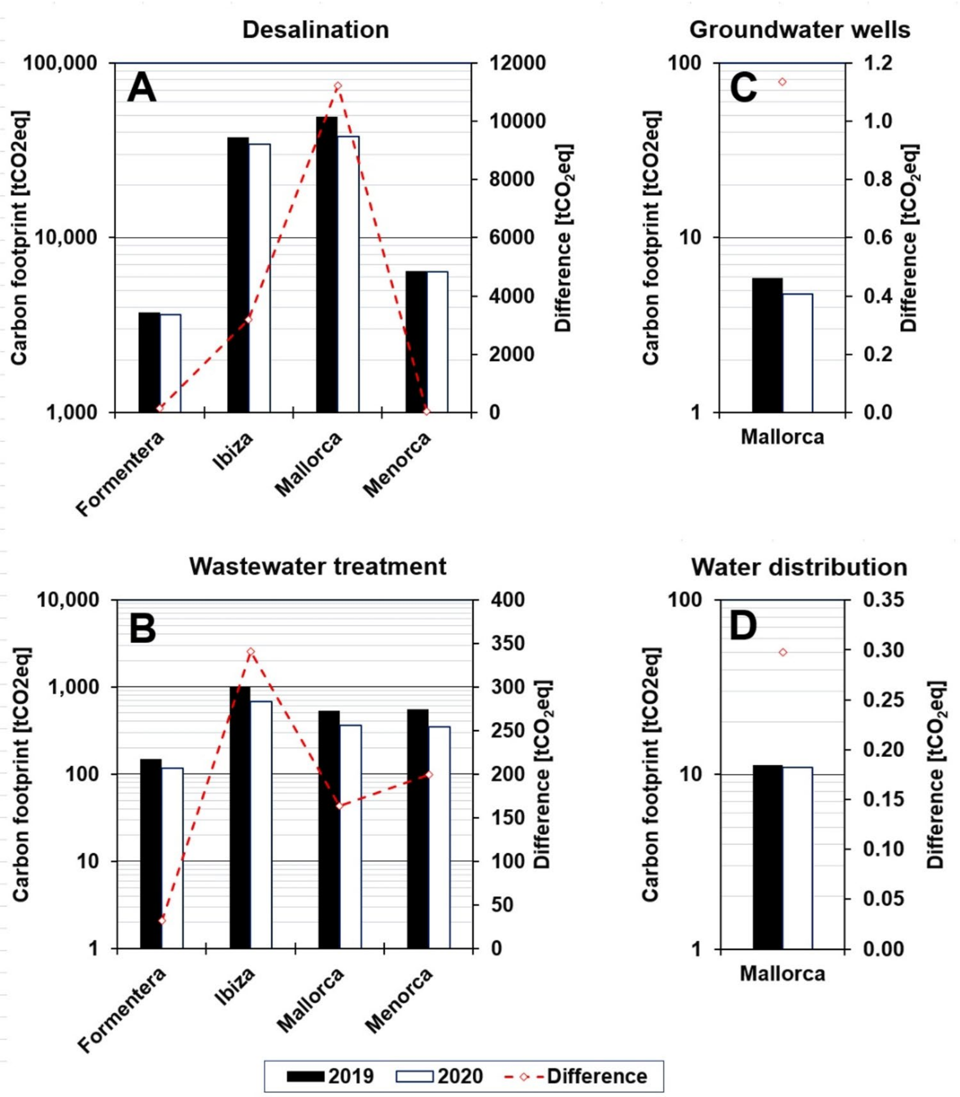

Fig. 6 Carbon footprint and difference between 2019 and 2020 for each of the facilities studied in each of the Balearic Islands

desalination plants (see Table 4). This is mainly because, in most cases, the flow captured by the desalination plant was lower in 2020 (possibly due to the decrease in tourist activity on the island, amongst others), as well as the decrease in the emission factor in the two companies that supply electricity.

It is observed that a lower volume of water captured in the desalination plant does not necessarily imply a lower carbon footprint (see Fig. 4). This is due to the following influences on the different scopes:

- Scope 1: those facilities that make use of fossil fuels in fixed installations and vehicles increase Scope 1
- Scope 2: electricity consumption is directly related to the working capacity of the plant.
- Scope 3: The management of the desalination plant (suppliers and waste management), as well as the number of workers at the plant, either increases or decreases the carbon footprint in each case. We found that desalination plants with a higher number of workers and external contracted companies increase the carbon footprint in Scope 3.

Figure 4 shows how the trend appears to be reversing at lower flows, as less water was desalinated overall in 2020, but the carbon footprint is larger. However, for high volumes in 2020, the footprint was reduced at similar flows. This finding can also be observed in a similar study conducted in the Canary Islands, the other Spanish archipelago, which, in turn, is an outermost region of Europe (Cruz-Pérez et al. 2022).

Overall results

Finally, Figs. 5 and 6 are added where the following information can be consulted: Fig. 5 shows the relationship between the volume of water treated by the facilities and the normalised carbon footprint, per cubic hectometre; Fig. 6 shows the carbon footprint for each of the four blocks studied (desalination, wells, wastewater treatment and water distribution) for each of the four islands of the Balearic archipelago (in the red-dotted line, you can see the difference between the years 2019 and 2020).

Conclusion

The aim when starting this work was to determine which facilities had the largest carbon footprint in the water cycle in the Balearic Islands, where it was concluded that the largest footprint was from seawater desalination plants, mainly due to their high electricity consumption. In addition, as none of the facilities have an electricity supplier whose electricity mix is equal to zero, Scope 2 is not cancelled in any of the cases, being of notable importance in seawater desalination plants.

Next would be the drinking water pumping stations that extract water from the aquifer, since they require energy produced by burning fossil fuels (Scope 1) and/or electricity (Scope 2) to send the water obtained from the subsoil to the surface. The drinking water distribution network also has a carbon footprint comparable to that of pumping since, in some sections of the network, it is necessary to propel the water (mainly due to differences in elevation along the route).

Therefore, by reducing the use of fossil fuels in the installation and relying on electricity supply companies whose electricity mix is zero, it is possible to significantly reduce the first two scopes of the carbon footprint. With respect to Scope 3, it should be considered that these are not emissions that depend directly on the operating company, but they should also be considered to improve overall management and the company's relationship with its environment.

Calculating the carbon footprint, therefore, provides a number of benefits, including reducing greenhouse gas emissions associated with improved energy efficiency and economic savings, establishing communication policies in organisations, reducing the costs associated with legislative changes by achieving early adaptation to new requirements, improving energy efficiency by reducing operating costs and evaluating alternatives for future actions.

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Declarations

Conflict of 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.

Geoethical scope This study has sought to identify the main greenhouse gas emissions linked to the production of drinking water in the Balearic Islands (Spain). The production of drinking water in the Spanish archipelagos is a great challenge due to the great pressures on aquifers in highly touristic regions and a growing population. The intention has been to link the production of drinking water with its effect on climate change through the energy consumed by this sector. Importance has been given to the water-energy nexus through the calculation of the carbon footprint, which mainly establishes the emissions generated by the consumption of fossil fuels necessary for the production of drinking water, especially in those installations that require the most energy, such as seawater desalination plants or the extraction of water from wells. The aim is to raise public awareness of the importance of implementing renewables to prevent water consumption from putting extra stress on the planet, especially in areas that are highly dependent on desalination. It is also hoped that this study will be useful for regional water governance and help decision-making to improve the ecological transition in the sector.

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