EVALUATION OF THE CARBON FOOTPRINT IN THE TREATMENT OF URBAN WASTEWATER IN THE CANARY ISLANDS (SPAIN)

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ABSTRACT:

Wastewater treatment plants are important to protect water and human health from pollution caused by human activities. However, these processes can also have negative impacts on the environment. Footprint assessment has been used to study how treatment plants affect the environment and evaluate their sustainability. Carbon footprint, as well as other footprints such as nitrogen and phosphorus, have been investigated to assess water pollution. The advantages and disadvantages of these assessments were discussed and suggestions for improvement were proposed. Critical research points for future studies were identified, focusing on the relationship between water, carbon, and energy. The ultimate goal of the study is to reduce the carbon footprint, both in direct and indirect emissions, using new tools and methods.

Key Words: Footprint; Waste water; Canary Islands

RESUMEN:

Las plantas de tratamiento de aguas residuales son importantes para proteger el agua y la salud humana de la contaminación causada por actividades humanas. Sin embargo, estos procesos también pueden tener impactos negativos en el medio ambiente. Se ha utilizado la evaluación de la huella para estudiar cómo las plantas de tratamiento afectan al medio ambiente y evaluar su sostenibilidad. Se investigó la huella de carbono, así como otras huellas como las de nitrógeno y fósforo para evaluar la contaminación de cuerpos de agua. Se discutieron las ventajas y desventajas de estas evaluaciones y se propusieron sugerencias para mejorarlas. Se identificaron puntos críticos de investigación para futuros estudios, centrándose en la relación entre agua, carbono y energía. El objetivo final del estudio es reducir la huella de carbono, tanto en emisiones directas como indirectas, utilizando nuevas herramientas y métodos.

Palabras Clave: Huella de Carbono; Agua Residual; Islas Canarias

1. INTRODUCTION

The Carbon Footprint (CF) measures greenhouse gas emissions caused by human activities. Wastewater treatment plants are major generators of greenhouse gases[1-2-3-4]]. According to the IPCC, they account for 3% of global emissions. UNE-EN ISO 14064-1:2019[14] will be followed to calculate carbon production in functional units. Three scopes are considered: direct, indirect energy and other indirect. The characteristics of the study area, the purification process, the calculation methodology and the results are detailed. Mitigation of the carbon footprint will be sought [5-6-7-8-9-10].

2. MATERIALS AND METHODS

2.1 AREA STUDY

The Canary Islands are part of Spain and the European Union. They consist of seven main islands divided into two provinces with a total population of over two million inhabitants. They also include six volcanic islets in the north. The total area of the archipelago is 7,446 km2 in a sea area of approximately 100,000 km² [14-15-16-17-18-19] , as shown in Table 1.

Table 1: Surface area of each island and maximum altitude (Source: ISTAC [20]).

Island	Area (km)2	Maximum Altitude (m.)
Lanzarote	845,94	671 (Peñas del Chache)
Fuerteventura	1.659,74	807 (Jandía)
Gran Canaria	1.560,10	1.949 (Peak of Las Nieves)
Tenerife	2.034,38	3,718 (Teide)
La Gomera	369,76	1,487 (Garajonay)
La Palma	708,32	2.423 (Roque de Los Muchachos)
El Hierro	268,71	1,501 (Malpaso)

The demographic data for each island is presented below, indicating that the behaviour of population growth is not homogeneous across the islands, as shown in table 2:

Table 2: Distribution of the population by islands (Source: Canary Islands Statistics Institute and National Statistics Institute.

	2021	2020	2000	Increase 2000-2020
CANARY ISLANDS	2.172.944	2.175.952	1.716.276	26,8
LANZAROTE	156.189	155.812	96.310	61,8
FUERTEVENTURA	119.662	119.732	60.124	99,1
GRAND CANARY	852.688	855.521	741.161	15,4
TENERIFE	927.993	928.604	709.365	30,9
LA GOMERA	21.734	21.678	18.300	18,5
LA PALMA	83.380	83.458	82.483	1,2
THE IRON	11.298	11.147	8.533	30,6

In the Canary Islands there are a total of 158 wastewater treatment plants, distributed among the different islands as shown in Table 3 below:

Table 3: Number of wastewater treatment plants in the Canary Islands Source:

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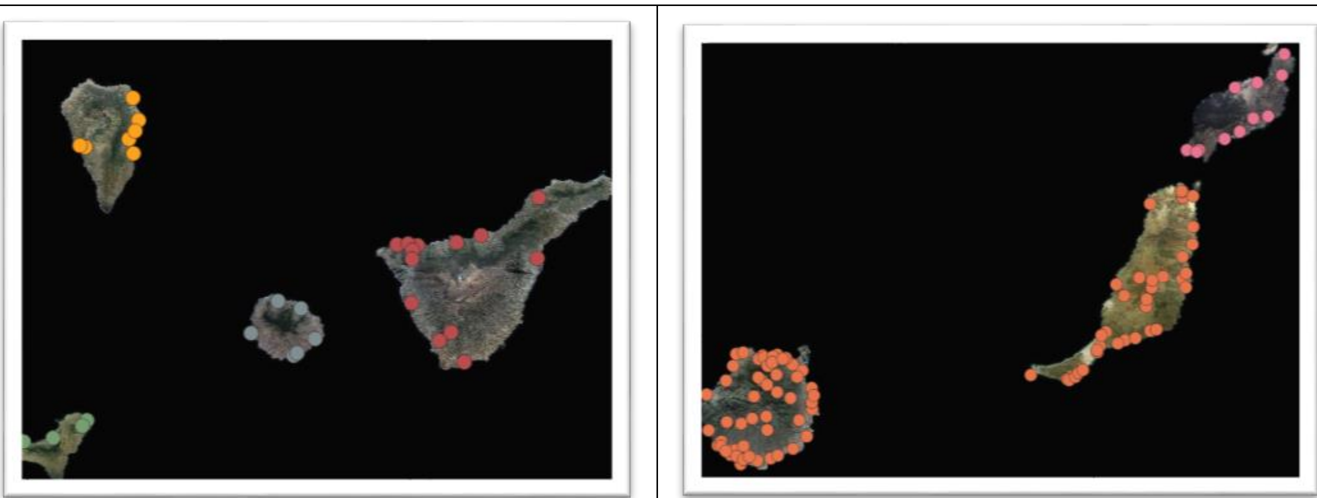
Island	Number of stations
Gran Canaria	57
Tenerife	36
Lanzarote	12
Fuerteventura	36
La Palma	7
La Gomera	6
El Hierro	4



Distribution of WWTPs in the province of Tenerife	Distribution of WWTPs in the province of Las Palmas

Figure 3. Locations of WWTPs in the Canary archipelago

The volume of wastewater treated in the Canary Islands amounted to 282,590 m_3 /d in 2018, of which only approximately 22% was reclaimed for reuse in the agricultural sector (ISTAC) [20].

With regard to the management of the WWTPs, 79% are managed by Municipal Services or by the Island Councils of each island, while the rest correspond to private entities in the hotel sector or industrial waste treatment plants.

2.2 PURIFICATION PROCESSES

In general, in the Canary Islands, water is discharged into the sewerage network, without exceeding the maximum values permitted in the different Hydrological Plans of each island, which are shown in Table 4.

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Table 4. Limiting the concentration of waste water quality parameters.

Concentration(mg/l)			
BOD (Biological Demand)	1000	Chlorides	300
pH	5.5-5.9	Sulphites	2
COD (Chemical Demand)	1600	Sulphates	350
Temperature	45ºC	Total phosphates	10
Suspended Solids	1200	Ammonium	50
Oils and Fats	500	Nitric Nitrogen	20

The WWTP treats the wastewater to remove pollutants and return it to the sewerage system. An anaerobic process is used to stabilise the sludge generated, which is further treated for dewatering.

3. METHODOLOGY

The methodology used in this article is divided into the following sections:

A) Protocol of the Intergovernmental Panel on Climate Change (IPCC) for the calculation of the Carbon Footprint of WWTPs

B) Classification of WWTPs

C) Calculation data

3.1 IPCC PROTOCOL

The IPCC methodology provides the basis for most of the above-mentioned documents and consists of a wide range of values and technical data evaluated by expert commissions. These data values are especially necessary for application in the Canary Islands due to the lack of information on this sector in the local territory [15], as shown in table 5.

Table 5. Methodologies used for greenhouse gas calculations

Methodology	Advantages	Disadvantages
LGO	Top-down methodology Free access and easy to use. It provides various forms of calculation that allow you to be more precise depending on the availability of site-specific data.	IPCC and USEPA approaches Standardised set of guidelines to assist local governments in the USA.
USEPA	Different levels of requirements, rigour and accuracy of data Free and easy to use access.	National and state level estimates using IPCC baseline Most appropriate method for the state of California.
NERP	Top-down methodology Free and easy to use access.	The methodology follows the IPCC guidelines and the IPCC good practice guide. It does not provide a default operational database. Country-specific data on the direct N emission factor O $_2$
IPCC	Internationally recognised Core for subsequent protocols Top-down methodology Designed for macro-scale evaluations Large input of reviewed data.	It does not use installation-specific information.

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The IPCC Carbon Emissions model is used to assess carbon emissions from wastewater treatment plants. Information on human activities is combined with emission coefficients to calculate emissions. The carbon footprint is divided into direct and indirect emissions, which include gases such as nitrous oxide and methane released at the plants.

3.2. CLASSIFICATION OF WATER TREATMENT PLANTS

In order to classify the different wastewater treatment plants in the Canary Islands, the system used in each of them will be considered. Given that there are different sizes of these plants on all the islands, some ranges have been established in order to categorise them, which are detailed in Table 6.

Table 6: The classification ranges

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	Very small <10,000 H.E.	Small 10.000-50000 H.E.	Medium 50,000-100000 H.E.	Big 100.000 H.E.<
CANARY ISLANDS				
LANZAROTE	50%	33,3%	16,7%	-
FUERTEVENTURA	44,44%	55,55%	-	-
GRAND CANARY	61,54%	19,23%	7,69%	19,23%
TENERIFE	74,28%	14,28%	5,71%	5,71%
LA GOMERA	100%	-	-	-
LA PALMA	100%	-	-	-
THE IRON	100%	-	-	-

There is a big difference between the technological systems of small and large wastewater treatment plants. Small and medium-sized wastewater treatment plants often lack aeration control systems. In addition, the design, based on mechanical robustness, implies a certain oversizing of the electromechanical equipment. Therefore, the unit consumption in such plants is relatively high.

3.3. CALCULATION DATA

The following considerations have been taken into account in the calculations:

CO2 in wastewater treatment is natural, but methane and nitrous oxide are greenhouse gases. Poorly designed plants produce methane. The sources of nitrous oxide are nitrification and denitrification in Secondary Decantation. The inventory considers emissions of N_2 O from these stages, as well as methane and nitrous oxide in sludge treatment, excluding biogas in most plants.

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3.3.1. DIRECT EMISSIONS

Wastewater can produce methane and nitrous oxide due to the action of bacteria in the treatment process. Emissions are divided into two categories: water treatment processes and sludge emissions. Emissions of CO_2 and CH4 are calculated from the removal of biological oxygen demand, and nitrous oxide emissions from the total nitrogen removal.

The CH emission$_4$ produced by anaerobic degradation and its quantification is a function of the degradable organic matter content of the wastewater as well as the temperature and type of treatment. The main empirical emission factors used to calculate direct emissions comprise FE N_2O = 0.016 kg N_2O/kg. For calculating direct emissions of N_2O from wastewater treatment processes (IPCC,2019), FE CH_4 = 0.0025 kg CH_4 /kg. To calculate direct CH4 emissions in the activated sludge process.

CO_2 = FE * MBOd, i (3)

CH_4 = FE * MBOD (4)

N_2O = FE + TM (5)

For further information, please find attached an annex with tables of the water treatment plants on each island with the different parameters:

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Table 7: DIRECT EMISSIONS FROM WWTP'S ON THE ISLAND OF GRAN CANARIA

EDAR GRAN CANARIA	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	FLOW IN M3/DAY (0,2)	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION IN PURIFICATION(KW/he.)	CONSUMPTION WITH UPDATED CONSUMPTION FACTOR 0.615CO/KWH	TOTAL
BARRANCO SECO I	10.000	130.000	0,2	2.000	0,5	1.000	0,615	615
BARRANCO SECO II	200.749	600.000	0,2	40.149,8	0,5	20.075	0,615	12.346,0635
SOUTHEAST(AGÜIMES)	134.000	150.000	0,2	26.800	0,5	13.400	0,615	8.241
THE BOARD (SBT)	64.941	100.000	0,2	12.988,2	0,5	6.494	0,615	3.993,8715
TELDE(HOYA DEL POZO)	80.000	100.000	0,2	16.000	0,5	8.000	0,615	4.920
JINAMAR (TELDE)	42.335	50.000	0,2	8.467	0,5	4.234	0,615	2.603,6025
ARGUINEGUIN (MOGAN)	11.502	30.000	0,2	2.300,4	0,5	1.150	0,615	707,373
GUIDE-GALDAR	31.481	30.000	0,2	6.296,2	0,5	3.148	0,615	1.936,0815
MOTOR GRANDE(ARUCAS)	25.247	20.000	0,2	5.049,4	0,5	2.525	0,615	1.552,6905
MOGAN BEACH	7.150	20.000	0,2	1.430	0,5	715	0,615	439,725
TAMARACEITE	5.191	13.600	0,2	1.038,2	0,5	519	0,615	319,2465
SAN NICOLAS	7.372	10.000	0,2	1.474,4	0,5	737	0,615	453,378
TEROR	9.647	10.000	0,2	1.929,4	0,5	965	0,615	593,2905
PLAYA DEL CURA(MOGAN)	2.600	10.000	0,2	520	0,5	260	0,615	159,9
AGAETE	5.626	7.000	0,2	1.125,2	0,5	563	0,615	345,999

TENOYA	6.884	6.800	0,2	1.376,8	0,5	688	0,615	423,366
VALSEQUILLO	8.400	6.000	0,2	1.680	0,5	840	0,615	516,6
FIRGAS	4.457	60.000	0,2	891,4	0,5	446	0,615	274,1055
EL FONDILLO (SASNTA BRIGIDA)	5.257	6.000	0,2	1.051,4	0,5	526	0,615	323,3055
GANDO	3.947	5.000	0,2	789,4	0,5	395	0,615	242,7405
BAÑADEROS(ARUCAS)	4.871	5.000	0,2	974,2	0,5	487	0,615	299,5665
CAPE VERDE	4.131	5.000	0,2	826,2	0,5	413	0,615	254,0565
SAINT MATTHEW	6.500	5.000	0,2	1.300	0,5	650	0,615	399,75
TAURITO(MOGAN)	3.300	3.500	0,2	660	0,5	330	0,615	202,95
BARRANCO VERGA	3.000	3.000	0,2	600	0,5	300	0,615	184,5
BAHIA FELIZ(SBT)	3.284	2.560	0,2	656,8	0,5	328	0,615	201,966
TOTAL VALUES	681.872	1.258,460				69.187		42.550,128

Table 8: DIRECT EMISSIONS WWTP'S TENERIFE

TENERIFE WWTP	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	FLOW IN M3/DAY (0,2)	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION IN PURIFICATION(kW/he.)	CONSUMPTION WITH UPDATED CONSUMPTION FACTOR 0.620 CO/KWH	TOTAL
ADEJE-ARONA	238.333	200.000	0	47.667	0,5	23833,3	0,62	14.776,646
BUENOS AIRES(SCT)	463.147	166.666	0	92.629	0,5	46314,7	0,62	28.715,114
VALLEY OF LA OROTAVA(PUERTO LA CRUZ)	72.548	60.000	0	14.510	0,5	7254,8	0,62	4.497,976
NORTHWEST(LAGUNA)	63.516	14.583	0	12.703	0,5	6351,6	0,62	3.937,992
SOUTHERN GOLF	21.574	6.300	0	4.315	0,5	2157,4	0,62	1.337,588
GARACHICO	3.903	6.000	0	781	0,5	390,3	0,62	241,986
AIRPORT TF SOUTH GARABOTO	6.041	6.000	0	1.208	0,5	604,1	0,62	374,542
BUENAVISTA DEL NORTE	2.574	4.000	0	515	0,5	257,4	0,62	159,588
YELLOW GOLF	2.433	0	0	487	0,5	243,3	0,62	150,846
ETAR OF THE SILOS	3.248	0	0	650	0,5	324,8	0,62	201,376
ETAR DE ACORAN (SCT)	4.402	0	0	880	0,5	440,2	0,62	272,924
SAN MIGUEL(GRANADILLA)	2.450	0	0	490	0,5	245	0,62	151,9
ETAR DE PUNTA BLANCA (GUIA DE ISORA)	1.988	0	0	398	0,5	198,8	0,62	123,256
ETAR DE PUERTO DE SANTIAGO	12.539	0	0	2.508	0,5	1253,9	0,62	777,418

(SANTIAGO DEL TEIDE)								
ETAR LOS GIGANTES (SANTIAGO DEL TEIDE)	4.546	0	0	909	0,5	454,6	0,62	281,852
ETAR DE SAN ANDRES(SCT)	4.618	0	0	924	0,5	461,8	0,62	286,316
ETAR DE SUEÑO AZUL (ADEJE)	9.750	0	0	1.950	0,5	975	0,62	604,5
ETAR DE AÑAZA(SCT)	6.603	0	0	1.321	0,5	660,3	0,62	409,386
ETAR DE TABAIBA	4.611	0	0	922	0,5	461,1	0,62	285,882
ARICO ENVIRONMENTAL COMPLEX	7.916	0	0	1.583	0,5	791,6	0,62	490,792
LA REINA PARK(ARONA)	3.283	0	0	657	0,5	328,3	0,62	203,546
COSTA DEL SILENCIO(ARONA)	14.640	0	0	2.928	0,5	1464	0,62	907,68
LAS GALLETAS(ARONA)	6.986	0	0	1.397	0,5	698,6	0,62	433,132
ETAR DE CALETILLAS (CANDELARIA)	2.442	0	0	488	0,5	244,2	0,62	151,404
ETAR OF SAN BLAS(CANDELARIA)	9.610	0	0	1.922	0,5	961	0,62	595,82
ETAR PUNTA LARGA(CANDELARIA)	9.446	0	0	1.889	0,5	944,6	0,62	585,652
ETTING THE COATS	4.087	0	0	817	0,5	408,7	0,62	253,394
ETAR DEL POL.IND.GRANADILLA	2.931	0	0	586	0,5	293,1	0,62	181,722
ETAR ENSENADA PELADA	21.900	0	0	4.380	0,5	2190	0,62	1357,8

GUIA DE ISORA	6.688	0	0	1.338	0,5	668,8	0,62	414,656
ETAR DE LOS TARAJALES (GUIMAR)	9.796	0	0	1.959	0,5	979,6	0,62	607,352
PUNTA DEL HIDALGO(LAGUNA)	7.143	0	0	1.429	0,5	714,3	0,62	442,866
ETAR PLAYA SAN JUAN	11.794	0	0	2.359	0,5	1179,4	0,62	731,228
ETAR RADAZUL	9.593	0	0	1.919	0,5	959,3	0,62	594,766
ETAR POL.IND.GUIMAR(ARAFO)	9.136	0	0	1.827	0,5	913,6	0,62	566,432
TOTAL VALUES	1.066.215	463.549				106.621,5		66.105,33

Table 9: LANZAROTE WWTP'S DIRECT EMISSIONS

LANZAROTE WWTP	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	M3/DAY AVERAGE PER PERSON	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION IN PURIFICATION (kW/h.e.)	CONSUMPTION WITH UPDATED FACTOR 0.689 CO/KWH	TOTAL
ARRECIFE	52.600	60.000	0	10.520	0,5	5.260	0,689	3.624,14
TIAS	33.000	60.000	0	6.600	0,5	3.300	0,689	2.273,7
TEGUISE COAST	30.100	20.000	0	6.020	0,5	3.010	0,689	2.073,89
PARROT(YAIZA)	0	9.960	0	0	0,5	0	0,689	0
PLAYA BLANCA(YAIZA)	15.260	9.000	0	3.052	0,5	1526	0,689	1.051,414
HARIA	4.000	2.250	0	800	0,5	400	0,689	275,6
RED MOUNTAIN(YAIZA)	0	2.000	0	0	0,5	0	0,689	0
LA SANTA(TINAJO)	2.000	2.500	0	400	0,5	200	0,689	137,8
TOTAL VALUES	136.960	165.710				13.696		9.436,544

Table 10: FUERTEVENTURA WWTP'S DIRECT EMISSIONS

FUERTEVENTURA WASTEWATER TREATMENT PLANT	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	M3/DAY AVERAGE PER PERSON	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION IN PURIFICATION(kW/he.)	CONSUMPTION WITH UPDATED FACTOR 0.726 CO/KWH	TOTAL
MORRO JABLE II (PAJARA)	23.454	58.334	0	4.691	0,5	2345,4	0,726	1.702,76
COSTA CALMA(PAJARA)	18.333	42.494	0	3.667	0,5	1833,3	0,726	1.330,976
PUERTO DEL ROSARIO	18.334	30.000	0	3.667	0,5	1833,4	0,726	1.331,048
GEAFOND 2 WWTP	16.000	185.000	0	3.200	0,5	1600	0,726	1161,6
WHITE MOUNTAIN(OLD)	15.416	17.500	0	3.083	0,5	1541,6	0,726	1.119,202
GRAN TARAJAL(TUINEJE)	6.250	15.000	0	1.250	0,5	625	0,726	453,75
FUERTEVENTURA AIRPORT	3.131	8.914	0	626	0,5	313,1	0,726	227,3106
THE SEAGULLS(PAJARA)	3.400	4.000	0	680	0,5	340	0,726	246,84
BEACHES OF JANDIA	3.992	3.992	0	798	0,5	399,2	0,726	289,8192
TOTAL VALUES	108.310	365.234				10.831		7.863,306

Table 11: DIRECT EMISSIONS WWTP'S LA PALMA

LA PALMA WWTP	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	M3/DAY AVERAGE PER PERSON	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION IN PURIFICATION (kW/h.e.)	CONSUMPTION WITH UPDATED FACTOR 0,710 CO/KWH	TOTAL
LOS LLANOS DE ARIDANE	7.817	30.000	0	1.563	0,5	781,7	0,71	555,007
SANTA CRUZ DE LA PALMA	9.762	18.666	0	1.952	0,5	976,2	0,71	693,102
TAZACORTE(PUERTO)	1.785	10.000	0	357	0,5	178,5	0,71	126,735
REGIONAL BREÑAS MAZO	2.441	8.125	0	488	0,5	244,1	0,71	173,311
NAOS PORT	2.327	4.000	0	465	0,5	232,7	0,71	165,217
SAN ANDRES Y SAUCES	2.345	2.304	0	469	0,5	234,5	0,71	166,495
TOTAL VALUES	26.477	73.095				2.647,7		1.879,867

Table 12: DIRECT EMISSIONS FROM LA GOMERA WWTPs

LA GOMERA WWTP	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	M3/DAY AVERAGE PER PERSON	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION AT PURIFICATION (kWH/he.)	CONSUMPTION WITH UPDATED CONSUMPTION FACTOR 0.776 CO/KWH	TOTAL
SAN SEBASTIAN DE LA GOMERA	7.200	7.500	0	1.440	0,5	720	0,776	558,72
VALLEY GREAT KING	5.100	5.000	0	1.020	0,5	510	0,776	395,76
TOTAL VALUES	12.300	12.500				1230		954,48

Table 13: DIRECT EMISSIONS WWTP'S EL HIERRO

EL HIERRO WWTP	FLOW H.E.	DESIGN POPULATION H.E.	M3/DAY AVERAGE PER PERSON	M3/DAY AVERAGE PER PERSON	AVERAGE PURIFICATION CONSUMPTION 0,5 KWH/m³	CONSUMPTION AT PURIFICATION (kWH/he.)	CONSUMPTION WITH UPDATED CONSUMPTION FACTOR 0,455 CO/KWH	TOTAL
VALVERDE	1.771	3.000	0	354	0,5	177,1	0,455	80,580
TOTALS	1.771	3.000				177,1		80,6

3.3.2 INDIRECT EMISSIONS

Indirect emissions include GHG emissions from the energy, chemical and transport sectors. EFs include both general factors and plant-specific factors. The general factors are kept constant for all sites in each country. These factors refer to transport, chemical manufacturing and fugitive emissions of CH_4 and N_2O.

Plant-specific factors are unique and variable between WWTPs. They vary between sites depending on the energy supplier and the source of energy or fuels used in their electricity and heat generation processes [11].

The total energy consumed depends on the renewable and non-renewable energy of the electricity system and the local renewable energy produced by themselves. Because of this, the equation that represents it is as follows [17]:

ETc = ERn + ENRn + ELR being (6)

ETc: Total energy consumed by the system

ERn: Renewable energy from the grid

ENRn: Non-renewable energy from the grid

ELR: Local renewable energy

Depending on the local renewable energy, the carbon footprint will vary. They will decrease as much as local renewable energy is produced. As can be seen in Table 14 the energy coming from the electricity system could be non-renewable energy (diesel, gas turbine, steam turbine and combined cycle) but also renewable energy mainly from wind and photovoltaic energy. In the figure we can see that in the last 20 years energy from renewable sources has increased from 8% to 20%. When selecting the appropriate emission factor, the origin of the energy must be taken into account, as shown in table 14.

Table 14. Electricity balance in the Canary Islands

	2017	2018	2019	2020	2021
Hydraulic	3.272	3.277	3.510	3.481	3.043
Wind	395.925	622.029	1.138.117	1.100.549	1.310.025
Photovoltaic	273.627	272.073	278.920	258.863	262.265
Hydroeolian	20.233	23.656	23.249	19.540	23.088
Other renewables	9.565	8.932	9.774	9.187	8.054
Total renewables	702.622	929.966	1.453.568	1.391.621	1.606.476
Combined cycle	2.997.377	3.051.022	3.053.518	3.254.270	3.430.240
Diesel engines	2.242.324	2.121.135	1.949.945	1.717.409	1.716.908
Gas turbine	314.346	284.093	228.936	195.761	199.026
Steam turbine	2.674.394	2.455.432	2.189.011	1.387.608	1.108.038
Total non-renewable	8.228.441	7.911.682	7.421.410	6.555.047	6.454.210
Demand in B.C.	8.931.063	8.841.647	8.874.978	7.946.668	8.060.686

Source: https://www.ree.es/es/datos/balance/balance-electrico

In this sense, following the specific environmental impact indicator model [18] and the formula used by Red Eléctrica Española for the emissions factor in non-renewable generation in the electricity system for 2021.

FE=FMmd+FMtg+FMtv+Fmcc (7)

where we can define according to the Ministry of Ecological Transition:

FM: Electricity Mix Emission Factor (tCO_2 /kWh)

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FMmd: Mix of Diesel Engine Factors (tCO_2 /kWh)

FMtg: Mixed Gas Turbine Factors (tCO_2 /kWh)

FMtv: Steam Turbine Factor Mix (tCO_2 /kWh)

CCcf: Combined Cycle Factor Mixture (tCO_2 /kWh)

RE: Energy Efficiency (kWh/m3)

HCMIX: Carbon Footprint of the Energy Mix (tCO)$_2$

E1tMIX: Real Energy from the technologies of the Energy Mix (kWh)

E2tMIX: Future Energy of the Energy Mix of Technologies (kWh)Ei: Energy of each technology (kWh)

Pt: Percentage of use of each technology in the Energy Mix

The FM is calculated for each technology and island with the total energy consumption per island, associated to the Carbon Footprint and the percentage of a technology in the Energy Mix, including renewable and non-renewable energies. Consequently, the FM of a given technology "i" per island is as follows:

FMi=Pti/100-HCi/Ei (8)

In this way, the Carbon Footprint of the current and future Energy Mix is calculated, considering the sum of the energies of each technology and its emissions mix factor.

HCMIX=ΣEiFMi (9)

The current energy and future energy of the technologies in the Energy Mix are as follows:

E1tMIX=ΣEi at initial time (10)

E2tMIX=ΣEi at end point in time (11)

Installed wind power capacity in the Canary Islands has increased from 467 MW in 2020 to 560 MW in 2021 and is the second largest source of generation ahead of gas turbines, diesel engines and steam turbines. By 31 December 2021, wind power will account for 17.7% of installed capacity in the island system (15.3% in 2020).

For the island of El Hierro, an electricity system of special relevance due to the Gorona del Viento hydro-wind power plant. The continuous review of its operating criteria has enabled it to achieve very high levels of renewable integration. Thus, in July 2021, the monthly renewable integration in this system reached 81%, reaching 48.3% for the year as a whole.

Table 15 below shows the Emission Factor for the entire electricity system for the year 2020, calculated as the total GHG emissions from electricity generation (corresponding to emissions from thermal power plants) divided by the total final electricity.

Table 15. Emission factor of the electricity system by islands. Year 2020

	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canary Islands
GHG emission(tCO2eq)	1.863.104	1.812.588	463.838	364.492	166.894	49272	19.857	4.740.046
Electricity (MWh)	3.028.008	2.924.718	673.148	502.077	253.164	63.460	43.613	7.470.190
Emission factor	0,615	0,620	0,689	0,726	0,710	0,776	0,455	0,635

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Table 16. WWTP according to cycles

	Very small <10.000 H.E.	Small 10.000-50.000 H.E.	Medium 50.000-100000 H.E.	Big 100.000 H.E.<
CANARY ISLANDS				
LANZAROTE	50%-(4)	33,3%-(3)	16,7%-(1)	-
FUERTEVENTURA	44,44%-(4)	55,55%-(5)	-	-
GRAND CANARY	65,38%-(17)	19,23%-(5)	7,69%-(2)	7.63%-(2)
TENERIFE	74,28%-(26)	14,28%-(5)	5,71%-(2)	5,71%-(2)
LA GOMERA	100%-(2)	-	-	-
LA PALMA	100%-(6)	-	-	-
THE IRON	100%-(1)	-	-	-
TOTAL EDAR CANARIAS	68,96%-(60)	20,68%-(18)	5,74%-(5)	4,59%-(4)

Table 17. Emission factor of the electricity system by islands. Year 2020

TREATMENT CYCLES IN THE WWTPS OF THE CANARY ISLANDS	
PRE-TREATMENT	100%
PRIMARY TREATMENT	100%
SECONDARY TREATMENT	100%
TERTIARY TREATMENT	13,33%

In a WWTP, energy consumption varies according to its size, the pollutant load of the influent, the type of treatment and the technology used in the operation, which means that the cost of energy will vary from one treatment plant to another. Table 18 below shows the percentage distribution of electricity consumption by treatment or service.

Table 18. Electricity consumption according to treatment or service (González and Moreno, 2009) [20].

POWER CONSUMPTION ACCORDING TO TREATMENT CYCLE	
GENERAL SERVICES	8%
PRE-TREATMENT AND PRIMARY TREATMENT	14%
SECONDARY TREATMENT	73%
TERTIARY TREATMENT	5%

In the Canary Islands, the total energy used, including direct and indirect expenditure, is 1,022,967 Kw/h.e. As for the expenditure of the Waste Water Treatment Plants (WWTP), 65% is due to installations, which means that it is an indirect energy consumption, according to the Study of Innovative Energy Saving and Efficiency Measures in Waste Water Treatment Plants[20].

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We can deduce that from the total energy consumption of 1,022,967 Kw/he, we will have a Total Indirect Cost of 664,928.55 Kw/he (65%) and Direct Expenditure of 358,035.45 Kw/he (35%).

The value of Indirect Costs will be broken down according to Table 19, giving the following results:

Table 19. Electricity consumption by treatment or service

INDIRECT ENERGY COSTS OF WATER PURIFICATION	Indirect Kw/h.e.	
GENERAL SERVICES	8%	53.194,28
PRE-TREATMENT AND PRIMARY TREATMENT	14%	93.089,9
SECONDARY TREATMENT	73%	485.397,84
TERTIARY TREATMENT	5%	33.246,42

In conclusion, one of the lines of research for the development of a possible mitigation in the indirect consumption system would be to obtain energy from an alternative source, which in turn would eliminate part of the CO_2 that is emitted in this cycle.

4. RESULTS AND DATA

We have compiled the results and data from the different Island Water Councils throughout the Canary Islands that have collaborated in this research, providing data for the approximate calculation of the carbon footprint generated first by island, second by province and third overall in the entire Canary Islands archipelago.

The calculation system that is generated is to always carry out the study with the most unfavourable data, in this case with the maximum flow that can be given in each WWTP. According to data from the IDAE [19], the pumped electricity consumption is estimated at 447 GWh/year in the collection, supply and distribution of urban water. In treatment, the average specific consumption of the WWTP is 0.5, which means an electricity consumption of 2,225 GWh/year for the facilities as a whole.

Taking these data into account, we have estimated the energy costs according to the flow rate for purification, for which the study is carried out firstly by islands, as shown in table 20.

Table 20: AVERAGE SPECIFIC CO EMISSIONS FOR EACH ISLAND

ISLAND	G.C	TF	LANZ	FV	L.P	GOM	H
CO/Kwh	0,615	0,620	0,689	0,726	0,71	0,776	0,455

5. CONCLUSIONS: STRATEGIES TO REDUCE THE CARBON FOOTPRINT

This article shows a comprehensive review of carbon footprint assessment for wastewater treatment plant (WWTP) processes in the Canary Islands Archipelago, Spain. The review shown in this article has been carried out through direct and indirect emission factors using new tools and methodologies that have been adapted to the characteristics of the island systems.

The criterion followed in this work is the determination of carbon emissions for the functional units in relation to the wastewater treatment flows capable of covering the sum of each WWTP sectorised by islands, provinces and finally for the entire Canary Islands archipelago. An important conclusion from this study is that the carbon footprint can be used to assess the sustainability of WWTPs. In addition to carbon dioxide, nitrogen and phosphorus were also considered within the footprint to assess the eutrophication of water bodies.

To promote the application of footprint assessment, this article regulates the objectives of the study, the frameworks, the limits of the system, the data treatment methods and the resulting interpretation process. The pros and cons of footprint assessment are discussed and investigated in detail, examining the production of CO_2 on each island of the Canary archipelago.

The analysis of footprint assessments at different wastewater treatment plants revealed that wastewater treatment technologies and scales had a significant impact. In addition, the research hotspots identified through a keyword network diagram showed that the water-carbon-energy nexus was a promising direction for future studies.

ABBREVIATIONS: AUTHOR CONTRIBUTIONS

Conceptualization J.V.R., R.L.Q, B.R.G., A.R.M.; Data curation J.V.R., R.L.Q, Formal Analysis, J.V.R., R.L.Q.; Funding acquisition S.O.P.B ; Investigation, Methodology, J.V.R., R.L.Q, B.R.G.,A.R.M.; Project administration, S.O.P.B. ; Resources, S.O.P.B. ; Supervision, J.V.R., A.R.M., S.O.P.B.; Visualization, J.V.R., A.R.M., S.O.P.B.; Writing - original draft, J.V.R., R.L.Q.; Writing - review & editing: J.V.R., A.R.M., B.R.G., S.O.P.B.

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