Brilliant Engineering 1 (2020) 21-25

Brilliant Engineering

www.acapublishing.com

Research Article

Carbon footprint associated to urban water cycle of Córdoba (Spain)

Rafael Marín Galvín[a]

[a]*Empresa Municipal de Aguas de Córdoba, S.A, C/Los Plateros, 1, 14012 Córdoba, Spain*

Abstract

Carbon footprint is a measure used to quantify greenhouse gases (GHG) emissions associated with organizations, events or activities or with the life cycle of a product to determine its contribution to climate change, being expressed in kg of CO_2 equivalent. GHG emissions can be direct or indirect, derived last ones from energy consumption. In the case of the urban water cycle (which uses 3% of the total energy consumption in Spain), the emissions come mainly from the use of energy. Thus, to estimate this type of emissions it can be taken into account both, energy consumption and emission factors, these last ones which associate quantity of energy consumed and quantity of gases emitted. This work presents the result to calculate the carbon footprint related to urban water cycle of Córdoba in the last six years: 4,225.541 T of CO_2 eq/year are emitted, at a rate of 12.92 kg of CO_2 eq/year per inhabitant, and 0.176 kg of CO_2 eq. per m^3/water managed by the company. If we compare this result with the obtained in our last studied period (2012-14) which reached a value of 5,015.80 T of CO_2 eq/year (-15%) and a rate of 15.2 kg of CO_2 eq/year per inhabitant, we can conclude that the company has shown a relevant positive environmental balance.

Keywords: Carbon footprint, greenhouse effect gases, urban water cycle, drinking water treatment, water distribution, sewer sanitation, wastewater treatment.

1.Introduction

Directive 27/2003/CE of European Parliament (October 13, 2003) after modified by the Directive (UE) 208/410 of European Parliament and European Council (march, 2018), implemented in the European legislation the Framework Convention of the United Nations on Climate Change, and the Kyoto Protocol, in order to have a mechanism to the protocolize monitoring of CO_2 emissions and other greenhouse gases (GHG) proactive in the global warming [1,2,3,4]. This Directive included in its scope the following activities:

- Energy activities: combustion facilities with thermal power >20 MW, oil and coke refinery.
- Production and transformation of ferrous metals.
- Minerals industries: cements and ceramic products.
- Other activities: pulp paper and cardboard production.

This Directive established the need to have permissions to GHG emission for the activities affected, rights and obligations, also requiring a National Emission Allocation Plan for EEMMs prepared according to the criteria established in the Directive itself, as well as the possibility to transfer, delivery and cancellation of emission rights between nationals and transnationals and other criteria on the validity of GHG emission rights.

Later, Directive 27/2012/EU established a common framework of measures for the promotion of energy efficiency, and to ensure the achievement of the objective of obtaining energy savings in the EU of 20% by 2020 as form to minimize the environmental impact derived of use of energy, and that of associated GHG production. This directive so-called "Trading of GHG emission rights" enables the compensation of CO_2 emission rights between individuals based on certain perfectly defined conditions. Likewise, the new European framework for the year 2030 doubles the effort of GHG reductions in relation to 2020 and triples the effort in diffuse sectors, these last ones not included in Directive 27/2012/EU, which are the following:

- Commercial, residential and institutional activities.
- Agriculture and livestock.
- Transportation.
- Industrials not affected by the Trade Directive.
- Waste.
- Fluorinated gases used in refrigeration equipment, cosmetics and pharmaceuticals.

This group of activities emit around 100 million of T of CO_2 eq/year in Spain, that is, 60% of total emissions of GHG. In any case, the term carbon footprint [4,7] is a measure used to describe the calculation of the emissions of all GHGs associated with organizations, events or activities or with the life cycle of a product, to determine its contribution to climate change being expressed in kg of CO_2 equivalent. Moreover, carbon footprint is a component of the so-called "ecological footprint" and is related with the "hydric footprint" [7].

On the other hand, to know the carbon footprint linked to any human activity can contribute to the following [1,2,3]:

I. Quantify, minimize and neutralize CO_2 emissions associated to products and organizations in fight against climate change,
II. Promote a market of products and services with low CO_2 generation,
III. Identify saving opportunities in companies and activities, and finally,
IV. Demonstrate the compromise of organizations to work in reverse the climate change.

In order to quantify GHG emissions can be applied the ISO standard 14064 part 1, which is in agreement with the *Greenhouse Gas Protocol*

*Corresponding Author: rmargal@emacsa.es
(R. MARÍN GALVÍN)
Received 5 Dec 2019 Revised 10 Dec 2019 Accepted 10 Dec 2019
Brilliant Engineering 1 (2020) 21-25

https://doi.org/10.36937/ben.2020.001.004

(World Resources Institute and World Business Council for Sustainable Development). Later, the ISO standard 14067 established a specific methodology to extend this calculation to companies, events, activities and life cycle of products and services. Almost, Spain has from 2014 with a voluntary register of carbon footprint, methodology for compensation and CO_2 absorption projects for companies committed to sustainability.

2.General information on the calculation of HGH emissions

GHG emissions are classified in two groups: those included in the 27/2012/UE Directive, and those not included, or diffuse emissions. In this sense, emissions included can be: (a)direct, that is, emanating from sources that the subject of the activity has or control; and (b)indirect from sources non controlled by the subject [1,2,3,4].

Direct emissions

As examples here are included emissions from boiler combustion, use of vehicles and transport in own fleet, as well as other emissions from industrial facilities operated by the subject, which correspond to Scope 1 of GHG emissions.

Indirect emissions

Firstly, those derived from the consumption of electricity and heat, steam or cold. They are not produced in the facility in which electricity or heat is generated or used corresponding to Scope 2 of GHG emissions.

At the same time, there has been established a second group of indirect emissions related to extraction and production of materials acquired to subject activity, professional staff trips, transport of materials, fuels and products, waste treatments, financial costs, and use of products and services by others (Scope 3 of GHG emissions).

With respect to urban cycle water, emissions here generated are mainly promoted by energy use [1,5,6,7,8,9], because this industrial sector consumes 3% of total energy consumption in Spain. To estimate CO_2 emissions for the urban cycle water at Córdoba City (EMACSA, Municipal Company Córdoba´s Water) we have applied an emissive factor to electric consumption extracted to dates existing in bibliography [2,13,14]. Almost, we have taken into account emissions linked to use of fuels in transport under company (in both cases, Scope 1 of GHG emissions).

Finally, we have considered emissions of Scope 3 for estimation. This calculation methodology is the used for all the Spanish water companies and in the following item we are going to present it [7,10,11].

2.1. Emissions associated with energy

<u>*Electric consumption*</u>

For this type of emissions, it must be considered the specific taxpayers that make up the total mix of electric power production in each period considered (periodically updated) [2,10,11,12,13,14]. The set of all these contributions defines the amount of CO_2 equivalent that is associated with the production of an energy unit. In this way, the last data for our company associated emission of 0.390 kg of CO_2 equivalent to produce 1 kWh or electric power.

<u>*Fossil fuels consumption*</u>

For this section, emissions are a function of type of fuel considered. Thus, each unit of fuel is associated with a lot of CO_2 produced. We are going to apply the last emission factors obtained from bibliography.

<u>*Biomass and renewable energy consumption*</u>

Biomass consumption does not contribute to GHG emissions because the emitted CO_2 has been firstly removed from atmosphere for the generation of own biomass. Any examples of neutral biomass with respect to emission of CO_2, are the following:

a. Plants: straw, hay, grass, leaves, wood, roots, and crops such as corn.

b. Biomass waste and by-products: industrial waste wood, used wood, wood-based waste, forestry waste, animal and fish food, sewage sludge, biogas produced by digestion, port and mass sediments of water, and landfill gas from organic waste treatment facilities.

c. Biomass fractions of mixed materials: floating remnants of water mass management, food production waste, fractions of wood waste, textiles, paper, cardboard, and municipal and industrial waste remains.

d. Fuels obtained from biomass: bioethanol, biodiesel, bio-methane, bio-dimethyl ether, bio-oil and biogas.

To estimate the GHG reduction linked to biomass use, it must be applied the amount of conventional energy substituted by biomass with respect to total energy balance of activity. In the same way, it can be estimated GHG reduction linked to renewable energy consumption (solar energy, for example). Finally, the amount of conventional energy substituted (using the corresponding emission factors) must be subtracted of the original total energy balance of activity.

2.2. Emissions associated to transport

<u>*Road transport*</u>

In this case, calculation is based on the type of fuel used and the associated emission factors. The value of the specific factors may vary depending on the method of calculation and estimation applied, recalculated periodically [13,14,15]. Factors can be applied to cars, vans, motorcycles, buses and coaches, and can become more complex if other modulating factors are applied such as type, brand and age of the vehicle, km traveled (city or road): all this type of peculiarities can be found in bibliography. As complementary information, there are CO_2 emission calculators based on the specific casuistry of each activity that they can be found on the Internet.

<u>*Sea transport*</u>

Without too much interest in the case of the urban water cycle, there are also emission factors for each type of fuel (see also bibliography) [1,2,4].

<u>*Air transport*</u>

As in the previous case, air transport has a little impact in the case of the carbon footprint in the urban water cycle. As an introduction to the topic, it can be said that the associated GHG emissions include distance traveled, takeoff and navigation height, number of passengers, type of aircraft, fuel and others [1,2,4].

In addition, each hour of flight of a commercial aircraft means an average emission of 435 kg of CO_2 to atmosphere, together with other associated greenhouse gases. There are also CO_2 emission calculators based on each air route to be made, type of aircraft, travel circumstances, etc., which are available on the Internet for free download, even provided by the airlines themselves.

3. Carbon footprint associated to urban water cycle of Córdoba (Spain)

As it was said above, for its calculation we will apply the methodology of considering energy consumption and associated GHG emission factors (according to bibliography and references). In addition, we will apply, in principle, Scopes 1 (own transport, fossil fuel expenditure) and Scope 2 (expenditure on electricity in drinking water, water distribution, sanitation and purification).

Typical systems consumer of energy in the urban water cycle of Córdoba are the following:

- Pumping and elevations of drinking water and wastewater.
- Air production systems.
- Systems for preparing and dosing gaseous reagents.
- Systems for preparing and dosing liquid reagents.
- Valve control elements.
- Flowmeters.
- Measuring probes.
- Electrical panels.

Shown data corresponded to mean values of the last six years (2013-2018). As starting data, production of drinking water in Córdoba reaches 24,077,000 m^3/year (Drinking Water Treatment Plant -DWTP- of Villa Azul), treated wastewater reaches 24,619,250 m^3/year (Wastewater Treatment Plant -WWTP- of La Golondrina, operated by active aerobic sludge). Moreover, the city has 327,000 inhabitants.

Scope 1, own transport

Total consumption of fuels in own transport used in the company reached 53,894 L/year (sum of gasoline and diesel) while the emissions factors applied have been:

- 2.26 kg of CO_2 equivalent emitted per liter of used gasoline.
- 2.79 kg de CO_2 equivalent emitted per liter of used diesel.

By applying the total consumptions occurred in EMACSA, we obtain that:

- 25,984 L/year of gasoline x 2.26 kg of CO_2 equivalent/L = 58,724 kg of CO_2 eq/year.
- 28,000 L/year of diesel x 2.79 kg of CO_2 equivalent/L = 78,120 kg of CO_2 eq/year.

By adding the two amounts above, we should obtain a total of ***136.844 T of CO_2 eq/year***, what expressed for inhabitant and year should be:

- (136,844 kg of CO_2 equivalent/year) / (327,000 inhab.) = ***0.418 kg CO_2 eq/inhab/year.***

We can express emissions for cubic meter of water (m^3) produced by the population, that is:

- (136,844 kg of CO_2 equivalent/year) / (24,077,000 m^3/year) = ***5.68 g of CO_2 eq/m^3.***

If we express emissions for m^3 of wastewater treated in the city, result should be:

- (136,844 kg of CO_2 equivalent/year) / (24,619,250 m^3/year) = ***5.56 g of CO_2 eq/m^3.***

Additionally, the company has a fleet of 100% electric vehicles, recharged in the Villa Azul DWTP, so its contribution to the generation of GHG is computed within the total electricity consumption of this installation.

Scope 2, electric energy consumption

We are going to sectorize this calculation according to the four component subsectors of the urban water cycle: *production of drinking water*, *distribution of water to the population*, *sanitation and sewerage*, and finally, *treatment of the generated urban wastewater*. As a previous phase, a GHG emission factor must be established derived from the use of electric energy by the company, from its specific commercial supplier.
Table 1 shows the origin of electric energy used in EMACSA during 2017: the main contributor for the electric mix was nuclear energy, followed by carbon and natural gas.

Table 1. Origin sources (%) of electric energy for EMACSA (according to specific marketer).

Sources of electric energy production	*% vs total*
Renewable	13.6
Cogeneration	0.3
High efficiency cogeneration	13.1
Gas natural combined cycle	18.4
Carbon	22.4
Combined Fuel/Gas	3.5
Nuclear	27.5
Other sources	1.2

With this electric mix composition and applying the equivalence routines existing in bibliography and references, it can be inferred that each ***kWh of electric energy used was associated to the emission of 0.390 kg of CO_2 equivalent*** to environment.

Drinking water production

Treatment applied to lead drinking water production depends of raw water quality: this marks the practical operation of the plant. Nevertheless, the Villa Azul´s DWTP is equipped with several systems that consume electrical energy being able to contribute to the GHG emission: these systems are presented in Table-2.

The measurement of electrical consumptions is centralized for all systems of DWTP, without discrimination of specific elements, the highest consumption being those of sand filter washing (which operate daily) and that of production of air and ozonized air (which operate discretionary). Finally, total mean consumption along the last six years has been 776,464 kWh/year. Then, by applying the emission factor above indicated, it results:

- (776,464 kWh/year) x (0,39 kg of CO_2 equivalent/kWh) = ***302.821 T de CO_2 eq/year***, associated to drinking water production.

We can express emissions for cubic meter of water (m^3) produced, that is:

- (302,821 kg CO_2 equivalent/year) / (24.077.000 m^3/year) = ***0,0126 kg CO_2 eq/m^3.***

Finally, if we express emissions for inhabitant of the city, result should be:

(302,821 kg CO_2 equivalent/year) / (327.000 inhab.) = ***0,926 kg CO_2 eq/inhab/year.***

Table 2. Electric energy consuming systems in Villa Azul´s DWTP.

Operating Systems in Villa Azul´s Drinking Water Treatment Plant
Air production
Ozonized air production
Powder active carbon dosing
Chlorine gas production by means evaporation and dosing
Chlorine leak neutralization system
Chlorine dioxide production and dosing
Potassium permanganate dosing
Sodium hidroxide dosing
Aluminium polychloride dosing
Ammonia dosing for disinfection
Ammonia leak neutralization system
Decanter and associated pump purge operation
Production of air for sand filter washing and other uses
Power supply of dosing control systems
Power supply of variable control systems via SCADA
Pumping of drinking water to the network from ETAP tanks
Repairs, cleaning and other uses

Drinking water distribution to network

Part of the distribution of water to the population is get via gravity, so energy consumption is very low, and only networked flow control systems are involved. On the contrary, for the distribution of water to rest of the network, 10 pumping systems are required for storage and distribution tanks, other emergency pumps and periodic or on-demand cleaning elements of the distribution network. In this way, total mean drinking water distributed to population has been 22,630,000 m^3/year.

Total mean consumption along the last six years for this activity has reached 1,198,326 kWh/year. By operating with the emission factor of electric energy, we obtain:

- (1,198,326 kWh/year) x (0,39 kg of CO_2 equivalent/kWh) = ***467.347 T of CO_2 eq/year***, associated to drinking water distribution to network.

We can also express emissions for cubic meter of water (m^3) distributed to population, that is:

- (467,347 kg CO_2 equivalent/year) / (22,630,000 m^3/year) = ***0,0207 kg CO_2 eq/m^3.***

Finally, if we express emissions for inhabitant of the city, result should be:

(467,347 kg CO_2 equivalent/year) / (327,000 inhab.) = ***1,429 kg CO_2 eq/inhab/year.***

Sanitation and sewerage. Wastewater transport to WWTP

The management wastewater phase includes the collection of urban wastewater (domestic and industrial ones) and that of water channels not currently used in the city. The transport of wastewater to the WWTP requires a series of water pumps, installed at strategic points of the sewage network to raise the level of the water line used, and facilitate its access to the WWTP with the minimum need for elevation of water at the entrance of the plant.

In this case, 11 operational wastewater pumps are available in the sanitation network (Archimedes screws and pumps). In addition, the sanitation network has 52 points of relief of water in the riverbed, by means gravity: it entails a minimum energy expenditure (only control of valves and flow control). Total mean of wastewater transported by network sanitation has reached 24.619.250 m^3/year.

In this case, total mean consumption of electric energy associated to sanitation and sewerage along the last six years has been 1,374,566 kWh/year. By operating with the emission factor of electric energy, we obtain:

- (1,374,566 kWh/year) x (0,39 kg of CO_2 equivalent/kWh) = ***536.081 T of CO_2 eq/year***, produced in sanitation and sewerage in the city.

We can also express emissions for cubic meter of wastewater (m^3) collected in the sanitation, that is:

- (536,081 kg CO_2 equivalent/year) / (24.619.250 m^3/year) = ***0.0218 kg CO_2 eq/m^3.***

Finally, if we express emissions for inhabitant of the city, result should be:

- (536,081 kg CO_2 equivalent/year) / (327,000 inhab.) = ***1.639 kg CO_2 eq/inhab/year.***

Wastewater treatment and channel delivery to river

Wastewater treatment facility for the city is named La Golondrina´s WWTP. This is equipped with all systems to carry out a complete process integrated by: pre-treatment, primary decanter (without chemical reagents), aeration, secondary decanter, disinfection of treated water an sludge treatment. In this way, all the systems with electricity consumption in WWTP are described in Table 3. The average energy consumption of the WWTP during the last six years has been 4,265,670 kWh/year. Of this, of the order of ≈70% is due to the generation of air for the biological treatment.

Table 3. Electric energy consuming systems in La Golondrina´s WWTP.

Operating Systems in La Golondrina´s Wastewater Treatment Plant
General bypass operation and evacuation of thick solids
Water elevation in head of plant
Sieves and cleaning operation
Pumps for emptying de-sanding and degreasing channels. Air supply Tilt bridge operation. Other control systems
Emptying pumps of primary decanters. Tilt bridge operation. Other control systems
Air supply for biological treatment rafts. Control systems
Emptying pumps of secondary decanters. Tilt bridge operation. Other control systems
Pumps of primary sludge to gravity thickeners
Pumps of secondary sludge to flotation thickeners
Driving sludge to sludge buffer deposits
Polyelectrolite dosing
Dosing and control of chemical reagents for deodorization in WWTP
Anaerobic digestion system (AD) for wastewater treatment from effluents of yeast factory. Its contribution to the energy consumption of the WWTP is very insignificant because generated electricity is integrated into the supply network
Periodic or occasional internal cleaning systems
SCADA control systems
Systems of measure, flowmeters and other additional systems

In relation to the anaerobic digestion system, this is itself already represents an important contribution of GHG to the global balance of the treatment plant: thus, there are generated in the order of 2,000,000 m^3/year of gas destined for cogeneration that enters in the global energy balance of the WWTP as a contribution; due to this has already been subtracted from the global energy consumption of the plant.

However, this gas contains a 24% average of CO_2 which is emitted directly to the medium, that is 480,000 m^3/year. Now using the conversion of 1 m^3 of CO_2 equals to 1,832 kg of gas by weight, we would have the direct emission of 879,360 T of CO_2/year.

If we continue with the energy calculation again, we now can apply the GHG emission factor indicated above, what results:

- (4,265,670 kWh/year) x (0,39 kg de CO_2 equivalent/kWh) = ***1,663.611 T of CO_2 eq/year***, generated by the wastewater treatment in the WWTP.

We must add here 879.36 T/year of CO_2 produced in the anaerobic digestion. Thus, total amount should be: (1,663.611 T/year + 879.360 T/year) = ***2,542.971 T of CO_2 eq/year.***

We can also express emissions for cubic meter of wastewater (m^3) treated in plant, that is:

- (2,542,971 kg CO_2 equivalent/year) / (24,619,250 m^3/year) = ***0.103 kg CO_2 eq/m^3.***

Finally, if we express emissions for inhabitant of the city, result should be:

- (2,542,971 kg CO_2 equivalent/year) / (327.000 inhab.) = ***7.777 kg CO_2 eq/inhab/year.***

4. Final balance of the carbon footprint in the urban water cycle in Córdoba (Spain)

Results obtained have only included Scope 1 and 2 of GHG emissions. We can complete the study by incorporating the Scope 3 of emissions, which are those attributable to external transport to the company. To do this, we can consider the estimated values of the contribution of road transport on the total energy consumption in Spain (data from the Ministry for Ecological Transition) and the specific situation of logistics derived from activities of EMACSA [13,14]. Thus, we can value this amount as 1.75 times of total fuel consumption of company and consequently, in 1.75 times over the emission of GHG for such activity in relation to the calculation of EMACSA.

With this estimate we would obtain a value of 239.477 T of CO_2 eq/year. Incorporated this data to the final balance, we would have:

- ✓ ***Total emissions in CO_2/year: 4,225.541 T of CO_2 eq.***
- ✓ ***Emissions of CO_2 eq/inhab/year in the city: 12.92 kg CO_2 eq.***
- ✓ ***Emissions of CO_2 eq/m^3 of total collected water/year: 0.176 kg CO_2 eq.***

We now can finish the final balance of the carbon footprint in the urban water cycle in our city.

Table 4. GHG emissions of the urban water cycle in the studied case (Córdoba, 2013-18).

	Consumption/ year	*T CO_2 eq/year*	*% vs total*
Own transport	53,984 L	136.844	3.2%
Drinking water production	776,464 kWh	302.821	7.2%
Drinking water distribution to network	1,198,326 kWh	467.347	11.1%

Sanitation and sewerage. Wastewater transport to WWTP	1,374,566 kWh	536.081	12.7%
Wastewater treatment and chanell delivery to river	4,265,670 kWh	2,542.971	60.2%
External transport	94,472 L	239.477	5.6%
TOTAL	-	4,225,541	100%

The data obtained (Table 4) conclude that the urban water cycle in Córdoba generates a GHG emission expressed as T CO_2 eq/year of 4,225,541, linked to the activities of the company.

This data is in line with other ones existing in the literature, for example, 3,045.31 T CO_2 eq/year calculated for the case of Lleida (Aigües de Lleida -146,000 inhab.-) [10] or 2,801.34 T CO_2 eq/year in Murcia (EMUASA, 440,000 inhab.) [11] although in this case there are several systems of cogeneration that make the balance more favorable.

In the case of Córdoba, the biggest contributor to GHG emissions is that of wastewater treatment which 60.2%, followed by sanitation and sewerage: these two activities suppose the 72.9% of total emissions (this result is similar to existing in bibliography). On the other hand, drinking water production and distribution only reache with 18.3% over total. Finally, external and own transport generate 8.8% of total emissions.

Summarizing, all data of interest can be the following:

- ✓ Total emissions of CO_2 eq/inhab/year for the city: 12.92 kg CO_2 eq.
- ✓ Total emissions of CO_2 eq/m^3 of collected-produced water/year: 0.176 kg CO_2 eq.
- ✓ Total emissions of CO_2 eq/m^3 of drinking water distributed/year (taking into account 50% of emissions generated by transport): 0.189 kg CO_2 eq.
- ✓ Total emissions of CO_2 eq/m^3 of wastewater treated/year (taking into account 50% of emissions generated by transport): 0.172 kg CO_2 eq.

Finally, if we compare the total GHG emissions obtained in this study along 2013-18 (4,225,541 T of CO_2 eq/year), with the value obtained in our above study carried out in the 2012-14 period (5,015,80 T of CO_2 eq/year) [15], we can conclude that the situation in our city has improved significantly, because we have reduced the carbon footprint 15.8%. So, we have stopped 790 T of CO_2 eq/year to environment.

References

[1] Entitat Metropolitana de Serveis Hidràulics i Tractament de Residus (2011). Cálculo de la Huella de carbono en las instalaciones de tratamiento de agua residual y fango de la EMSHTR en 2010. www.perfil.amb.cat .

[2] Generalitat de Catalunya. Oficina Catalana del Canvi Climàtic (2011). Guía práctica para el cálculo de emisiones de gases efecto invernadero (GEI). (Barcelona) 66 pp.

[3] Massagué A. (2010). Aplicación de una calculadora de huella de carbono en la operación de instalaciones del ciclo urbano de agua: CAFCA. Ponencia en el 10º Congreso Nacional de Medio Ambiente, Madrid.

[4] Mirta de los Ángeles M. (2011). Huella de Carbono. *Actas del Seminario sobre Huella de Carbono. Instituto Nacional de Tecnología Industrial-Ministerio de Industria (Salta, Argentina).*

[5] Akerman A., Massagué A., Mehier S. and Audic J.M. (2010). Methodology for the assessment of the greenhouse gas impact of wastewater sludge treatment. *J. of Water and Climate Change,* (1) 4, 227-237.

[6] Yi L., Luo X., Huang S., Wang D. and Zang W. (2013). Life Cycle Assessment of a municipal wastewater treatment plant: A case study in Suzhou, China. *J. of Cleaner Production, 57, 221-227.*

[7] Gómez Larrambe A. (2016). Evaluación de la Huella Hídrica del Ciclo Integral del Agua de la Mancomunidad de la Comarca de Pamplona. Tesis de Grado, Universidad Pública de Navarra.

[8] Blanco D., Collado S., Díaz M., Suárez Mª P., Pérez J. A. y Sánchez J. (2014). Análisis de la huella de carbono en una planta de tratamiento de agua tipo carrusel. *Tecnoaqua,* (marzo-abril), 52-57.

[9] Environmental Agency of United Kingdom (2009). Transforming wastewater treatment to reduce carbon emissions. www.gov.uk .

[10] Hernández Moreno E., Pérez de Boers J., y Quintillá F. (2013). Reducir las emisiones de CO_2: Aigües de Lleida reduce las emisiones de CO_2. *AENOR,* 287, 36-39.

[11] Nevado Santos S., Gomis Ivorra A., Mena Gil E. y Castro García M. (2016). Cáculo de la huella de carbono del ciclo urbano del agua. La experiencia de EMUASA. *Tecnoaqua,* 19, 58-65.

[12] Remy C., Lesjean B. and Waschnewski J. (2013). Identifying energy and carbon footprint optimization potentials of a sludge treatment line with Life Cycle Assessment. *Water Science and Technology, 67 (1), 63-73.*

[13] Ministerio de Agricultura, Alimentación y Medio Ambiente (2015). Factores de emisión. Registro de huella de carbono, compensación y proyectos de absorción de dióxido de carbono. www.magrama.gob.es

[14] Ministerio para la Transición Ecológica (2018). Informes varios sobre consumos energéticos en España, y diferentes contribuciones por sectores y actividades. www.miteco.gob.es

[15] Marín Galvín R. (2016). Flujos de materias (agua y sólidos) y huella de carbono asociados al ciclo integral del agua en Córdoba. *Ingeniería Municipal,* 303, 40-44.