Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 72 - 85
https://doi.org/10.22320/07190700.2021.11.01.06

Recibido 22/02/2021
Aceptado 24/07/2021

APPLICATION OF THE "FOOTPRINT FAMILY" FOR THE ENVIRONMENTAL EVALUATION OF PUBLIC BUILDINGS IN SPAIN. CASE STUDY: EDUCATIONAL CENTER.

APLICACIÓN DE LA "FOOTPRINT FAMILY" PARA LA EVALUACION AMBIENTAL DE EDIFICIOS PUBLICOS EN ESPAÑA. ESTUDIO DE CASO: CENTRO EDUCATIVO.

CRISTINA RIVERO-CAMACHO
Doctora en Arquitectura
Investigadora del grupo ARDITEC. ETS Ingeniería de Edificación
- Departamento de Construcciones Arquitectónicas II.
Universidad de Sevilla
Sevilla, España
https://orcid.org/0000-0001-9411-7311
cririvcam@gmail.com

ANTONIO FERREIRA-SÁNCHEZ
Doctor en Arquitectura
Funcionario del Ministerio
"Misterios de Defensa de España"
Madrid, España
https://orcid.org/0000-0001-5814-4179
ferreirasanchez@hotmail.com

RESUMEN

Dentro de los compromisos de la Agenda 2030, destacan los objetivos socioeconómicos para un desarrollo sostenible del conjunto de la sociedad, que plantean minimizar el impacto producido por la Administración Pública sobre el medio ambiente en todas sus actividades. Por ello, la creación y reforma de sus infraestructuras, necesarias para su funcionamiento y los servicios que presta, supone un gran impacto. El objetivo del presente trabajo se centra en una adaptación metodológica para evaluación ambiental de las obras promovidas por entes públicos, cuantificando y localizando los focos de impacto para poder tomar las medidas que los minimicen. Para ello, se proponen como indicadores la familia de las huellas, ecológica, de carbono e hídrica, caracterizadas por la simpleza del mensaje y la facilidad para implantarse en el sector de la construcción, a través del control de costes de los proyectos. En concreto, se presenta un estudio de caso, la construcción de un centro de educación infantil en la ciudad de Madrid, para cuyo análisis se exponen y analizan los datos necesarios. Los resultados reflejan información interesante, en términos de huellas, sobre los elementos que deben ser controlados y mejorados en el diseño del proyecto, tales como el hormigón y acero.

Palabras clave
Ingeniería de la construcción, impacto ambiental, indicadores ambientales.

ABSTRACT

Within the commitments of the 2030 Agenda, the socio-economic objectives for a sustainable development of society as a whole, stand out, which propose minimizing the impact produced by all the activities of the Public Administration on the environment. Therefore, the creation and retrofitting of its infrastructures, needed for its operation and the services it provides, has a great impact. The goal of this work focuses on a methodological adaptation for the environmental evaluation of the works promoted by public organizations, quantifying and locating the sources of impact with the purpose of taking the measures to minimize them. For this, the footprint family, ecological, carbon, and water, are proposed as indicators, characterized by the simplicity of their message and the ease of their implementation in the construction sector, by controlling project costs. A case study is presented, the construction of an early childhood education center in the city of Madrid, for which the data needed for the calculation are presented and analyzed. The results reflect interesting information in terms of footprints, on the elements that must be controlled and improved in the project design, such as concrete and steel.

Keywords
Construction engineering, Environmental impact, Environmental indicators.

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 72 - 85
https://doi.org/10.22320/07190700.2021.11.01.06

INTRODUCTION

Within the guidelines outlined by the 2030 Agenda for the Sustainable Development of Spanish society, objectives are established on developing sustainable infrastructures and reducing their impact, as well as guiding business and public activity towards a reduction of greenhouse gas emissions. Among Public Administration activities, the construction of new buildings or retrofitting of existing ones, assume an impact that needs to be quantified to be able to implement measures to minimize this and, at the same time, help in decision making. It has been determined that the construction sector, in its production aspect, accounts for 40% of the consumption of all natural resources, as well as 30% of the energy consumed, while producing more than 30% of the greenhouse gases emitted (Fundación General de la Universidad Complutense de Madrid, 2010). When considering that public works procurement activities in 2019, represented up to 23% of the total amount paid out by the Spanish General State Administration (National Commission of Markets and Competition, 2019), an amount of nearly 1 billion euros, or 5% of the country's GDP, it is possible to provide an idea of the relevant impact of the construction sector on production activities.

The need of defining indicators, whose applications are quick, and whose interpretations are simple, make the Carbon (CF), ecological (EF), and water (WF) footprints, valuable tools to evaluate the impact of the construction process (Zhang, Dzakpasu, Chen & Wang, 2017). They are also successful because the results they produce are understandable for the non-scientific society, and because of their ease of application in decision-making (Bare, Hofstetter, Pennington & Udo de Haes, 2000) and policy. Together, these are called the "footprint family" (Vanham *et al.*, 2019). Footprints are ideal as environmental indicators within public procurement (Kairies, Muñoz & Martínez, 2021) and legislative development on sustainability, despite the need for progress in the standardization of their use (Laurent & Owsianiak, 2017).

First of all, CF as the most widely used, measures the total amount of greenhouse gas (GHG) emissions and is expressed in units of mass of CO_2 equivalent. There are many bibliographic reviews related to using the CF indicator in construction (Geng, Mansouri & Aktas, 2017). However, the results are not always comparable, due to the absence of a methodology that follows international standards (Dossche, Boel & De Corte 2017). For this reason, studies have also been made in recent years to establish scales that allow defining reasonable ranges of CO_2 emissions in construction processes (Chartas, Theodosiou, Kontoleon & Bikas, 2018).

Second, water consumption stands out. Here the WF indicator measures the volume of water used, both directly (water consumed from the network), as well as indirectly, also known as Virtual Water (VW). The concept was formulated by Allan (1993) as an indicator of the freshwater consumed in any production process. Although still in crisis (Velázquez, Madrid & Beltrán, 2011; Beltrán & Velázquez, 2015), the concept has been greatly developed and is useful to achieve better water management associated to buildings. However, few building studies use this indicator. VW in construction is defined as the volume of fresh water consumed to produce building materials from their origin to the factory door. Among the studies, ones from Australia on the tertiary sector that focus on VW consumption during the construction stage compared to the rest of the Building Life Cycle (BLC) stand out (McCormack, Treloar, Palmowski & Crawford, 2007). Crawford and Pullen (2011) also analyzed water in residential BLC over a period of 50 years and concluded that VW in building materials is higher than the direct consumption of homes, showing that water policies should also include virtual consumption. Férriz Papí (2012) made a study on the water consumption used by building materials throughout their life cycle and obtained similar statistical results, during 3 years in 200 projects in Catalonia.

The third indicator in the footprint family is EF, which is conceived as the area of land needed to supply resources (cereals, fodder, firewood, fish and urban land) and to absorb emissions (CO_2) of the society. It measures the productive land area in global hectares (gha). In recent years, some research has confirmed the suitability of the indicator to analyze the environmental impact of buildings. Regarding the building life cycle, the works of González, Marrero and Solís (2015), which develop a quantification methodology for building construction, stand out. Martínez-Rocamora, Solís-Guzmán and Marrero (2016b), for their part, have designed a method to calculate the economic costs and environmental impact during use and maintenance, yielding data in terms of EF. Alba-Rodríguez (2016) proposes the development of a methodology to get to know the environmental viability of the building retrofitting versus their demolition. Freire, Alba and Marrero (2019) determine the EF of elements that are

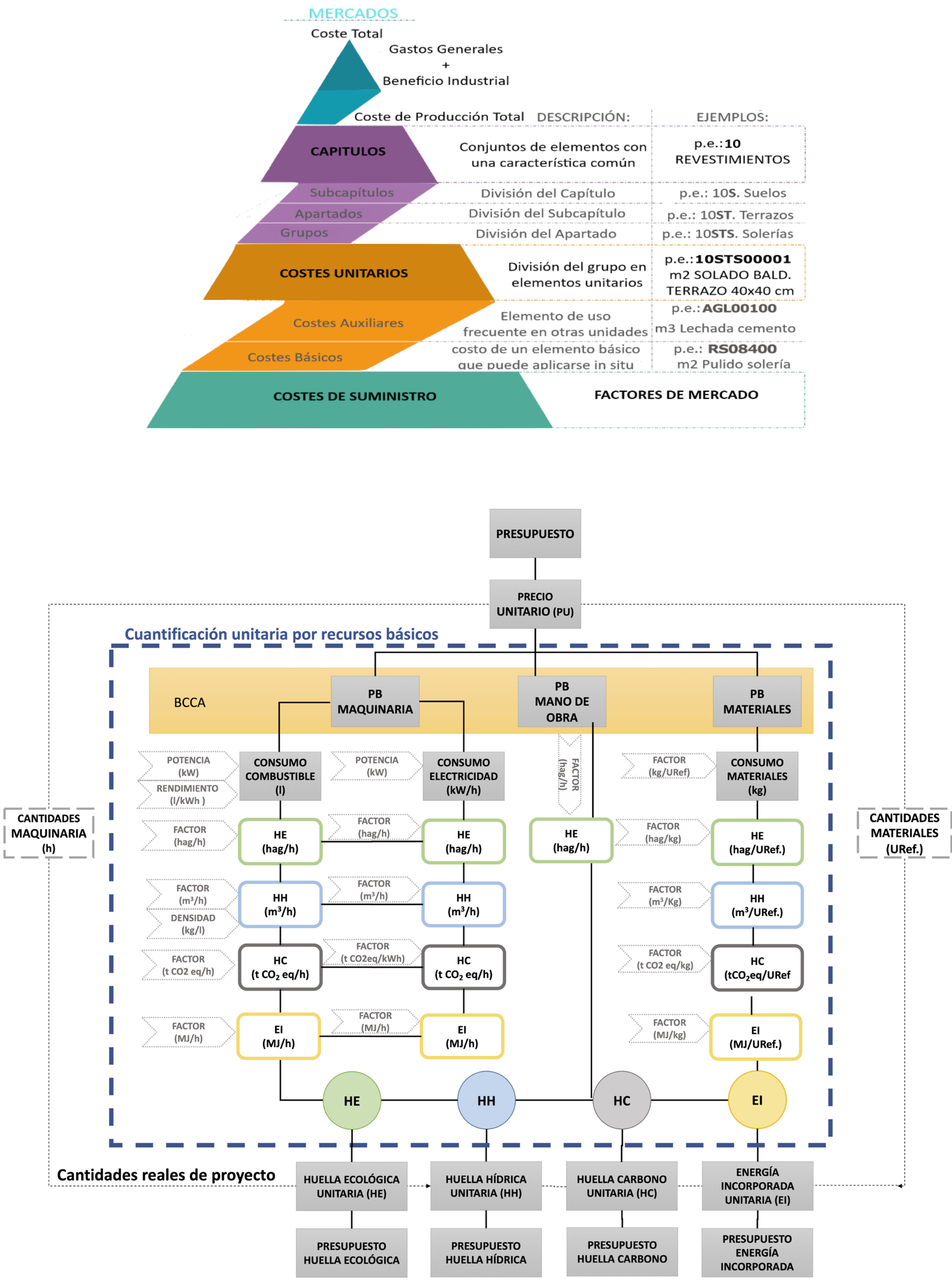

Figure 1. (a) BCCA pricing structure. (b) Application of general methodology to unit costs/prices. Embodied energy (EE) is an intermediate impact which is also calculated. Source: (a) Prepared using Marrero et al., 2020. (b) (Rivero, 2020, p. 39).

part of traditional construction costs and, finally, Rivero (2020) verifies all the stages of the BLC of residential constructions from a new perspective of "environmental budget".

Currently, the Spanish public administration is committed to minimizing the impact of its activities on the environment. This is reinforced by public policies from the European Union for public procurement, which urge that contract awards be made based on a plurality of economic, qualitative and social criteria, giving great relevance to environmental aspects (Public Sector Contracts Law, 2017). As a result, it is necessary to bring project budgets in line with this type of environmental impact assessment methodologies, so that these are adapted to the singularities of public infrastructures. From this perspective, and following the line of the environmental budget, the impact of the construction of a building of the tertiary sector, specifically, a nursery school in Madrid, Spain, is evaluated here. Its global analysis is based on the three footprints presented: carbon, water and ecological.

METHODOLOGY

To achieve the goal set out, the economic works budget is looked at which, considering the cost structure established by the Law on Public Sector Contracts, and its development regulation (Regulation of the Law on Public Sector Contracts, 2001), this is broken down into Basic (BP), Auxiliary (AP) and Unit (UP) Prices, which are assigned to the direct and indirect costs of each unit of work. Figure 1a shows the pyramidal classification of this cost/price structure in the particular case of its application in the Andalusian Construction Cost Bank (Marrero & Ramírez de Arellano, 2010). Subsequently, with the measurement of work unit prices or UP, the amount of each one is obtained and, together, the total budget of the work.

The determination of the different indicators, EF, CF and WF (Figure 1-b) is done following the methodology defined by Freire and Marrero (2015a). The impact of materials and machinery is calculated by converting the unit of measurement of the budget to kg. The impacts per kg are obtained from the life cycle analysis database, Ecoinvent LCA (Ecoinvent Center, 2013), which is known as being one of the most complete databases at a European level (Martínez-Rocamora *et al.*, 2016a), and its integration is done using Simapro LCA software (PRé Sustainability, 2016). The work is similar to that carried out for the CF calculation with the SOFIAS tool, which uses data from the environmental declarations of products, OpenDAP, or the BEDEC platform, developed by the Catalonia Institute of Construction Technology [ITeC, in Spanish] (ITeC, 2013). Figure 1-b schematically shows the integration of footprints into construction budgets for the particular case of the Andalusian Bank of Construction Costs (BCCA) (Marrero & Ramírez de Arellano, 2010). The formulation is summarized in Table 1 for EF, and Table 3 for CF and WF. The methodology, which is organized into three levels (input data, impacts and footprints), allows obtaining, from the general works data and the economic data of the budget, the environmental impact of the project. This study evaluates, within the life cycle, the construction stage that includes what is consumed in the works, so that the contours of the impacts correspond to the measurement criteria in the budget.

On-site machinery is calculated based on engine power and hours of use on-site, while the energy consumed in kWh that will be converted into CO_2 emissions is determined (Freire & Marrero, 2015a). Construction and Demolition Waste (C&D) of the transport machinery is also included in the calculation. This part of the construction budget is included, in an independent chapter, as established by RD 105/2008 (Marrero & Ramírez de Arellano, 2010) which regulates C&D management in Spain.

In the particular case of the impact of labor, which is only calculated in the EF indicator, the food consumed as the worker's source of energy is determined (Table 2). A typical menu for an adult consisting of meat, fish, cereals and water is used as its basis (Grunewald, Galli, Katsunori, Halle & Gressot, 2015), and the relative EF is determined in: pastures, sea and crops. The EF of the workforce also includes their Municipal Solid Waste (MSW), which corresponds to the average generated by each worker, and its corresponding emission factors.

EF also takes into account the impact related to the area of land occupied, which will not be agriculturally productive, and the water consumed in the execution. All impacts are assigned a partial EF in different categories of the indicator (sea, pastures, crops, soil) to, ultimately, through conversion factors, obtain the global footprint in an equivalent area.

In the direct consumption of water and energy in the works themselves, the value of consumption in cubic meters of water has been empirically established according to the built area (González *et al.*, 2015), where the transformation into CO_2 emissions applies, through the energy in kWh needed to obtain one cubic meter of water. Similarly, the electricity consumed is determined (Freire and Marrero, 2015b).

ECOLOGICAL FOOTPRINT	equation n°
Workforce	
EF_{FOOD}: EF produced by food consumption (gha)	
$EF_{FOOD\ i} = (H_{WORK} / H_D) \times (PC/100) \times (EF_i/365)$	1
H_{WORK}: Number of hours worked (h)	
H_D : Number of hours worked per day (8h/day/person)	
PC: Percentage that represents the breakfast and lunch of worker's food (60%)	
EF_i: Food consumption footprint in EF category i (gha/person) (Table 2)	
365: days in a year	
EF_{MSW}: EF produced by municipal solid waste (gha)	
$EF_{MSW} = (H_{WORK} \times R_{MSW} \times E_{MSW} \times 0.72)/A_F) \times EF_F$	2
R_{MSW}: Quantity of MSW produced per working hour (0.000077 t/h per person) (EUROSTAT 2015);	
E_{MSW}: emission factor by waste (0.244 t CO_2/ tMSW) (Almasi & Milios, 2013)	
0.72: CO_2 absorbed by forests. Remaining 28% = ocean absorption(Borucke et al., 2013)	
A_F: forest absorption factor (3.59 t CO_2/ha)	
EF_F: forest equivalence factor (gha/ha)	
Materials	
EF_{MAT}: EF of Building materials (ha)	
$EF_{MAT} = ((\Sigma_i Cm_i \times E_{MAT}) \times 0.72)/A_F) \times EF_F + EF_{TRAN} \times Cm$	3
Cm_i: Consumption of material i (kg)	
$E_{MAT:}$ emissions by material (kg CO_2/kg material)	
EF_{TRAN}: ecological footprint of transport of building materials (ha/kg)	
Machinery	
V: fuel consumption (liters) (50)	
V = (Pow x TU x Perf)	4
Pow: electric machinery motor power (kW)	
TU: time used according to measurements (hours)	
Perf: fuel consumed by the engine whether diesel or gasoline (l / kWh)	
EF_{COMB}: EF of (fossil) fuel consumption of machinery (gha)	
$EF_{COMB} = ((V \times E_{COMB} \times 0.72)/A_F) \times EF_F$	5
E_{COMB} fuel emission factor (kg CO_2/liter). Spanish data: 2.616 kg CO_2/ l (IDAE, 2011);	
EF_{ELEC}: EF of machinery electricity consumption (gha)	
$EF_{ELEC} = ((Pow \times TU) \times E_{ELEC} \times 0.72)/A_F) \times EF_F$	6
E_{ELECT} energy mix emission factor (kg CO_2/kWh). Spanish data: 0.248 kg CO_2/ kWh (REE, 2014).	
Water consumed	
EF_{WATER}: EF of water consumed (gha)	
$EF_{WATER} = ((C \times EI_{WATER} \times E_{WATER} \times 0.72)/A_F) \times EF_F$	7
C: consumption (m^3)	
EI_{WATER}: water energy intensity (0.44 kWh/m^3) (EMASESA, 2005)	
E_{WATER}: electricity emission factor (0.000248 kg CO_2/kWh) (REE, 2014)	
Area consumed	
EF_{sur}: EF of area consumed (gha)	
$_{EFsur} = S \times FE_x$	8
S: direct occupation area (ha)	
FEX: built area equivalence factor (gha/ha).	

Table 1. Formulation of the EF model. Source: Preparation by the Authors.

Revista Hábitat Sustentable Vol. 11, N°. 1. ISSN 0719 - 0700 / Págs. 72 - 85
https://doi.org/10.22320/07190700.2021.11.01.06

Crops (10^{-3} gha)		Pastures (10^{-3} gha)	Sea (10^{-3} gha)	Fossil (10^{-3} gha)
1,45	0,27	0,41	0,49	

Table 2. EF of the daily food consumption per year and person in Spain. Source: González Vallejo (2017, p. 270).

CARBON FOOTPRINT	
Materials	
CF_{MAT}: CF of Building materials (tCO_2eq)	
$CF_{MAT} = (\sum_i Cm_i \times X_{MAT}) + (CF_{TRAN} \times Cm_i)$	9
Cm_i: consumption of material i (kg)	
E_{MAT} emissions by material (tCO_2eq/kg of material)	
HC_{TRAN}: carbon footprint of the transport of building materials (tCO_2eq / kg)	
Machinery	
V: fuel consumption (liters)	
V = (Pow x TU x Perf)	10
Pow: electric machinery motor power (kW)	
TU: time used according to measurements (hours)	
Perf: fuel consumed by the engine whether diesel or gasoline (l/kWh)	
CF_{COMB}: CF (fossil) fuel consumption of machinery (tCO_2eq)	
$CF_{COMB} = V \times E_{COMB}$	11
E_{COMB} fuel emission factor (tCO_2eq/liters). Data: 2.616 kg CO_2/ l (IDAE, 2011);	
CF_{ELEC}: CF of machinery electricity consumption (tCO_2eq)	
$CF_{ELEC} = (Pow \times TU) \times E_{ELEC}$	12
E_{ELEC} energy mix emission factor (kg CO_2/kWh). Data: 0.248 kg CO_2/ kWh (REE, 2014).	
WATER FOOTPRINT	
Building materials	
WFma: Partial water footprint of material consumption (m^3)	
$$WF_{ma} = \sum (C_{ma_i} \cdot VW_{ma_i})$$	13
C_{mai}: Material consumption i (kg)	
VW_{mai}: Virtual water of material i (m^3/kg)	
WF_{tr}: Partial footprint of material transportation (m^3)	
$$WF_{tr} = \sum (\frac{W_{ma_i}}{T_{cap}} \cdot D_{ma}) \cdot T_{con} \cdot VW_f$$	14
W_{mai}: Weight of consumption of material i (t)	
T_{cap}: Transport capacity (t)	
D_{ma}: Average transport distance (km)	
T_{con}: Transport fuel consumption (l/100 km)	
VW_f: Virtual water factor of the fuel (m^3/liter)	
Machinery	
WF_{mc}: Partial water footprint of machinery (m^3)	
$$WF_{mc} = \sum (H_{mc_i} \cdot C_{f_i} \cdot VW_{f_i})$$	15
H_{mci}: Hours of use of machinery i (h)	
C_{fi}: Consumption factor of machinery i (l/h or kW)	
E_{fi}: Virtual water factor of fuel used by machinery i (m^3/l or m^3/kWh)	

Table 3. Formulation of CF and WF models. Source: Preparation by the Authors.

Figure 2. a) Main elevation and sides of the nursery school in El Goloso. (b) Real photo. Source: a) Taken from Barbero (2018, p. 352). (b) Made using Google maps.

CASE STUDY

Spain has 34,168 non-university educational centers, according to the State Register of Non-University Teaching Centers of the Ministry of Education, Culture and Sport. Of these, most are public (65.9%). Therefore, as a representative public building, for the case study, the impact of the construction of a nursery school in El Goloso, Madrid is calculated. The building has two floors, a total built area of 874.72m^2, and is fully equipped to accommodate 84 children. A building has been chosen with the most frequent constructive solutions of current public buildings in Spain, and considers a wide variety of different work items to house different staff and student numbers along with facilities. It consists of classrooms, toilets, kitchen, nurse's station, and administration. Its floor plan is built in a U, around the partially covered playground, and its access is through the main facade (Figure 2). Its budget is €1,834,831.14 and it has been built over a 12-month period.

Constructively, it is supported on reinforced concrete slab foundations, with a suspended floor structure on the ground floor, and a reinforced concrete upper slab, the latter supported on reinforced concrete pillars. The main enclosure is characterized by its ventilated facade finished in lacquered aluminum panels and rock wool insulation, while the side and rear facades have a double brickwork enclosure, coated with a white finish one coat mortar. The interior partitions are made using a laminated drywall system and removable false ceilings. The building's roof is flat and landscaped, and the playground has a green wall and rubber flooring adapted for children. The interior carpentry is made of wood and the exterior of aluminum, with thermal bridges and double glazing. The interior finishes are linoleum floors, except in the kitchen and toilets, which are non-slip stoneware. Regarding the fittings, the building has the basic sanitation, water, electricity, air conditioning, communications and fire protection elements. As for the urbanization, the paving and walkways connecting the general facilities and surrounding roads are partly replaced.

RESULTS AND DISCUSSION

The first step consists in obtaining, from life cycle analysis databases, the impact by building material families (Table 4). These data apply to the quantities of project units included in the budget.

The project obtained a total EF of 361.6 global hectares/year (Table 5), where activities related to masonry work correspond to 17.3% of the total, the highest EF, followed by the foundation and the structure, with 14.4% and 14.0%, respectively. The total weight of the building materials is 1,986,086.61 kg, which represents

MATERIAL	WF (m^3/t)	EF (hag/t)	CF (t CO_2 eq. /t)
Soil	0	0,005	0,004
Wood	2,62	-0,483	-0,990
Concrete	1,68	0,057	0,112
Asphalt	3,0	0,098	0,21
Ceramics	1,0	0,107	0,22
Aggregates and stones	1,2	0,005	0,004
Metals	81	0,907	2,01
Plastics	456	0,898	1,97
Glass	17	0,30	0,669
Mortar and plaster	67	0,294	0,610

Table 4. Footprints of material families per ton. Source: Preparation by the Authors.

Project sections	EF (gha)	CF (tCO2eq)	WF (m3)
C01.: Demolitions	22,747	53,426	685,630
C02.: Land preparation	23,270	57,177	705,403
C03.: Foundation	52,062	122,665	2,012,721
C04.: Sanitation	7,056	17.153	301,713
C05.: Structure	50,776	116,693	1,904,439
C06.: Masonry	62,697	138,381	2,107,457
C07.: Roof	13,188	26.854	723,513
C08. 1: Air-conditioning and ventilation	5,812	11.913	387,321
C08. 2: Electrical fittings	4,988	15.967	176,894
C08. 3: Water fittings (supply and sewer)	13,206	26.404	190,653
C08. 4: Hot water production fittings	9,524	23.723	759,060
C08. 5: Accessibility fittings	14,628	32.875	297,379
C09. Insulation	3,133	8.874	148,149
C10. Coating	30,980	66,404	1,783,008
C11. Carpentry, security and protection	7,866	16,487	380,069
C12. Glazing	3,719	8,292	250,583
C13. Paint	6,671	10,516	268,751
C15. Urbanization	29,263	64,923	949,244
TOTAL	361,586	818,728	14,031,988

Table 5. Results obtained by project sections.Source: Authors ' elaboration.

an impact of 2,270.54 kg/m^2. While the built area generates 95,136.07 kg of C&D or 108.76 kg/m^2.

The materials with the greatest environmental impact, with more than 69% of the EF, are presented in this order: concrete, metals and alloys, and ceramics (Figure 3). Given this, changes in the embodied energy in manufacturing processes, or in emissions from their processes, such as using recycled materials or ones with a high waste content, can significantly reduce the project's footprint (Freire *et al.*, 2019). These materials are also the ones that weigh the most: concrete is almost 70% of the total weight, and the weight of water which represents

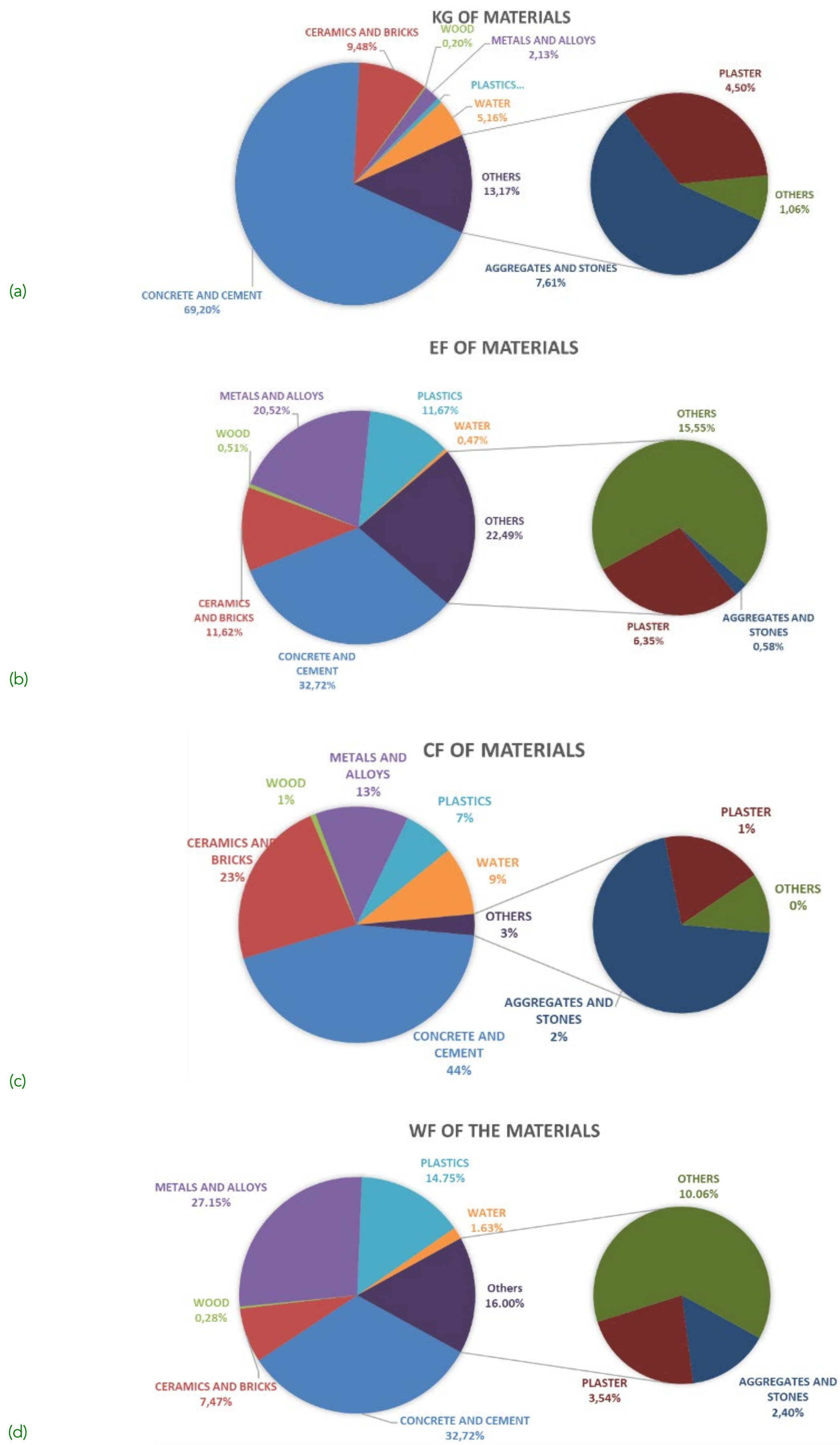

Figure 3. (a) The weight of materials in the project. Footprints of materials: (b) ecological; (c) carbon; (d) water. Source: Preparation by the Authors.

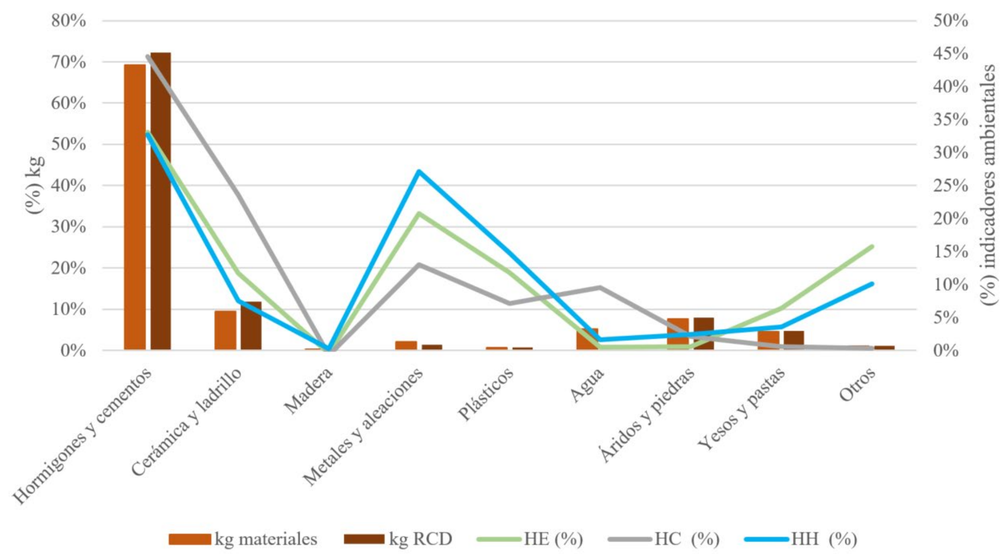

Figure 4. Impacts by material families. Source: Preparation by the Authors.

15% of the total, also stands out. In the calculation of the other footprints, as in the work of Marrero, Rivero and Alba (2020), it is the same materials that register the greatest impact. Construction materials account for 80% of the total project, compared to 18.5% of machinery; while the impact of workers only accounts for 1.5% of the total.

Regarding CF (Figure 3), the high impact of concrete in the process is confirmed with 44%, followed by ceramic elements with 23%, while metallic materials and alloys account for 13% of its CF. Wood is at the opposite end of the scale, with only 1% of the impact. This footprint has the same proportions as the ecological one, due to the great importance of building materials in both calculations. A total CF impact of 653.62 tCO2eq and an impact of 0.7472 tCO2eq/m^2 is calculated.

The WF of the materials is in line with the previous two, as shown in Figure 4, although the impact of the concrete compared to the CF is reduced, dropping to 32%. Meanwhile, the impact of metals and alloys is increased, and the importance of ceramic materials falls to 7%. The low impact maintained by wood stands out. The total volume of WF is estimated at 12,601 m^3, which means an impact of 14,340 m^3/m^2 from the construction. Figure 4 shows the results of the impact of construction materials in percentages, which allows comparing the importance of each type and, simultaneously, presenting the respective waste generated. It can be seen how the water footprint is less important in ceramic materials than in the case of metals, unlike with the carbon footprint, so a single indicator does not seem enough to highlight the materials that must be improved in the project. Concrete and cement are the most widely used materials, with the highest amount of C&D and, at the same time, the most impactful in all categories, so taking actions to reduce their impact will represent an overall improvement of the project. On the other hand, metals, although not important in weight and waste, their impact is very high in all footprints and should be the second category to be improved when retrofitting with more sustainable constructive solutions.

In the analysis by project sections, the results are very similar to those obtained by other authors (González, Muñoz Sanguinetti & Marrero, 2019). In the case of social housing analysis, where the sections with the greatest impact are foundations, structures and masonry, once again, due to the materials being used in large volumes, these involve a lot of energy and CO_2 emissions in their manufacturing processes. It can therefore be determined that, despite the constructive and technical differences of public educational buildings, which are equipped with larger electromechanical fittings and more unique materials, their environmental impact is in line with residential buildings.

CONCLUSIONS

The model proposed by Rivero (2020) combines footprint evaluation with the economic valuation of building construction. With this work, the adaptability of existing consolidated methodology for the environmental evaluation and control of projects of any type of buildings is verified, since this is based on a cost structure or systematic price classification systems.

On being a methodology that is supported by the current classification systems, it allows sector professionals to quickly prepare an economic budget that can include the environmental impact. The footprint analysis includes building materials from their origin to the worksite, for all the elements that are part of the project. It also includes labor, using its source of energy (food intake), and machinery, with its energy consumption.

This methodology can be easily and satisfactorily implemented by the Spanish public administration. This is thanks to the fact that it comes from the traditional works classification model, which is widely used by the technical experts involved in the construction process. This study used the systematic classification of the Andalusian Construction Cost Bank, but it could be replicated with other domestic classifications or costs banks. The clarity of the data obtained and its easy interpretation by non-specialized personnel make the model a valuable tool to assess the environmental impact of construction.

The main difference between public and private projects lies in the constructive solutions used, as well as in the consumption of resources by built area. It would be advisable to apply the model to other types of public constructions such as museums, offices, communication centers, etc., both in those that are built in new floor plans, and in those that retrofit existing buildings, within the spectrum of public infrastructures, given the constructive singularities of each of them. In this way, it is possible to define reference impacts that serve as a basis for making environmental decisions in the construction process. The results obtained in this work serve as a starting point to generate new impact examples of public buildings and databases for future research, to compare and make improvement proposals in the designs of the projects evaluated.

As a conclusion, and as the footprint calculation is based on the works budget, bidder proposal evaluation systems can be developed within public procurement procedures to minimize the impact of construction that also form part of the contract specifications. This could provide technical support to assess environmental improvement measures in the public tender.

ACKNOWLEDGMENTS

We would like to thank the VI Plan of the University of Seville for funding part of the research work presented here, through a pre-doctoral contract or PIF, reference VIPPIT-2016-IV.3, to carry out the R+D+i program between 2016 and 2020.

BIBLIOGRAPHIC REFERENCES

ALLAN, J. A. (1993). Fortunately there are Substitutes for Water Otherwise our Hydro-political Futures would be Impossible. En *Priorities for Water Resources Allocation and Management* (13-26). London: ODA.

ALMASI, A. M. Y MILIOS, L. (2013). *Municipal waste management in Spain*. European Environment Agency. Recuperado de https://www.eea.europa.eu/ds_resolveuid/UD8Z6VW5GB

BARBERO ARRABÉ, I. (2018). *Proyecto de construcción de Centro de Educación Infantil*. Madrid: Centro de Proyectos del Ejército. Dirección de Infraestructura (DIIN).

BARE, J., HOFSTETTER, P., PENNINGTON, D.W. Y UDO DE HAES, H.A. (2000). Life cycle impact assessment workshop summary. Midpoints versus endpoints: the sacrifices and benefits. *International Journal of Life Cycle Assessment*, *5*(6), 319-326.

BELTRÁN, M. J. Y VELÁZQUEZ, E. (2015). La ecología política del agua virtual y huella hídrica. Reflexiones sobre la necesidad de un análisis crítico de los indicadores de flujos virtuales de agua en la economía. *Revista de Economía Crítica*, (20). Recuperado de http://www.revistaeconomiacritica.org/node/770

COMISIÓN NACIONAL DEL MERCADO Y LA COMPETENCIA (2019). *Radiografía de los procedimientos de contratación pública en España*. Madrid: Comisión Nacional de los Mercados y la Competencia. Recuperado de https://www.cnmc.es/expedientes/ecnmc00418

CHASTAS, P., THEODOSIOU, T., KONTOLEON, K. J. Y BIKAS, D., (2018). Normalizing and assessing carbon emissions in the building sector: A review on the embodied CO_2 emissions of residential buildings. *Building and Environment*, *130*, 212–226. DOI: https://doi.org/10.1016/j.buildenv.2017.12.032

CRAWFORD, R. H. Y PULLEN, S. (2011). Life cycle water analysis of a residential building and its occupants. *Building Research and Information*, *39*(6), 589-602. DOI: https://doi.org/10.1080/09613218.2011.584212

DOSSCHE, C., BOEL, V. Y DE CORTE, W. (2017). Use of life cycle assessments in the construction sector: critical review. *Procedia Engineering*, *171*, 302-311. DOI: https://doi.org/10.1016/j.proeng.2017.01.338

ECOINVENT CENTER (2013). *Ecoinvent database v3 Ecoinvent Report*. Recuperado de www.ecoinvent.org

EMASESA (2005). *Sostenibilidad y Gestión. Éramos así, así somos* (1975-2005). Recuperado de https://www.emasesa.com/asi-eramos-asi-somos-1975-2005/

FÉRRIZ PAPÍ, J.A. (2012). Water consumption in buildings: Embebed water in construction materials. Trabajo presentado en *1st International Congress on Water, Waste and Energy Management.* Salamanca. Recuperado de https://www.researchgate.net/publication/277716798_Water_Consumption_in_Buildings_Embebed_Water_in_Construction_Materials

FREIRE GUERRERO, A., ALBA RODRÍGUEZ, Mª D. Y MARRERO MELÉNDEZ, M. (2019). A budget for the ecological footprint of buildings is possible: a case study using the dwelling construction cost database of Andalusia. *Sustainable Cities and Society*, 51. DOI: https://doi.org/10.1016/j.scs.2019.101737

FREIRE GUERRERO, A. Y MARRERO, M. (2015a). Ecological Footprint in Indirect Costs of Construction. *Proceedings of the II International congress on sustainable construction and eco-efficient solutions: Seville 25-27 may* 2015 (pp. 969-980). Recuperado de http://hdl.handle.net/11441/59685

FREIRE GUERRERO, A. Y MARRERO, M. (2015b). Evaluación a través del presupuesto de la energía incorporada al proyecto de edificación. *Revista Hábitat Sustentable*, 5(1), 54-63. Recuperado de http://revistas.ubiobio.cl/index.php/RHS/article/view/1812

FUNDACIÓN GENERAL DE LA UNIVERSIDAD COMPLUTENSE DE MADRID (2010). *Cambio Global España 2020/50. Sector edificación.* Programa Cambio Global España 2020/50 del Centro Complutense de Estudios e Información Medioambiental. Madrid.

GENG, R., MANSOURI, A. Y AKTAS, E. (2017). The relationship between green supply chain management and performance: A meta-analysis of empirical evidences in Asian emerging economies. *International Journal of Production Economics, 183*, 245–258. https://doi.org/10.1016/j.ijpe.2016.10.008

GONZÁLEZ VALLEJO. P, MUÑOZ SANGUINETTI C. Y MARRERO MELÉNDEZ, M, (2019). Environmental and economic assessment of dwelling construction in Spain and Chile. A comparative analysis of two representative case studies. *Journal of Cleaner Production*, *208*, 621-635. DOI: https://doi.org/10.1016/j.jclepro.2018.10.063

GONZÁLEZ VALLEJO, P. (2017). *Evaluación económica y ambiental de la construcción de edificios residenciales. Aplicación a España y Chile*. Tesis doctoral de Arquitectura, Universidad de Sevilla.

González Vallejo, P., Marrero, M. y Solís Guzmán, J. (2015). The ecological footprint of dwelling construction in Spain. *Ecological Indicators*, *52*, 75-84, DOI: http://dx.doi.org/10.1016/j.ecolind.2014.11.016.

GRUNEWALD, N., GALLI, A., KATSUNORI, I., HALLE, M. Y GRESSOT, M. (2015). *The Ecological Footprint of Mediterranean Diets.* Recuperado de https://www.researchgate.net/publication/275349456_The_Ecological_Footprint_of_Mediterranean_Diets

IDAE (2011). *Factores de Emisión de CO_2*. Recuperado de https://www.idae.es/informacion-y-publicaciones

INSTITUTO DE TECNOLOGÍA DE LA CONSTRUCCIÓN DE CATALUÑA (ITEC) (2013). Recuperado de http://www.itec.es/nouBedec.e/bedec.aspx (accessed on Dec 3, 2013).

KAIRIES ALVARADO, D., MUÑOZ SANGUINETTI, C. Y MARTÍNEZ ROCAMORA, A., (2021). Contribution of energy efficiency standards to life-cycle carbon footprint reduction in public buildings in Chile, *Energy and Buildings*, *236*, DOI: https://doi.org/10.1016/j.enbuild.2021.110797

LAURENT, A. Y OWSIANIAK, M. (2017). Potentials and limitations of footprints for gauging environmental sustainability. *Current Opinion in Environmental Sustainability*, *25*, 20-27, DOI: https://doi.org/10.1016/j.cosust.2017.04.003

MARTÍNEZ-ROCAMORA, A., SOLÍS-GUZMÁN, J. Y MARRERO, M. (2016a). LCA databases focused on construction materials: A review. *Renewable and Sustainable Energy Reviews*, *58*, 565-573. DOI: https://doi.org/10.1016/j.rser.2015.12.243

MARTÍNEZ-ROCAMORA, A., SOLÍS-GUZMÁN, J. Y MARRERO, M. (2016b). Toward the Ecological Footprint of the use and maintenance phase of buildings: Utility consumption and cleaning tasks. *Ecological Indicators, 69*, 66–77. DOI: https://doi.org/10.1016/j.ecolind.2016.04.007

MARRERO, M. Y RAMÍREZ DE ARELLANO, A. (2010). The building cost system in Andalusia: application to construction and demolition waste management. *Construction Management and Economics*, *28*(5), 495-507. DOI: https://doi.org/10.1080/01446191003735500

MARRERO, M., RIVERO, C. Y ALBA, Mª D. (2020). What are we discarding during the life cycle of a building? Case studies of social housing in Andalusia, Spain. *Waste Management: international journal of integrated waste management, science and technology, 102*, 391-403. DOI: https://doi.org/10.1016/j.wasman.2019.11.002

MCCORMACK, M., TRELOAR, G.J., PALMOWSKI, L. Y CRAWFORD, R. (2007). Modelling direct and indirect water requirements of construction. *Building Research and Information*, *35*(2), 156-162. DOI: https://doi.org/10.1080/09613210601125383

PRÉ SUSTAINABILITY (2016). Simapro 8. Recuperado de https://simapro.com/

REE (2014-2018). El Sistema Eléctrico Español / The Spanish Electric System. Recuperado de https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/informe-del-sistema-electrico-espanol-2018

RIVERO, C. (2020). *Estudio de Huellas en el Ciclo de Vida del Edificio Residencial*. Tesis Doctoral. Universidad de Sevilla.

VANHAM, D., LEIP, A., GALLI, A., KASTNER, T., BRUCKNER, M., UWIZEYE, A., VAN DIJK, K., … Y HOEKSTRA, A. (2019). Environmental footprint family to address local to planetary sustainability and deliver on the SDGs. *Science of*

The Total Environment, *693*. DOI: https://doi.org/10.1016/j.scitotenv.2019.133642

VELÁZQUEZ, E., MADRID, C. Y BELTRÁN, M. J. (2011). Rethinking concepts of virtual water and water footprint in relation to the production–consumption binomial and the water–energy nexus. *Water Resources Management*, *25*, 743–761. DOI:10.1007/s11269-010-9724-7

ZHANG, L., DZAKPASU, M., CHEN, R. Y WANG, X. (2017). Validity and utility of ecological footprint accounting: A state-of-the-art review. *Sustainable Cities and Society, 32*, 411-416. DOI: https://doi.org/10.1016/j.scs.2017.04.016