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The Budget as a Basis for Ecological Management of Urbanization Projects. Case Study in Seville, Spain

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Abstract: Urbanization projects, understood as those supplying basic services for cities, such as drinking water, sewers, communication services, power, and lighting, are normally short-term extremely scattered actions, and it can be difficult to track their environmental impact. The present article's main contribution is to employ the project budgets of public urbanization work to provide an instrument for environmental improvement, thereby helping public procurement, including sustainability criteria. Two urban projects in Seville, Spain are studied: the first substitutes existing services, and the second also includes gardens and playgrounds in the street margins. The methodology finds the construction elements that must be controlled in each project from the perspective of three indicators: carbon, water footprints, and embodied energy. The main impacts found are due to only four construction units: concrete, aggregates, asphalt, and ceramic pipes for the sewer system, that represent 70% or more of the total impact in all indicators studied. The public developer can focus procurement on those few elements in order to exert a lower impact and to significantly reduce the environmental burden of urbanization projects.

Keywords: ecological management; urbanization; environmental product declaration; cost; carbon footprint; water footprint; embodied energy

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Glossary of Terms

Auxiliary costs (AC): Unit cost of a combination of basic elements, which frequently is used in different units of work.

Andalusia Construction Cost Database (ACCD): The database with a pyramidal structure (basic elements or units) of Prices of the Construction of the Community of Andalusia (Spain).

Basic costs (BC): Unit cost of a basic element ready to be applied on site.

Carbon footprint (CF): Someone's carbon footprint is a measurement of the amount of carbon dioxide that their activities produce.

Embodied energy (EE): Energy content of all the materials used in the building and technical installations, and the energy incurred at the time of new construction and renovation of the building.

Empresa de Abastecimiento y Saneamiento de Aguas de Sevilla S.A. (EMASESA): A public company dedicated to the management of all phases of the integral water cycle.

Environmental Product Declaration (EPD): An independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products in a credible way.

Global warming potential (GWP): Measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).

Greenhouse gas (GHG): Any gas that has the property of absorbing infrared radiation (net heat energy) emitted from Earth's surface and reradiating it back to Earth's surface, thus contributing to the greenhouse effect.

Green public procurement (GPP): the process by which a public organization buys supplies produced in a way that is not harmful to the environment.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Inventory (LCI): Quantifies the inputs and outputs of a system, material, and energy flows.

Sustainable Urban Drainage Systems (SUDS): Systems designed to efficiently manage the drainage of surface water in the urban environment that use and enhance natural processes, i.e., infiltration, evapotranspiration, filtration and re-use.

Unit costs (UC): The price that corresponds to a construction element formed by a combination of basic or auxiliary elements that make up a unit of work.

Water footprint (WF): Measures the amount of water used to produce each of the goods and services we use.

1. Introduction

Global goals of sustainable urban development [1] are focused on climate change and resource conservation, which can be applied to all levels of the construction sector, from the manufacture of materials to transport, construction, and the management of municipal services. Among the construction sector main elements, developers are a powerful vector of change since they can prioritize buying products of a more sustainable nature. Although the economic criterion carries a great weight in their decision-making process, developers are increasingly integrating other elements, such as environmental impact, into their strategic plans. The increased awareness of developers is leading to significant changes in companies, thus also implying the necessity of easy access to environmental information; procurement plays a key role because it covers whole supply chains [2].

At the material manufacturing level, Environmental Product Declarations (EPDs) incorporate the results of the Life Cycle Assessment (LCA) inventory and assess material resource use and efficiency problems [3]. Information could be helpful in developing robust weighting systems applicable to a more transparent contracting criterion [4,5]. In Europe, LCA has been implemented in construction work: those with the highest rates of implementation, known as the Green 7, are Austria, Denmark, Finland, Germany, Netherlands, Sweden, and the UK, while other countries outside the EU with a high implementation include the USA, Canada, Japan, and Korea [6]. Regarding procurement, Directive 2014/23/EU [7] incorporates the LCA concept as an award criterion in public development projects. Certificates issued by independent bodies may be needed to acknowledge that tenderers meet certain environmental management standards, for example, to be part of EMAS (Eco-Management and Audit Scheme) certification or other environmental management systems based on relevant European or international standards. However, the inclusion of environmental clauses in public procurement is not an easy task [8]. The object of the contract must, therefore, include protection of the environment [9]. In this respect, several studies are focused on non-residential buildings in the U.K. (educational and hospital) through the analysis of the reduction of CO_2 emissions and electricity and fuel consumption in the construction process [10], and also through a classification and environmental impact assessment for five different designs of the Karlsnäs Bridge in Sweden [11]. All these efforts are aimed at both guiding decision-makers in selecting the most feasible proposal from an LCA point of view, and mitigating the environmental burden from the initial stage.

Another approach involves green procurement and the criteria for its application in the construction sector, such as the conceptual and non-quantitative analyses carried out in Slovenia, where Srdić & Šelih (2011) [12] developed a model that integrates product quality and environmental sustainability based on the use of EDPs for the design and construction processes of building structures. In Slovakia, Kottner, Štofová, Szaryszová, & Lešková (2016) [13] analyzed the framework strategy of the Organization for Economic Co-operation and Development for the selection of environmental indicators in the procurement process; they also identify limitations due to the ambiguous definition of environmental criteria. Similar findings are those of a survey carried out in Sweden [14], which provides an overview of practices in both the public and private procurement of green building contracts: they identify problems and opportunities in the definition of environmental criteria for contracts to be awarded and in the monitoring of the requirements applied. In southern Europe, Pires and Teixeira (2009) [15] present a proposal to improve the procurement process in the construction sector in Portugal, through a comparative study between the criteria contained in the tender notices and the recommendations found in the literature. In the UAE, in order to improve its implementation, the mediating impact of employees' commitment to change is explored [16].

Public sector contracts in Spain (LPSC_9/2017, published in BOE No. 272 of 09/11/2017) [17] establish a new framework for public procurement in which the economic value is no longer the sole determining factor, and they incorporate the assessment of two new aspects: environmental and social. The green public procurement (GPP) concept is incorporated into Spanish legislation in 2019 with the inclusion of environmental policies related to climate change, resource use, and sustainable production and consumption [18]. This voluntary instrument sets out criteria for environmental requirements in the public procurement of works and services, such as transport, road construction, design and construction of offices, food, and gardening products and services.

Furthermore, in Spain, many tools evaluate the environmental impact of projects. The building certification systems LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Methodology) are used by national bodies, such as the Spanish Green Building Council [19] and BREEAM Spain [20]. SpainGBC presents VERDE tools [21], and includes urban development evaluation (VERDE DU). Other alternatives have appeared from several research projects in the last decade. ECOMETRO is an open-source web-based tool for the measurement of the environmental impact of a building [22]; it is similar to an EPD but is applied to entire buildings. Highly specialized platforms, such as the BEDEC cost database [23], SOFIAS tool [24], and E2CO_2Cero [25], allow CO_2 emissions to be calculated in detail according to project budget quantities. All these tools have low implementation in Spain; some barriers detected for their implementation are: complex concepts that are in need of expert evaluation, expensive implementation, and the difficulty of incorporating additional monetary expenses in the public sector [26].

There is an opportunity to include other indicators into public projects evaluation that, combined with the calculation of CO_2 emissions, can give a global view of the project impact, thereby revealing the most aggressive elements. A simplified environmental assessment can be defined, which starts with a more complex evaluation by the public entity of representative projects. The methodology can be implemented in public entities for the procurement of public projects. To this end, a method based on accessible data is considered, such as construction cost and LCA databases. The main objective of this paper is to develop a method to evaluate public urbanization projects in Spain to facilitate the introduction of GPP.

An urbanization project is defined in the present study, as in previous work by the authors, in the form of a project providing the city with basic services, such as drinking water, sewers, telephony, data, electricity, paving, and lighting (also sidewalks and paving and street gardens can be included) [27,28].

Two projects conducted by the public entity responsible for maintaining and preserving water services in the city of Seville are studied. In the first place, solutions traditionally used by the public entity and its specific construction cost database are employed. Secondly, a standardized classification is proposed to introduce the environmental product information, such as eco-labels and/or EPD, and LCA databases. In a third step, a methodology is proposed for the environmental evaluation of the projects, based on the construction project budget and the work units found in the first step. The embodied energy (EE), carbon footprint (CF), and water footprint (WF) are the indicators involved. Finally, a comparative analysis of the solutions and a simplified sustainability evaluation criterion is defined for the GPP of urbanization projects in the city of Seville.

2. Methodology

The methodology starts with the processing of simple and accessible data, as presented in Figure 1. This first level uses the general information necessary for the preparation of project budgets, such as public or private construction cost databases. In a second level, data from construction cost databases and environmental product information such as eco-labels and/or generic LCA databases are combined. In the third level, assessments are applied to the elements in the project budget, thereby obtaining the incorporated WF, CF, and EE, which together provide an "environmental budget" [29]. These three environmental impacts have also been assessed in urbanization projects [30], and by employing Building Information Modelling [31].

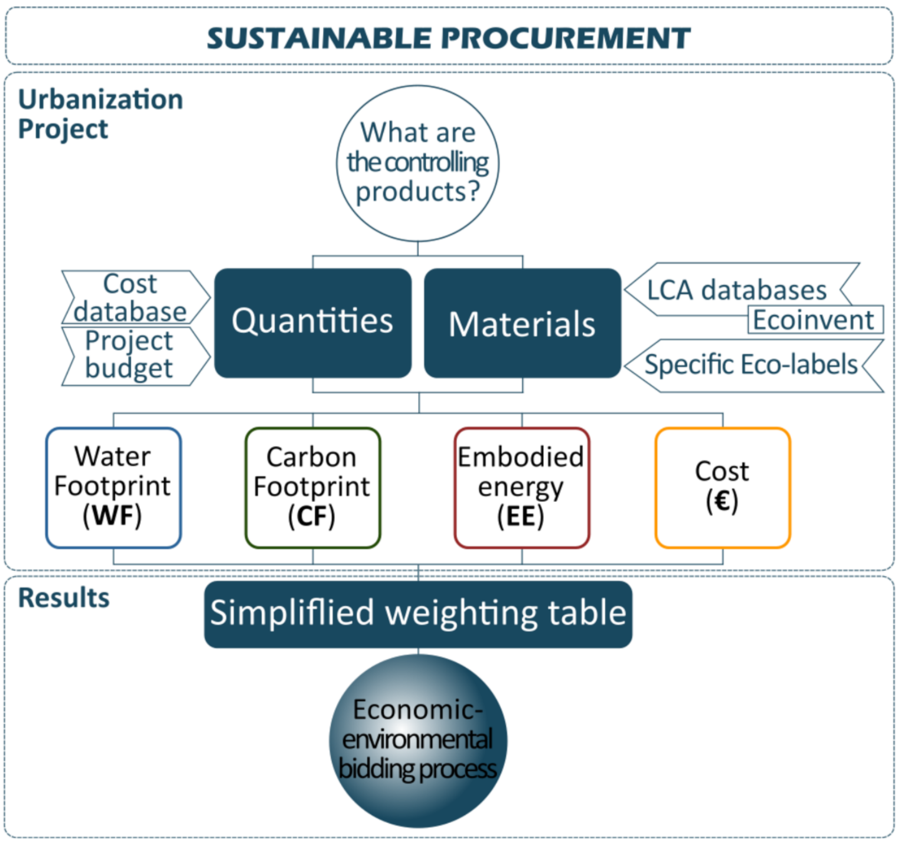

Figure 1. Methodology for the inclusion of the water footprint (m^3 of water), embodied energy (MJ), and carbon footprint ($tCO_2eq.$) in the green assessment of urbanization projects.

Finally, the results obtained by the calculation methodology allow, based on the technical information reflected in the project budget, the quantification of the environmental impact of the materials that cause the greatest impact. In this way, those materials can be targeted in public tendering processes in order to demand specific requirements. The theoretical framework is divided into two parts: the cost analysis of a project and its adaptation to the environmental analysis, which determines the items of the project where the most significant environmental impacts are exerted.

The project budget is the basis of the exposed methodology, and its standardized classification of construction units is employed by cost databases in the sector. The hierarchy of costs is employed to group together similar families of construction materials that can be found in LCA databases. As an intermediate step, it is necessary to transform traditional working units (m, m^2, tonne, etc.) into kg. For this, open free catalogs of construction products are employed in the calculations. The LCA information can be inserted into the construction cost database using the same structure and hierarchy. Once all elements that form the project are analyzed, this information serves as a base to benchmark the most environmental impacting elements that are representative of the project. The benchmark allows future, simpler evaluation tables to be implemented in the bidding, encouraging the use of construction material with EPDs that show their lower impact. This can help project developers or promoters in the public sector in the bid process to easily target the controlling elements.

2.1. Cost Analysis

The automation of data and its processing constitute advances in Information Technology (IT) that supply major advantages for predictive analysis. Classification systems of construction information prevail in the sector as the most widely used management tools. Their basic concept is that of breaking down a complex problem into simpler parts that can then be added together, without overlap or repetition, to define the complete development of a project. In Spain, construction cost databases have specific classification systems, such as those of the Institute of Construction Technology of Catalonia [32] and the Andalusian Construction Cost Database (ACCD) [33].

In this work, the ACCD [34], which is widely used in the region and has been published continuously since 1986, is applied. The Systematic Information Classification System contained in the database [33] is based on a hierarchical and arborescent structure with defined levels, where groups are divided into subgroups with homogeneous characteristics. Among other advantages, this system helps in the location of concepts in the budget structure. This organization of the work and its components breaks down a complex system into simpler basic elements, that is, materials, machinery, and labor.

The ACCD cost structure is created with clearly defined levels, in which (descending to the lower levels from the top of the hierarchy) each group is divided into subgroups of homogeneous characteristics (see Figure 2). Thus, the base of the pyramid is formed of basic units, which connect the system directly to the market. The structure is completed with intermediate levels [35], such as basic costs (BC), which are mainly distributed according to the three types mentioned (materials, machinery, and labor): auxiliary costs (AC), formed by the union of BC, and unit costs (UC), formed by the union of BC or of BC in combination with AC. All these elements are grouped in chapters that represent various stages of the construction process, such as Chapter 15 Urbanization, which includes street lighting, sewerage, gardening elements and street furniture. At the top of the pyramid, there are exogenous costs, such as industrial profit and overheads. All these characteristics facilitate the incorporation of environmental cost, which is based on the same boundaries as those defined in the calculation of economic cost.

2.2. Environmental Analysis

Several tools and calculation models to determine the environmental impact of the construction sector are in place; some are multi-variable, such as energy [36,37], the ecological footprint [38,39] or Eco-indicator, while others use single indicators, such as EE, WF, and CF [40–43].

The CF indicator is commonly used in construction assessment and some also employ the projects' bill of quantities [26,38,39]. In recent years, advances have been made in defining the ranges of CO_2 generated in the production of construction products [44]. The other two indicators proposed, due to their simple message, are the EE [45] and the WF [28,46]. The EE (embodied energy) represents the energy efficiency of the production of products, which is independent from the CF, provides added information, and has commonly been used in construction assessment, for which its direct and indirect impact has been calculated [47]. The WF, disseminated by the Water Footprint Network [48], is another interesting indicator which determines the amount consumed in the production of goods by following The Standard Calculation Methodology [49] and The Water Footprint Assessment Manual [50]. The combination of the three indicators, WF, CF and EE, have given interesting comparative results in the previous work by the authors [30] by employing Building Information Modelling [31].

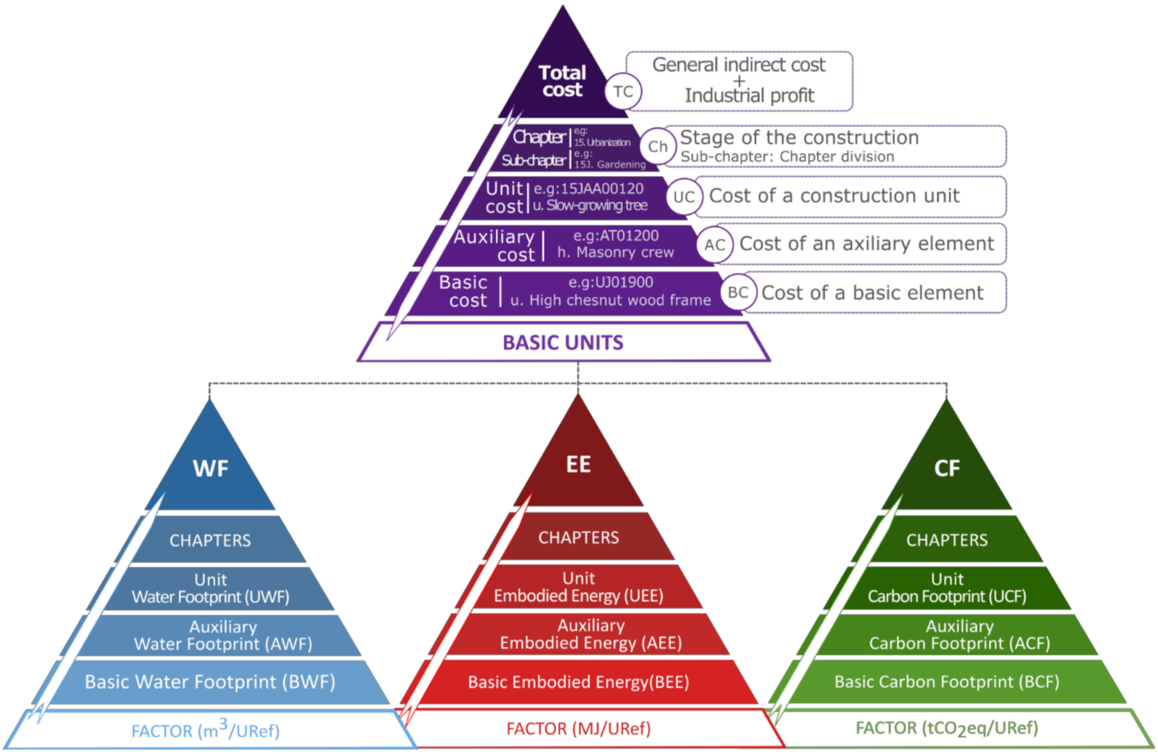

Figure 2. Hierarchical pyramid schema of the Andalusia Construction Cost Database, whose structure is translated into environmental impact pyramids (adapted from [33]).

The CF, WF, and EE indicators are quantified by using international LCA databases of construction products [51] and by using the EPDs available on ECO-Platform (www.eco-platform.org/, accessed on 1 Februay 2021), the European platform for EPD programs in the construction industry [52]. The consumption of natural resources on site is treated as an environmental cost. Direct costs in construction budgets correspond to machinery, labor, and materials, and similarly cause the direct use of resources on site through the energy expenditure of the machinery (fuel or electricity), the impact of labor (through the quantification of working hours), and the consumption of construction materials (during manufacture, transport, and commissioning).

2.2.1. Machinery

The impact of the use of machinery is defined by its direct energy consumption (fuel and electrical energy), which depends on its engine power. In order to obtain fuel consumption, the machinery manual prepared by SEOPAN (2008) is used, where the technical data of different models and typologies of machines on the market are collated. By choosing the most unfavorable consumption, the classified machinery is analyzed by applying a coefficient to the power of each engine to obtain the liters of fuel consumed, thereby differentiating whether the machine consumes diesel or petrol. Once the liters of fuel consumed are obtained, the coefficient is applied, thus showing the amount of CO_2

generated by one liter of fuel [53]. Data obtained from international LCA databases are applied, and hence their CF, WF, and EE are obtained: see Table 1, Equation (1).

Table 1. Equations for the calculation of the embodied energy, carbon footprint, and water footprint of the basic construction elements.

Impact Source	
Machinery Impact	**No. Equation Number**
IM_{COMB}: Combustion engine machinery (MJ; tCO_2eq; m^3 of water)	
$IM_{COMB} = V \times IU_{COMB}$	(1)
V: diesel consumption (L)	
$V = (P \times TU \times Per)$	(2)
P: power of the electric engine (kW)	
TU: time used (hours)	
Per: performance, liter of diesel or petrol consumed per engine power (L/kWh)	
IU_{COMB}: unit impact of diesel or petrol (MJ/L; tCO_2eq/L; m^3 of water/L), data: [55]	
IMELEC: Electric engine machinery (MJ; tCO_2eq; m^3)	
$IU_{ELEC} = (Pot \times TU) \times IU_{ELEC}$	(3)
IUELEC: unit impact of electric mix (MJ/L; tCO_2eq/L; m^3 of water/L), data: [48,56]	
ECOMB: emission factor of the diesel or petrol (kg CO_2/L). In Spain: 2.616 kg CO_2/L [56]	
EELEC: emission factor of electric mix (kg CO_2/kWh). In Spain: 0.248 kg CO_2/kWh [54]	
IMPACT of CONSTRUCTION MATERIALS	
IMAT: EE, CF, HF (MJ; tCO_2eq; m^3)	
$I_{MAT} = (\Sigma i\ Cmi \times IU_{MAT}) + (IU_{TRAN} \times Cmi)$	(4)
IUMAT: unit impact per material (MJ; $tCO_2eq.$; m^3 of water, all per kg of material)	
IUTRAN: unit impact of material transport (MJ; $tCO_2eq.$; m^3 of water, all per kg of material)	
Cmi: construction material i (kg)	

A similar approach is followed for the consumption of the electrical machinery used on site; the engine power and the hours of use are analyzed, thereby obtaining the total kWh consumed: see Table 1, Equation (3). The CO_2 emissions generated to produce one kWh of energy in the Spanish electrical system are taken into consideration [54]. The WF is also calculated for the embodied water in the production or generation of the energy source.

2.2.2. Building Materials

The environmental impact of materials includes the energy and water consumed in the provision of the building materials, from the cradle to the door of the factory and their transport to the construction site, whose approximated distance covered by transport is in Andalusia, Spain, is defined [29]. For the transportation of concrete, the truck capacity considered is 24,000 kg, and the distance travelled is 20 km. For other construction materials, it is 2000 kg per truck and 250 km travelled. The average diesel consumption is 26 L/100 km and its emissions are 2.62×10^{-3} tCO_2/L [56]. The diesel embodied water is 1.26 m^3/L, ant that of the energy is 57.7 MJ/L. The electricity embodied energy is 3.6 MJ/kWh. With this data, the tons of CO_2 that the transport of each material would entail can be obtained, and this data can subsequently be converted into each environmental indicator (CF, WF, and EE) by using Equations (1) and (2) in Table 1.

The original unit of measurement of each BC (m^3, m^2, meters, tons, thousands of units, etc.) is converted into m^3, so that the density established in support documents, such as the Catalogue of Construction Solutions of the Technical Building Code (IETc, 2010) [57] and the Spanish Technical Building Code [58], can then be translated into kilograms. In some cases, the weight can also be obtained directly from commercial data in supplier catalogs.

For the environmental information to be included in the assessment, among the various LCA databases, the Ecoinvent database [59], which is implemented in Simapro and developed by the Swiss Centre for Life Cycle Inventories, is chosen due to its transparency in the development of processes (reports, flowcharts, methodology, etc.), its consistency, and its references. This database is highlighted because it merges data from several databases of the construction industry [51]. From this database, a series of "environmental families" are obtained and handled for each BC and their corresponding impact units according to their similarity.

The reference used for the calculation of the WF is that disseminated by the Water Footprint Network (WFN), which is based on the concept developed by Hoekstra [60], the calculation methodology "The Standard Calculation Methodology [49], and also on "The Water Footprint Assessment Manual [50], which allows the calculation of direct and indirect consumption of any productive process expressed in volume of water consumed (m^3 water/kg). Finally, for the EE, data from the LCA inventory are used. It is expressed as an index of incorporated energy (MJ/kg) that includes the energy contained in the extraction and processing of the raw material and its transport to the worksite, and then for it to be incorporated into the construction process, thus contributing to the total energy involved in the work. Figure 3 summarizes the methodology, which combines the budget of the work or unit cost (UC), in this case, with the environmental impact from LCA databases.

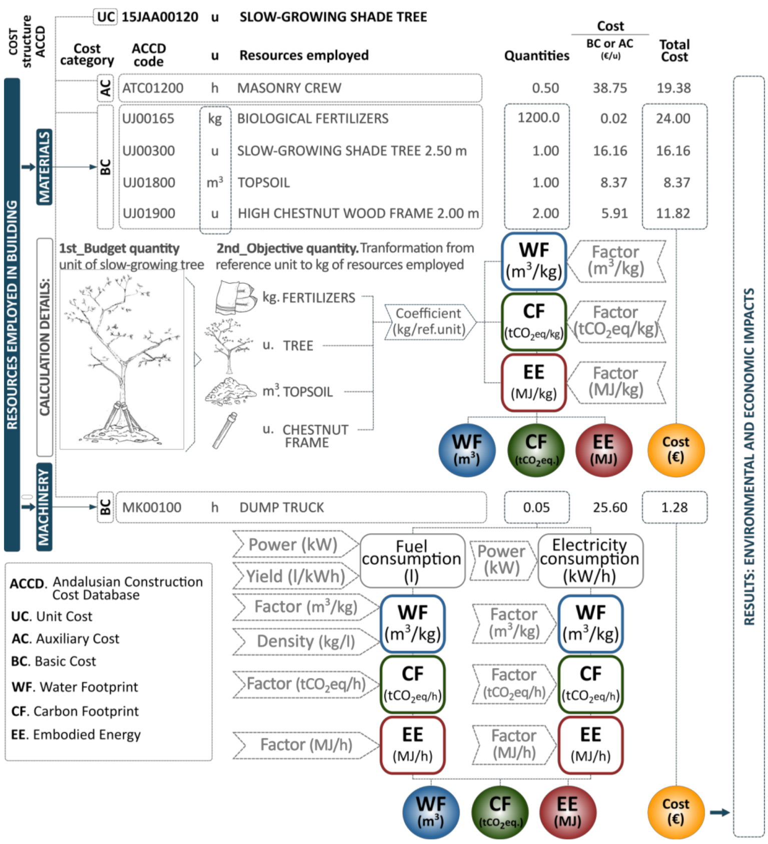

Figure 3. The Andalusia Construction Cost Database structure is employed to define urbanization costs and its environmental impact.

From the life cycle inventory (LCI) of each material, each impact has been analyzed as follows: the CF, that is, the emissions incorporated in construction materials, is obtained by applying the methodology of the IPCC 100 A, which is used by the carbon footprint indicator since it isolates CO_2 and other GHGs (greenhouse gas) from the LCI expressed in tCO_2eq/kg (Jaime Solís-Guzmán, Rivero-Camacho, Alba-Rodríguez, and Martínez-Rocamora, 2018).

3. Case Studies

The research samples are two projects developed by the Metropolitan Water Supply and Sewer Company of Seville (Empresa Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla S. A., EMASESA), the public enterprise dedicated to the management of all phases of the water cycle in the city of Seville. After meetings with EMASESA on the 17 April and 11 June 2018, the two projects were selected as the most representative in all the urbanization work in process. The first case study is economically and environmentally assessed, which includes conventional technology for the urban water cycle. The second case study is a renovated street, which introduces eco-efficient solutions. Both projects have an estimated duration of one year. The budget of each project is prepared using their own cost databases, thereby making it necessary to define a relationship between the elements codified in the original project to the ACCD code, in order to enable the results to be compared with other previous work and to prevent repetitions and the inclusion of incorrectly defined elements.

3.1. Project 1. Renovation of Water Networks

The conventional project, P1, consisted of the replacement of the existing sewer networks with new vitrified ceramic pipes, and the replacement of the supply networks with steel pipes, including the renewal of all connections, as well as valves, accessories, and inspection and exploration elements. The affected pavement was also replaced according to the guidelines of the Urban Planning Office of Seville City Council. The developed area covers 8750.0 m^2, see Figure 4.

(**a**) (**b**)

Figure 4. (**a**) Pictures of the conventional street (Project 1); (**b**) pictures of the integral action (Project 2).

3.2. Project 2. Integral Action

The project defined as integral action, P2, includes, along with the renovation of the supply and sewer networks, the reform of the geometry and morphology of the affected roads through a more environmentally friendly solution by expanding garden and pedestrian areas. The project implemented bicycle lanes, recreational equipment in pedestrian areas, public lighting of greater efficiency, a sustainable drainage system, and a system for storing and reusing rainwater for irrigation. The direct water footprint of the new garden has been assessed [28]. The covered area is 11,411.0 m^2, see Figure 4.

4. Results

The results are presented in Table 2 in terms of the total impact of each project and its distribution across the different sub chapters of the budget, all belonging to the urbanization chapter 15, expressed in units of impact per urbanization area. For this calculation, the area of the entire street is considered (pavements, roads, gardens, etc.) and the functional unit is m^2 of urbanized area or area covered by the project (construction site boundaries) as in the previous related work by the authors, giving rise to an interesting comparison and analysis [28]. The impact of the machinery used directly in each of the urbanization projects does not exceed 18% of the total impact in terms of CF and EE, while the WF remains at less than 1%. This impact is similar to the ecological footprint determined in previous work, analyzing urbanization and construction [27] and the building life cycle where the machinery represents 20% of the total impact [61].

Table 2. Quantification of the impacts of budget subchapters per m^2 of the project area.

ACCD Code.	Description	CF (kg CO_2 eq./m^2)		WF (m^3 Water/m^2)		EE (MJ/m^2)		Cost (€/m^2)	
	PROJECT	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**
15A	Civil work	35.3	47.7	0.94	1.13	582.4	936.5	35.0	58.5
15R	Connections	14.9	3.6	0.42	0.10	294.1	69.4	17.9	3.5
15P	Pavements	91.0	107.7	1.34	2.27	685.8	1316.8	36.0	45.8
15J	Gardening and irrigation network	-	12.4	-	0.58	-	169.6	-	25.2
15M	Sustainable urban drainage systems	-	14.3	-	1.26	-	355.9	-	14.4
15W	Other urban systems	-	70.8	-	1.91	-	1186.56	-	57.91
	TOTAL	141.2	256.5	2.70	7.25	1562.4	4034.8	88.9	205.3

In order to further compare the results with those of other studies, the impacts of the materials are divided into 10 families: concrete and cement, ceramics and brick, wood, metal and alloy, plastics, water, aggregate and stone, bitumen and asphalt, others, and the gardening chapter. The results of each of the two projects are presented in Figure 5. The materials in the urbanization slightly differ from those found in building construction, where the building finishes in a Chilean housing project (floor, tiles, etc.), and installations in Seville have also a significant impact [62].

By analyzing the results of the CF indicator, it can be observed that 71% of the impact on Project 1 (P1) is produced by the incorporation of concrete and cement in the work, followed by 15% from ceramic materials, 12% from aggregate and stone, and, to a much lesser extent, from metal and plastics. In Project 2 (P2), 80% of the CF is due to three families of materials: concrete and cement exert the greatest impact, with a 40% share of the total impact, followed by metallic materials with 23%, ceramic materials with 17%, and aggregate and stone with 13%.

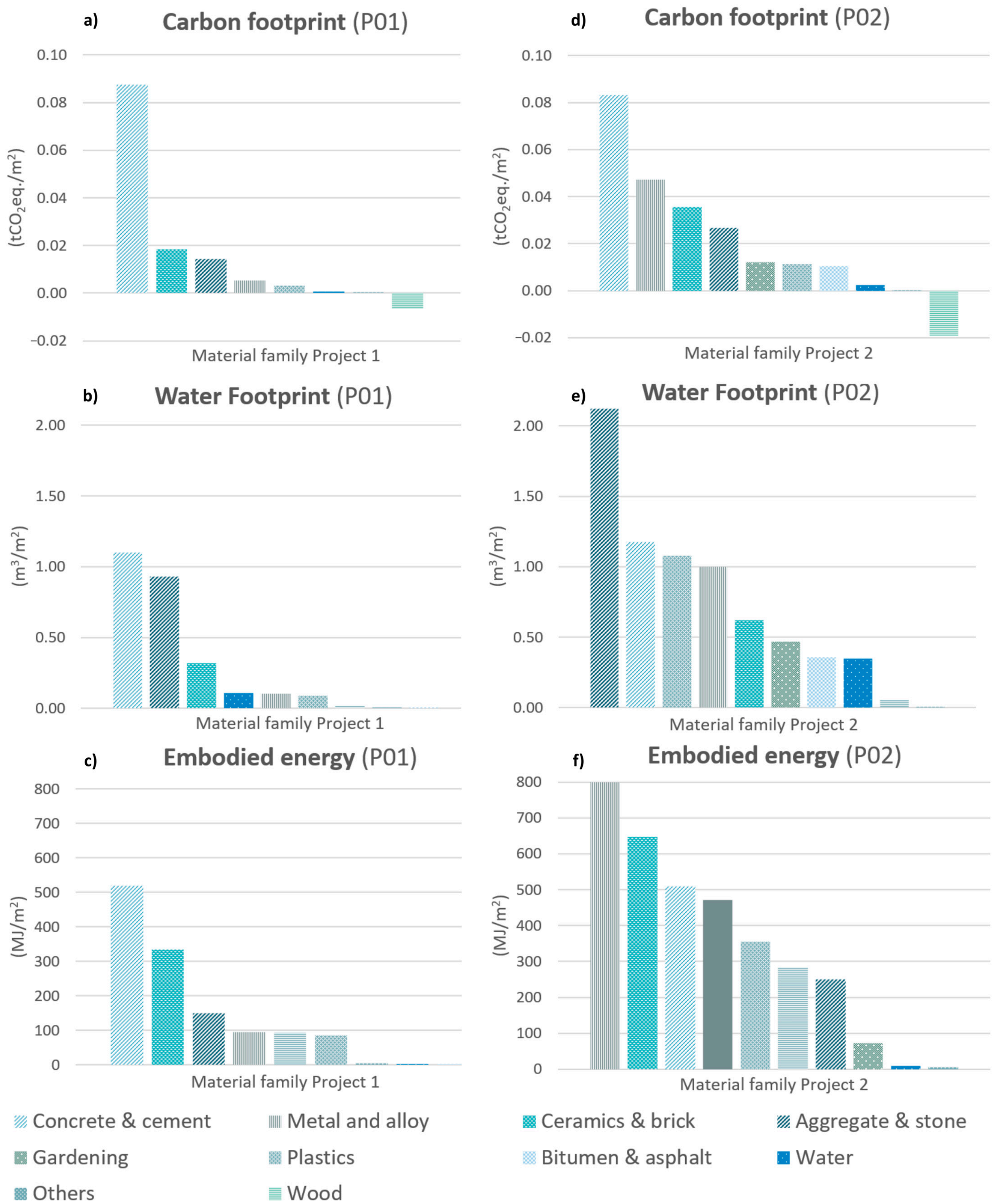

Figure 5. (**a**) Carbon footprint of Project 1 by area and material family, (**b**) water footprint of Project 1 by area and material family, (**c**) embodied energy of Project 1 by area and material family, (**d**) carbon footprint of Project 2 by area and material family, (**e**) water footprint of Project 2 by area and material family, (**f**) embodied energy of Project 2 by area and material family.

Similarly, by analyzing the results of the WF indicator, 41% of the impact on P1 is from concrete and cement, followed by 35% from aggregate and stone, and 12% from ceramics and brick. In P2, the family of aggregate and stone has the greatest impact with 30%, followed by concrete and cement with 17%, whereby metallic materials and plastics are both close to 15%.

As for the EE indicator, 40% of the impact on P1 was from concrete and cement, followed by 30% from ceramics and brick, and 12% from aggregate and stone, which reaffirmed the results obtained in the calculation of the CF indicator. In P2, the family of metallic materials had the greatest impact with 23%, followed by ceramic materials with 19%, and concrete and cement with 15%. In the three indicators, the same three families of materials control over 60% of these indicators, except for EE, for which the family of bitumen and asphalt is also important. The results obtained are similar to those in the previous research, where ten urbanization materials, in industrial and residential projects, control 91% of the total impact in terms of the ecological footprint, with the greatest impact provoked by asphalt and concrete [29].

The next step involves determining the BC or construction products with the highest impact (Table S1). In this respect, seven products, out of the 124 BC, handle 85% of the CF, 76% of the WF, and 73% of the EE (Table 3). Comparable results have been obtained using Building Information Modelling in a project that included a car park, a playground, and street construction [31].

Regarding P2, the BCs responsible for 86% of the CF and 74% of WF and EE (Table 3) come from the vitrified ceramic pieces for canalization, junctions, and drainage connections. The BCs with the greatest impact (out of 333 BCs in total) include: (1) pipes of large diameters; (2) prefabricated concrete tiles for replacing paving (paving stones and photocatalytic blocks); (3) public lighting and urban furniture; (4) the aggregate provided to improve the terrain for pavements and the sand beds for pipes; (5) drainage and filtering soil to ensure the correct functioning of the urban drainage systems (SUDSs); (6) prefabricated concrete pieces for drainage elements and registration elements; and (7) the concrete supplied in situ. As in the earlier case, the order of priority in the WF is different, since the incorporation of aggregate and PVC drainage pipes are also significant. Furthermore, ceramics, metallic materials, and bitumen and asphalt mixtures carry the greatest impact in the EE.

The incorporation of bituminous materials (from petroleum) and tars (from coal) into road paving projects involves significant amounts of embodied energy, thus justifying the necessity to develop new techniques and materials which would enable a reduction in the manufacturing and laying temperatures of asphalt mixtures in combination with the incorporation of a recyclable material without losing mechanical performance [63]. Information from manufacturers on the environmental implications of these changes must be obtained as an essential step towards more sustainability in the practices in the sector.

4.1. Sensitivity Analysis

Once the material resources with the most decisive environmental impact have been defined, a search is conducted to find those manufacturers who have registered their products within the databases of any of the bodies that administer Type III eco-label programs in accordance with the UNE-EN ISO 14025 International Standards Organization (ISO) [64].

From the list of materials with a high environmental impact of P2, three materials are chosen to be replaced with another material that meets the requirements specified in the contract and that provide the project with added environmental value: see Table 4.

Table 3. Construction products with the highest total environmental impact in each project per square meter of urbanization plot.

Code	U_{Ref}	Materials in P1	Weight (kg/m^2)	Weight (%)	CF (tCO_2eq/m^2)	CF (%)	WF (m^3/m^2)	WF (%)	EE (MJ/m^2)	EE (%)
CH45020	m^3	CONCRETE HM-25/P/40/I	2.92×10^2	13.7	3.36×10^{-2}	27.2	5.12×10^{-1}	19.2	2.04×10^2	15.9
UP01800	u	PAVER VIBRATED CONCRETE	9.67×10^1	4.5	2.46×10^{-2}	19.9	2.15×10^{-1}	8.1	1.42×10^2	11.0
UA0$$$$	u/m	VITRIFIED CERAMIC PIECES	2.09×10^1	1.0	1.73×10^{-2}	14.0	3.15×10^{-1}	11.8	3.21×10^2	25.0
UP03820	m	CURB CONCRETE	5.19×10^1	2.4	1.49×10^{-2}	12.1	1.83×10^{-1}	6.9	8.74×10^1	6.8
AW00100	m^3	ARTIFICIAL AGGREGATES	5.77×10^2	27.1	6.40×10^{-3}	5.2	6.93×10^{-1}	25.9	9.26×10^1	7.2
US1010$	m	DUCTILE CAST IRON	2.66×10^0	0.1	4.33×10^{-3}	3.5	8.13×10^{-2}	3.0	7.37×10^1	5.7
AP00100	m^3	SIFTED CHALKY SAND	4.25×10^2	20.0	3.86×10^{-3}	3.1	4.25×10^{-2}	1.6	2.23×10^1	1.7
		TOTAL IN PROJECT P1	1.47×10^3	68.9	1.05×10^{-1}	85.0	2.04×10^0	76.5	9.43×10^2	73.3
Code	U_{Ref}	**Materials in P2**	**Weight (kg/m^2)**	**Weight (%)**	**CF (tCO_2eq/m^2)**	**CF (%)**	**WF (m^3/m^2)**	**WF (%)**	**EE (MJ/m^2)**	**EE (%)**
UA0$$$$	u/m	VITRIFIED CERAMIC PIECES	4.06×10^1	1.0	3.35×10^{-2}	16.0	6.10×10^{-1}	8.4	6.23×10^2	18.3
UP037$$	u	PHOTOCATALYTIC CONCRETE	1.54×10^2	3.7	3.31×10^{-2}	15.8	4.68×10^{-1}	6.5	2.31×10^2	6.8
UU01$$$	u	URBAN FURNITURE (METALLIC)	4.31×10^0	0.1	3.27×10^{-2}	15.6	6.85×10^{-1}	9.5	5.47×10^2	16.1
CH420$$	m	MASS AND REINFORCED CONCRETE	2.83×10^2	6.8	3.18×10^{-2}	15.2	4.76×10^{-1}	6.6	1.75×10^2	5.1
AW00100	m3	ARTIFICIAL AGGREGATES	1.26×10^3	30.2	1.34×10^{-2}	6.4	1.50×10^0	20.7	1.80×10^2	5.3
AP00100	m3	SOILS SEATING AND FILLINGS	1.63×10^3	39.2	1.33×10^{-2}	6.4	6.23×10^{-1}	8.6	6.93×10^1	2.0
UA006$$	u	PRECAST CONCRETE ELEMENTS	5.08×10^1	1.2	9.33×10^{-3}	4.5	1.01×10^{-1}	1.4	5.45×10^1	1.6
UA03140	u	PVC PIPE DRAINER, DIAM. 200 mm	1.09×10^0	0.0	3.54×10^{-3}	1.7	5.49×10^{-1}	7.6	9.71×10^1	2.9
UP015$$	kg	BITUMEN AND ASPHALT MIXTURES	4.46×10^1	1.1	1.04×10^{-2}	5.0	3.56×10^{-1}	4.9	4.71×10^2	13.8
		TOTAL IN PROJECT P2	3.47×10^3	83.2	1.81×10^{-1}	86.4	5.36×10^0	74.3	2.45×10^3	74.4

Table 4. Environmental assessment of products with Eco-labels vs. original materials. The percentage correspond to the total quantities in the project.

CODE	U	Materials in Project P2	CF (kg CO_2 eq.)	CF (%)	WF m^3)	WF (%)	EE (GJ)	EE (%)
UP03710	u	PHOTOCATALYTIC CONCRETE PAVEMENT PIECES	377.66	15.79	5341	6.48	2641	6.80
UP03711	u	CONCRETE PAVEMENT PIECES WITH EPD	190.87	8.66	2656	3.33	738	2.00
UP01510	kg	BITUMEN AND ASPHALT MIXTURES	119.35	4.99	4075	4.94	5372	13.83
UP01511	kg	BITUMEN AND ASPHALT MIXTURES WITH EPD	76.57	3.26	3982	4.84	2071	5.83
UA03140	u	PVC PIPE DRAINER, DIAM. 200 mm	42.88	1.69	6264	7.60	1390	2.85
UA04140	u	PP STRUCTURED WALL DRAINAGE PIPE, DIAM. 200 mm WITH EPD	45.86	1.92	2469	3.14	1783	4.54

The materials replaced are, in the first place, photo-catalytic concrete kerbs and pavements, which are substituted with prefabricated concrete tiles with the same physical and mechanical characteristics, in whose production recycled raw materials have been used: 72% for the pavements, and 82% for the kerbs. This substitution reduces the CF and WF by half and EE by 70%, thereby deleting its environmental significance in the project. Secondly, the project incorporates bituminous materials and asphalt whose manufacturing process has a lower production temperature, and contains a greater amount of recycled asphalt (the proportion varies between 10% and 30%). Furthermore, it replaces the heating oil with renewable energy sources. This enables a significant reduction of the CF and EE, but not of WF which remains largely unchanged. Thirdly, the PVC pipes used for land drainage are replaced by PP plastic pipes, whose chemical composition is more neutral, and which can remain underground at the end of its useful life. This change in the plastic material reduces the WF by 60% and the EE by 30%, thereby removing this material as incurring a major environmental impact in the project. The increase in the CF of the product by 7% is not significant due to the low CF importance in the project (1.69%).

4.2. Environmental Assessment Criteria and the Environmental Label

The present methodology needs to be implemented in practice with the practitioner as part of its implementation. Other researchers have found that promoters are crucial in improving projects, but their lack of knowledge or experience in sustainable procurement needs to be overcome in order to include specific sustainable requirements [65]. Five stages can be established: call for bids, field inspection before bidding, bid opening, bid evaluation, and awards of bids [66]. For the bid evaluation, the winner is determined by experts who are invited to provide their assessment information for each candidate bidder with respect to the technical, business, and sustainability attributes in accordance with the scoring rules.

The intention of this work is to provide the promoter of public works with a simple weighting tool to facilitate the process of selecting the builder, introducing the use of environmental criteria by requiring improved materials that have eco-labels. The proposed weighting table distinguishes materials according to their environmental impact on the project, which is previously calculated using the present methodology.

The particular case of project P1 can be set as representative, as decided by the public enterprise EMASESA, where the supply and sewer networks are renewed (Table 4). The present study has allowed the identification of fresh concrete supporting the replacement of roads; the prefabricated concrete for kerbs and paving stones accounted for 80% of the environmental impacts. Filling aggregates that serve as settlement layers for pipes and fillers, together with pipes and special pieces of vitrified ceramics used in the sewer network, are materials of high impact and form part of group A. Metallic materials (e.g., supply pipes) and elements made of cast iron (e.g., grids and manhole lids in the pedestrian area) form group B, since these are materials with an average impact whose environmental influence on the total project remains lower than 5% of the total materials incorporated in the project. The remaining are included in group C as minimal impact materials.

Then, a simplified assessment for similar projects can be identified. Table 5 describes a proposal for the assessment of these types of projects, which includes a weighting of the impact of WF, CF, and EE, together with the types of eco-labels. A punctuation is assigned from 0 to 3. 3, where the highest punctuation corresponds to the best combination, which consists of a high impacting material which has a Type III eco-label.

Table 5. Environmental assessment of eco-labels for projects.

<table>
<tr><th rowspan="2">Environmental Classification</th><th rowspan="2">Project P1</th><th rowspan="2">Project P2</th><th colspan="3">Eco-label ISO</th></tr>
<tr><th>Type III</th><th>Type I</th><th>Type II</th></tr>
<tr><td rowspan="3">GROUP A</td><td colspan="2">concrete and cement</td><td rowspan="3">3</td><td rowspan="3">2</td><td rowspan="3">1</td></tr>
<tr><td colspan="2">aggregate and stone</td></tr>
<tr><td>ceramics and brick</td><td>metal and alloy</td></tr>
<tr><td rowspan="2">GROUP B</td><td>metal and alloy</td><td>ceramics and brick</td><td rowspan="2">2</td><td rowspan="2">1</td><td rowspan="2">1</td></tr>
<tr><td></td><td>plastics</td></tr>
<tr><td rowspan="5">GROUP C</td><td>plastics</td><td>water</td><td rowspan="5">1</td><td rowspan="5">0</td><td rowspan="5">0</td></tr>
<tr><td>water</td><td>gardening</td></tr>
<tr><td colspan="2">bitumen and asphalt</td></tr>
<tr><td>gardening</td><td>wood</td></tr>
<tr><td>other</td><td>other</td></tr>
</table>

P2 project represents a different kind of work by EMASESA, in which aesthetic, environmental, and social criteria are also presented. This led to the installation of large-diameter drainage pipes and an improvement in the terrain. Critical materials, included in group A, differed from the P1 project, with a different valuation table (Table 5).

Similar evaluations can be performed in the future for other representative projects in the city, and these can be grouped into categories. This strategy can ease the evaluation of the proposals: instead of analyzing them item by item, they could be treated in a briefer way by focusing on those materials with the greatest environmental impact in each category of project and by recognizing the efforts of each candidate bidder to reduce their impact with respect to traditional solutions.

5. Conclusions

Project cost control is normally implemented around the word, using either public or private construction cost databases, which makes them a suitable entry point for sustainability indicators. The databases, having been in place in the construction sector for several decades, can provide an excellent instrument for the introduction of environmental assessment. To this end, representative urbanization projects in the city of Seville have been studied. Two real-life projects are evaluated; one is a conventional action, in which the water supply and sewer network are renovated, and a second project in which gardens and leisure areas are added along the sides of the street. The analysis allows the materials or units of work with the greatest impact to be determined by a detailed evaluation of every item that is part of the project. In both projects, only a few materials, out of 124, such as concrete, aggregate, and stone, are those that control the environmental impact. This leads to the proposal for simple weighting tables to help in the procurement based on the indicators WF (m^3 water), EE (MJ), and CF (tCO_2eq).

The construction products with the highest environmental impact are identified, which enables the public entity to request construction companies to substitute traditional materials with other products on the market. This can be accredited by eco-labels and/or EPDs.

The methodology can be implemented in other cities by employing local construction cost databases that include a detailed material description. An effort is needed in the calculation of materials weight per reference units normally employed in the construction sector. Once the products weights are calculated, the information can be combined with LCA data. All this gives rise to the creation of a construction cost database that includes environmental impact. The case studies evaluate over 333 basic costs in P1, and 124 basic costs in P2; several of them, 176, are created new, because they are not included in the ACCD at the moment of this evaluation, but their classification and coding are employed. The unit costs are all created new; there are 367 unit costs in P1 and 118 unit costs in P2. Then, once all the elements in the project are evaluated, simplified tables can be defined with the most impacting construction products as improvement targets, and the tables can be used in the bidding processes' evaluation in order to include environmental criteria.

In future research, further project typologies will be explored in the urbanization and construction of buildings in public projects in order to advance in the general assessment of green procurement. The analysis will include not only the embodied impact of the projects, but the direct impact in terms of water consumption or CO_2 reduction by the gardens in a global project impact assessment.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13074078/s1, Table S1: Examples of calculation: unit elements with the highest environmental impact of project 1.

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