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Review Article

Mexican Sustainability Classification in Construction: Brief Review of Carbon, Life Cycle, and Water Footprints

Kenya Suarez-Dominguez[1], Ruth del Carmen Galindo-Lopez[2], Lisbeth A. Brandt-Garcia[1*], Alejandra Nuñez-Ramos[1]

[1]*Faculty of Architecture, Design, and Urbanism, UAT, Circuito Universitario S/N, Tampico, Tamaulipas, Mexico.*
[2]*Faculty of Engineering, UAT, Circuito Universitario S/N, Tampico, Tamaulipas, Mexico.*

**Corresponding Author : lbrandt@uat.edu.mx*

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Abstract *- Sustainability has gained widespread recognition on a global scale. Yet, its interpretation varies among researchers who may lack familiarity with their specific field's diverse criteria or possibilities. In the Mexican context, there is a dedicated effort to advance the development of new materials and sustainable processes for construction. Despite commendable initiatives, a significant issue arises from the insufficient determination of the environmental impact of these innovative materials. This gap is particularly pronounced in the swiftly evolving construction sector, where vernacular practices may align with sustainability criteria, but their environmental implications remain uncertain. To address this discrepancy, we propose a protocol brief review approach, providing a systematic method for evaluating the sustainability of materials or processes applied in construction. This approach underscores the importance of contextualizing sustainability criteria, recognizing that what may be considered sustainable in one environmental context may not hold the same designation in another. From a quantitative perspective, the proposal introduces a structured justification framework. This framework aims to guide researchers in articulating and substantiating claims regarding the sustainability of a given element, whether affirming or denying its status as sustainable. By integrating these considerations, this paper aims to enhance the precision and comprehensiveness of sustainability assessments within the construction realm. This contribution seeks to foster a more informed and nuanced understanding of the environmental impact of materials and processes in this dynamic field.*

Keywords *- Sustainability criteria, Environmental impact analysis, Environmental footprint, Life cycle, Water footprints.*

1. Introduction

When asserting whether something is sustainable, do we truly understand it, or is it merely an intuition-based consideration? Before addressing this question, it is imperative to understand sustainability, encompassing quantifiable terms, the context under which it is declared, the calculation methods employed, and the considerations guiding this determination.

In essence, sustainability refers to development that meets the needs of the present without compromising the ability to meet the needs of future generations according to the international ISO 14001, which establishes the requirements for environmental management systems. A specific standard exists in Mexico to identify sustainable buildings [1].

However, this standard predominantly focuses on reducing energy usage, concentrating on the consumption volume and the materials and electrical energy utilized. On an international scale, the ISO 15392:2019 standard [2] takes a broader approach, centering on the Life Cycle Analysis of buildings and their components as another criterion for sustainability.

These regulations provide explicit guidelines on the steps to be followed in determining the sustainability of a structure. Therefore, if a processing element is asserted to be sustainable in Mexico, it is crucial to specify the criteria under which this claim is made.

These criteria can be delineated by sections, such as the direct amount of energy usage [3] or through individual analyses employing one of the existing methods.

This paper seeks to scrutinize the primary options for measuring sustainability. It underscores the importance of utilizing appropriate standards or processes in determining the impact of a given process or product.

2. Method

There are several methodologies and systems to define the same concept, which contributes to confusion in the field, continuously developing to find precise and verifiable procedures and understanding each other [4].

Currently, there is no standard and uniform methodological framework for measuring GHG emissions adapted to specific projects that respond to approval criteria of the mechanism to which they are applied [5]. In Mexico and most Latin American countries, regulations are optional. This document addresses the following possibilities for the determination of a sustainable element:

1. Carbon Footprint
2. Life Cycle Assessment
3. Water Footprint
4. Environmental Footprint
5. The criterion for experimental gas measurement
6. Other specific criteria applicable

The importance of sustainability in construction and the necessity to classify sustainability in this sector within the Mexican context were briefly introduced. Key concepts such as carbon footprint, Life Cycle Assessment, and water footprint were defined, and their relevance in sustainable construction was explored. Specific methods employed in Mexico to classify sustainability in construction were detailed, including an examination of government initiatives, regulations, or standards adopted in the country.

A detailed review was provided on how the carbon footprint is calculated and utilized in the context of construction in Mexico, accompanied by practical examples of projects or companies implementing measures to reduce carbon footprints. The application of Life Cycle Assessment (LCA) in the Mexican construction sector was explored, with highlighted case studies illustrating how LCA influenced sustainable decision-making.

The importance and calculation methods of the water footprint in Mexican construction projects were analyzed, showcasing concrete examples of strategies used to minimize the water footprint in the sector. The benefits of implementing these classification methods in sustainable construction in Mexico were examined, alongside addressing challenges and limitations associated with their application.

3. Results and Discussion

3.1. Carbon Footprint

Carbon footprint studies can be adapted to various scales, from households and organizations to corporations, industries, countries, and cities [6]. The carbon footprint, also known as the ecological footprint, is a component of Green House Gases [7]. This criterion holds global significance, leading to diverse environmental policies aimed at its reduction. The responsibility for quantification lies with each company [8], and one notable measure in this regard is the Kyoto Protocol of 1997, which has been in effect since 2005 [9].

Mexico has committed to a 35% reduction in emissions by 2030 [10], positioning itself among the top 10 globally for developing projects under the clean development mechanism. These projects encompass methane recovery, renewable energies, energy efficiency, industrial processes, and waste management, among others mentioned in SEMARNAT (Mexican Governmental Organization for the Environment and Natural Resources).

In the assessment and quantification of emissions, it is essential to consider not only carbon dioxide but also other greenhouse gases such as Methane (CH_4), Nitrogen Oxide (NO), Ozone (O_3), and water vapor [10]. When applying this criterion, greenhouse gas emissions must be presented in terms of carbon dioxide equivalent within a specified timeframe [11].

As mentioned above, there is no comparable or traceable international standard structure for emissions measurement, but accepted proposals have been made in the appropriate application contexts, with three possibilities [12]:

- Private software developed by consultants.
- Tools made available by non-governmental organizations.
- Tools developed or supported by state agencies.

It is important to emphasize that the carbon footprint can be applied to multiple concepts, mainly a company or administration, a territory, a good or service, an event, or a person [13]. The carbon footprint can also be measured at different scales, perimeters, and scopes.

Carbon footprint scopes are the most common and standardized definitions for classifying direct and indirect emissions. They were developed in 2001 by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) and addressed to corporations and categorized according to 3 domains (in 2014, it was extended to cities):

- Scope 1: Direct emissions (which physically occur within the analyzed perimeter, such as fuel consumption or waste generation.
- Scope 2: Indirect emissions linked to energy consumption (such as energy consumption provided by interconnected networks).
- Scope 3: All other indirect emissions (such as those linked to raw material suppliers and the products' use and end-of-life generated).

Notwithstanding the mentioned diversity, prominent attention is given to methodological frameworks that acknowledge and impact ongoing progress.

In alignment with the approach taken by developed nations, the analysis of carbon footprint, at least in the short and medium term, centers on the following three methodological frameworks [14]:

- Greenhouse Gas Protocol (GHG Protocol)
- Bilan Carbone ®
- PAS 2050/2060

The International Standard Organization (ISO) has developed standards for measuring GHG emissions. Previously developed standards and methodologies generally inspire these and aim to be a recognized, trusted framework in GHG measurement project operations. These standards are:

- ISO 14.064 and 14.065
- ISO 14.067
- ISO/WD 14.069

The GHG Protocol method, widely utilized today, was established in 2001 through a collaborative effort involving companies, governments, and non-governmental organizations. Various online tools are available to bolster the revised method [18].

Table 1 briefly outlines the primary tools, encompassing features from Bilan Carbone and PAS 2050/2060, developed by Bilan Carbone for calculating the carbon footprint. Of these tools, the three main streams issued by WRI/WBCSD (GHG Protocol), England (PAS 2050/2060), and France (Bilan Carbon ®) stand out, which guide the determination of international methodological frameworks with the potential to lead to a carbon tax. One developed in Mexico is included.

While numerous tools exist, each regulation or procedure incorporates a table featuring default values. For instance, pre-existing data, including the roster of fuels considered for oil equivalences, is readily accessible [15]. The responsibility for registering emitted greenhouse gases in Mexico falls under the National Registry of Emissions [16].

Table 1. Tool for the determination of carbon footprint

	GHG Protocol	**Bilan Carbone ®**	**PAS 2050**	**PAS 2060**	**(RENE) Version 3.0 SEMARNAT**
GHG emissions accounting function	MS Excel (with guides in PDF format)	MS Excel (with guides in PDF format)	PDF Guide	PDF Guide	MS Excel (with guides in PDF format)
Reduction recommendation function	Yes	Yes	Yes	Yes	Yes
Compensation recommendation function	Little	Yes	No	Yes	Little
Scale	Top 6 (Kyoto Protocol)	All GHGs	All GHGs	All GHGs	GHG
License	Site (company): Yes Territory: Yes Product: Yes	Site (company): Yes Territory: Yes Product: Yes (With a specific module)	Site (company): No Territory: No Product: Yes	Site (company): Yes Territory: Yes Product: No	Free
Transparency	Technical guides clearly explain emission processes and drivers and are available on the website	Free after taking a training course with a cost between 1300 and 2000€	Free	95Ƀ	Free

Presently, in adherence to Mexican legislation, various sectors are obligated to report their direct and indirect emissions of greenhouse gases or compounds from all their facilities when such emissions exceed 25,000 tons of CO_2 equivalent (tCO_2e):

- Energy,
- Industry,
- Transport,
- Agricultural,
- Waste, and
- Trade & Services.

This is set out in the following set of existing Regulations and Secretarial Agreements:

- Regulation of the general law on climate change regarding the National Registry of Emissions.
- Agreement that establishes greenhouse gases or compounds that are grouped to report emissions, as well as their warming potentials.
- Agreement by which the instructions and format of the Annual Operating Certificate are disclosed.

On the other hand, the procedure in Mexico for the determination of calculation methodologies is held in:

- The agreement establishes the technical particularities and formulas for applying methods for calculating greenhouse gas emissions or compounds.
- Agreement establishing the steps for the direct measurement of carbon dioxide emissions.

The tool for calculating the carbon footprint, found in an Excel table with the greenhouse emissions accounting function, has been developed by the National Institute of Ecology and Climate Change.

3.2. Life Cycle Assessment

Life cycle assessment is a broader process for determining sustainability. Obtaining "Green" or sustainable products, with a better environmental practice intended to change the perception of a market, allows manufacturers to ensure in some way that they do not damage natural ecosystems or comply with international standards.

Unfortunately, intuition is used rather than peer review of the products employed when materials or processes are new, which is common in the self-construction industry. It is essential to know that ISO 14040 shows all the life cycle analysis equations. Unlike the Carbon Footprint, this analysis considers the aspect, as the name implies, of the life cycle or "From the cradle to the grave," quantifying potential impacts stages of existence. That said, the applicable standard has all aspects related to this calculation. This analysis can improve environmental performance by identifying more significant impacts in some stages and making better decisions from institutions and governments. ISO 14044 details the requirements for carrying out an LCA. There are four phases to a stroke study:

1. The phase of defining the objective and scope,
2. The inventory analysis phase,
3. The environmental impact assessment phase, and
4. The interpretation phase.

Life product begins in the design and development of this and ends with the activities of reuse and recycling, passing through the following stages:

1. Raw materials acquisition, including all energy supply activities and materials extraction.
2. Steps in the procurement or manufacturing process, including all activities to convert raw materials and energy into what is desired (including human actions and interventions).
3. Transport for distribution includes transfers to the user or area of use.
4. Use, reuse, and maintenance that includes emissions or energy consumption throughout the life of the product or service analyzed.
5. Recycling considers the initial function for which the product or process is designed + or is completed, adapted, or recycled through a system to obtain a new product.
6. Waste management refers to the end life of the material or process in which it is returned to the environment or its disposal is made.

The products used in construction, mainly those in structural elements such as cement derivatives and concrete, have been one of the first in which Life Cycle Analysis was applied, which is part of various databases. In 2007, 10 years after the first international studies, a call was launched to learn about the analysis of different materials used in construction. In the case of concrete, improvements have been made in the mixtures to reduce the environmental impact. This has been quantified from the same Life Cycle Analysis, which has allowed the verification of a decrease in emissions [17].

The application of life cycle assessment can consider multi-criteria decisions for analyzing elements from various perspectives [3]. Recognizing the emissions for each mixture allows new components to be reviewed. Some of them are cement, which has been replaced and evaluated from emissions in this scope [18]. Recycling products allows them to reduce emissions and increase their lives by more than 10% [19]. Most of the calculation processes in Mexico, the general determinations the previous ones were born in the last decade, specifically after 2010, although Mexico has participated in the reduction of climate change emissions since the beginning of the XXI century, so much so that in 2005 the parameters for life cycle analysis were established, which are:

- Mexican Standard IMNC. ISO 14040:2006. NMX-SAA-14040. IMNC-2008. Environmental Management-Life Cycle Assessment- Principles and framework.
- Mexican Standard IMNC. ISO 14044:2006. NMX-SAA-14044. IMNC-2008. Environmental Management-Life Cycle Assessment- Requirements and guidelines.

3.3. Water Footprint Criteria

The Water Footprint is one of the determinations of knowing an emphasis on environmental space. It consists of determining the water that is directly and indirectly required for a process or a product; it is the sum of water, blue, and gray necessary for the product and its distribution with water units per year. The Water Footprint was established in 2002. It is well known that the water currently available for human consumption is less than 1% of that existing on the planet and measures the amount of water directly and indirectly used to develop a process and obtain a product.

A proportion of this is known as the water footprint or virtual water footprint, which corresponds to water that is not physically seen but is necessary to make a product. Agua.org.mx [20] has an equivalent water database for processes and products worldwide. This footprint is composed of three elements.

1. Green water orphan is obtained naturally from rainfall, stored in the soil, or captured by terrestrial flora or fauna.
2. Blue water footprint refers to water from underground or surface water resources (such as rivers or lagoons) and domestic use.
3. Gray water footprint corresponds to the freshwater required to dilute contaminated water in production.

It is measured from,

1. The total volume of water consumption
2. Consumption patterns
3. Climate
4. Agricultural practices

Each country has a regulatory body. In the case of Mexico, it is the National Water Commission (CONAGUA) that is responsible for making records and determining the water footprint in Mexico; for example, “For the period 1996-2005, the average per capita water footprint of Mexico was estimated at 1,978 cubic meters per year, higher than the world average, calculated at 1,385 cubic meters per year”.

Several tools exist on the internet, although the regulation is found in NMX-AA-184-SCFI-2021 Methodology to determine the volume of efficient use of national waters and the direct blue water footprint. Mexico has an Education and Training Center for Sustainable Development and the Fund for Communication and Environmental Education, which has established documents on the water footprint as well as the calculation process [20].

The water footprint provides the requirements and guidance for the calculation and reporting of the water footprint as an individual audit or as part of a more comprehensive environmental audit based on ISO 14046, which includes the assessment of the water footprint, as well as the study from the definitions, Application of processes for impact assessment and interpretation of results. This sustainability indicator’s methodology is based on the Life Cycle Assessment (LCA) method, which serves to know the different environmental impacts. It has practically been obtained mainly for agricultural products [21].

The Water Footprint is useful mainly for organizations but highly relevant for construction products that require water [22].

3.4. The Criterion by Experimental Measurement or Thermodynamic Calculation

Some papers mention the processes and details of the equations and calculation structures that must be used. The vast majority of researchers use existing tools on the internet, some with cost or commercial use. Unfortunately, commercial tools mostly correspond to various whose source data is “confidential” and unverifiable. People are dedicated to calculating sustainability, as it was developed in principle with measures obtained directly from the set of models from the laws of thermodynamics and applied chemistry [26].

A theoretical-experimental example should be found in [27]. A particular sustainability parameter is indirectly obtained when a product’s life is determined. For example, a product that emits 100kg CO_2 eq to produce it has a life of 5 years but has another of 200kg CO_2 eq. Still, with a dash of 15 years, the second can be considered with greater sustainability: contrast analysis must be carried out from the aging of a material and obtaining greenhouse gases emitted.

The life of the material used, considering the most used ASTM G154, requires a calibrated machine for measuring the emission of ultraviolet rays and controlled temperature and humidity. Microbiological degradation can be another sustainability analysis, mainly for cases in which the lifetime is short for a material, such as plastic packaging [28].

3.5. Environmental or Ecological Footprint

The environmental footprint consists of various tools determining a set of footprints, highlighting water, climate change (or greenhouse gases), resources, atmospheric, waste, and biodiversity. Ecological footprints have been determined in concrete and cement-based materials, in conjunction with recycled components [29], as well as a set of tests throughout history with sustainable concrete [30]. The overall environmental footprint provides a broad view of a product's impact on the organization.

3.5.1. Other Sustainability Criteria in Mexico

In Mexico, there are limited strides in ecological measurement, particularly within construction, although international alternatives have been delineated earlier. The existing standards for enhancing energy efficiency in homes include:

- NOM-007-ENER-2014 focuses on energy efficiency for lighting systems in non-residential buildings.
- NOM-008-ENER-2001 emphasizes energy efficiency in buildings, explicitly addressing the envelope of non-residential buildings.
- NOM-020-ENER-2011 targets energy efficiency in buildings, specifically focusing on the building envelope for residential use.

The assessment provided in the sections aligned with the third governmental guiding axis at the national level, about urban development, ecology, and the environment, highlights issues such as the absence of comprehensive urban planning for land use and territorial reserves, along with the lack of regulations governing urban development and sustainability. The report underscores the imperative to augment services and infrastructure directly linked to housing and urban planning while addressing pollution-related challenges.

Notably, some states in the Mexican Republic are leading in these efforts. For instance, Mexico city took a significant step in 2008 by instituting the Sustainable Building Certification Program (PCES) and the standard:

- NMX-AA-164-SCF1-2013 for Sustainable Building.

Similar initiatives have been undertaken in the hotel industry, with standards such as:

- NMX-AA-171-SCFI-2014 outlining requirements and specifications for the environmental performance of lodging establishments.

Moreover, a standard in the realm of tourist real estate developments has been established, specifically for the coastal zone of the Yucatan Peninsula:

- NMX-AA-SCFI-157-2012 delineates sustainability requirements and specifications for site selection, design, construction, operation, and site abandonment.

Public policy in Mexico on sustainability was scarce before 2010 but possible but not at the pace of other countries such as Europe, noting Gómez M. D. L. A. et al. 2018 on page 3:

Mexican federal authorities are carrying out ecological, sustainable projects To meet the needs of the urban and rural population. Among them, it is considered the sustainable housing program, the recycling of liquids and solids, the care and conservation of forests and jungles, rivers and seas, and the protection of endangered animal species. Of these, the only one that advances as planned is that of sustainable housing. In the other projects, it depends on several instances that hinder its realization.

3.6. Waste

According to the UN, in its information brochure number 35, p.7, mentions that within the states, there are:

Section 31 (1) guarantees access to adequate housing, which means structurally, hygienic and sanitary safe housing, i.e., housing with all basic facilities, such as water, heating, waste disposal, sanitation, and electricity.

Where individuals are entitled to housing complete with waste disposal amenities.

In Mexico, the National Registry of Emissions (RENE) documents the release of compounds and greenhouse gases. The government has set a target to reduce carbon gas emissions from the Gross Domestic Product (GDP) by approximately 37% from 2014 to 2030. There is also the Secretariat of Environment and Natural Resources (Semarnat) is a government agency whose fundamental purpose is to constitute the State policy on environmental protection, and that helps other areas, among which is the National Commission of Protected Areas or the National Institute of Ecology or Climate Change (INECC).

With the latter, 30 measures were proposed in 2015 in eight sectors of the national economy in sectoral support to reduce emissions that impact the environment of various economic areas, among which are "transportation, electrical, residential and commercial, oil and gas, industrial, agriculture and livestock, waste, and land use, land use change and forestry (USCUSS)" highlighting construction and building. The government will spend over 143 billion dollars on this mitigation until 2030, according to the Mexico Newsletter, 2018. Regardless of the above-proposed analysis, there are several guidelines to carry out this study, among which are, according to the government page of Semarnat, 2018, the following:

- User Guide National Emissions Registry (RENE) Version 3.0
- Emissions calculator of the National Registry of Emissions (RENE) version 6.0

The critical aspects of eco-efficiency are summarized according to Forbes 2016:

- A reduction in the material and energy intensity of goods and services.
- Reduced dispersion of toxic materials.
- Improved recycling capacity.
- Maximum use of renewable resources.
- The more outstanding durability of products.

In general, on the other hand, there are regulations for waste that must be used, mainly waste that goes to the soil, among which are,

3.6.1. Laws

- General law for the prevention and integral management of waste (LGPGIR)

3.6.2. Regulations

- LGPGIR Regulations

3.6.3. Official Mexican Standards (NOM)

- NOM-083-SEMARNAT
- NOM-098-SEMARNAT

3.6.4. Mexican Standards (NMX)

The Official Mexican Standard NOM-161-SEMARNAT-2011 establishes the criteria for classifying special management waste and determining which are subject to a management plan; the list thereof, the procedure for inclusion or exclusion from that list; as well as the elements and procedures for the formulation of management plans. At the regional level, precisely the same national regulations are followed, and they are limited mainly because they are mandatory only for companies but are not verified in housing cases. Waste classified as hazardous continues to be dangerous even if it is neutralized by another means or vitrified, so it always has to be finally directed to confinement.

4. Conclusion

This paper delves into the diverse landscape of sustainability measurement options, shedding light on the standards and processes crucial for assessing the impact of processes or products. The multifaceted benefits of determining footprints and applying sustainability criteria extend beyond mere economic or marketing advantages, playing a pivotal role in enhancing the reputation of companies.

While these benefits are significant, the paramount advantage lies in the positive environmental impact and the consequential emissions reduction that threaten human health and the ecological environment. Quantifying gas or water emissions through systematic calculations offers a scientific, quantifiable, and repeatable framework, providing invaluable insights into the environmental impact of various materials and processes. The significance of such determinations lies in generating data and facilitating robust comparisons across different materials and processes.

This comparative analysis contributes to identifying materials with proven sustainability credentials, enabling the endorsement of claims regarding the superior or inferior sustainability of specific elements. Furthermore, the scientific rigor in sustainability measurements ensures reliability and credibility, fostering industry transparency. Reliable data, generated through standardized processes, is a foundation for informed decision-making in selecting and endorsing materials and processes that align with sustainability goals. This, in turn, contributes to fostering a culture of responsible and sustainable practices within construction and other industries.

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