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A Proposal for Measuring In-Use Buildings' Impact through the Ecological Footprint Approach

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Abstract: To reduce the environmental impact of the construction sector, sustainable strategies for managing the in-use phase of buildings must be integrated urgently. Current green certifications present several limitations and, in particular, do not help determine where to focus for reducing the environmental demand of buildings. Among existing indicators, the ecological footprint (EF) is the most useful for assessing the buildings' environmental performance through impact sources that reveal the over-consumption of resources. The present paper expands EF by taking into account the role of human behavior in over-consumption, and thus the efficiency in buildings' use. After comparing ecological footprint with the existing green certifications, the paper demonstrates how a new integrated ecological footprint assessment can describe the impact of built-up, energy consumption, water consumption, material consumption, food and drink, mobility, waste generation, recycling potential, and occupants in the environmental efficiency of a building. The application of a case study demonstrates the reliability and the effectiveness of the model and shows that the estimated ecological deficit reflects not only the consumption of energy and materials, but also the behaviors of building users. This highlights the need for integrating a sustainable culture in the users of buildings.

Keywords: ecological footprint; in-use phase; sustainable development; green policies; environmental impacts; real estate; building life cycle

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1. Introduction

Studies on environmental assessment demonstrate the need for integrating sustainable management in the evaluation of buildings to monitor their impact on the environment more effectively and efficiently [1,2]. The construction sector is a major contributor to global warming, carbon emissions and environmental degradation [3–9].

Since the early 1980's, the concept of "sustainable development" has been recognized as a new value [10], which entails the goal of making economies more productive without damaging future generations [11]. While climate change does not seem to be slowing down, the implementation of new strategies and policies to reduce greenhouse gas emissions and energy consumption is urgent.

To improve the environmental performance of buildings, several methods, environmental standards, and policies have been elaborated. Globally, there are over 600 different sustainable building certifications [12,13], which makes the comparison of how buildings perform hard, as they are built on different baseline standards [14].

Given the multiplicity of tools (e.g., BREEAM, LEED, DGNB, CASBEE, and Green Star) [15–19], a few issues emerge, mainly showing two orders of problems: technical and methodological.

Among technical problems, each rating system is the result of building standards that vary not only from country to country but even at sub-national level. This inconsistency brings increasing challenges from an implementation standpoint as it makes the systems based on different parameters and structured through different schemes and languages, including the use of different weights to evaluate the same parameter. Therefore, the unique characteristics and focus of each rating tool constitute a barrier to increasing knowledge about the overall environmental impact and sustainability of buildings [20,21]. As the JRC Science for Policy Report states: "the lack of knowledge is not only due to a lack of information, but [. . .] depends very much on the way the information is provided" [22]. In effect, the limited comparability of these measures makes it difficult to convey among non-experts the real meaning of the results, which affects the individual energy-related conducts and decisions. Common standards and a global set of benchmark parameters are pre-requisites to increase the effectiveness, the flexibility of application, and the efficiency of green measures, as they would allow multiple stakeholders to compare buildings easily at an international level by using a shared "language" [23].

Among methodological problems, rating systems give a picture of a building's environmental impact in one single moment of their life cycle. For instance, while LEED standard certifies the "greenness" of buildings at the design stage, often the same buildings have been found to perform poorly once in normal operation, showing a significant shift between predicted and actual operation [24]. Of course, not only the construction phase, but also the occupancy phase is likely to affect the actual functioning of a building. Therefore, the need for continuous monitoring of how buildings work in their in-use phase comes to light, for both aligning operation with expectations and for ensuring the best environmental performance over time [25]. BREEAM tries to address this issue. It allows a test to be performed once a year, but this is just on a voluntary basis [20]. Thus, buildings certified "excellent" may downgrade their operations after some years but still maintain a high certification if this is not updated regularly. In addition, BREEAM uses different methods according to the stage of building life cycle (BLC) when the evaluation is performed. This strategy complicates the evaluation process, as each stage uses different categories of impact to define the environmental performance.

Finally, the last methodological problem regards the definition of buildings' inefficiency. Wackernagel and Rees [26] (p. 118) wrote that "It might be sustainable to operate a gas guzzling Rolls Royce if it was shared among twenty friends and maintained for a long time. On the other hand, it might be unsustainable for everybody to own an electric car". This, translated in the built environment, means that a high-performance building may be sustainable if shared among users. Therefore, it is necessary to account for the impact of building occupancy to reveal if the building is environmentally efficient or inefficient. Green certifications fail to express the concept of inefficiency.

A valuable approach to consider in the scope of solving the downsides of common green certification is the ecological footprint (EF) concept.

2. Why Use EF to Assess Building Sustainability

The science of sustainability (SS) needs to find a suitable index to explain complex human-nature interactions [27]. Sala et al. [27] highlight that SS requires a solution-oriented approach. The EF concept can come be handy for fulfilling this methodological requirement. Indeed, EF represents a reasonable measure for evaluating the built environment's contribution to sustainable development and can help decision-making and social learning by showing the concreteness of sustainability issues and producing goal-oriented and actionable knowledge about the ability of the built environment to respect biocapacity.

EF looks at the "biocapacity", namely the capacity of an ecosystem to renew what has been consumed by the demand [28,29]. The Earth is a closed, material, and limited system with defined capacity of natural resources production and waste absorption [30]. Even if the biocapacity of Earth has increased by about 27% in the past 50 years thanks to technology, humanity is in overshoot, meaning that people are using more resources than the Earth can renew [31]. The importance of implementing the concept of "sustainable development" in all sectors is urgent [10,11].

Measures for sustainable development can be indicators or ratings [32,33]. Whereas indicators report only one dimension of sustainability (i.e., energy), ratings (or indices) are aggregations of underlying indicators [10]. Therefore, ratings, such as green certifications, provide a multidimensional and simplified overview of a system of indicators [11].

What is missing from rating systems is to define the use and overuse of Earth's resources. Mancini [34] argues that the one sustainable index able to reveal them is the EF. This is a multiscale approach, applicable at all levels of aggregation, from individual to global scale.

2.1. EF and Definition

EF calculates the resources used and waste generated by a society and compares them to the planet's capacity to produce resources and absorb waste. More recently, the EF has been used as an indicator of corporate environmental performances [35].

There are primarily two methods of estimating the EF as global hectares of land (gha) [36]. The "comprehensive method" calculates EF through macroscopic statistics on overall consumption, using life cycle assessment (LCA) data. The "component method" calculates EF by considering six types of equivalence productive lands (i.e., cropland, grazing land, forest land, fishing land, built-up land and CO_2 sinks) that are impacted by the consumption of different products [26]. The latter, which is an input-output analysis method, seems a more useful approach with the goal for EF to evaluate the environmental impact of buildings, but a link between EF and LCA would improve the effectiveness of the EF index [37].

The EF principle is based on the concept of converting impact sources, such as electricity, water, waste generation, fuel consumption, food consumption and more into the equivalence productive lands that would be needed to produce and/or absorb their impacts [38]. To do this conversion, the EF calculation methodology relies on two steps, as Figure 1 shows. First the so-called "world yield-factors" (WYF) convert consumptions and/or emissions into equivalence productive lands. Subsequently, "equivalence factors" (EQF) convert the productive lands into global hectares (gha) that correspond to common hectares [38,39].

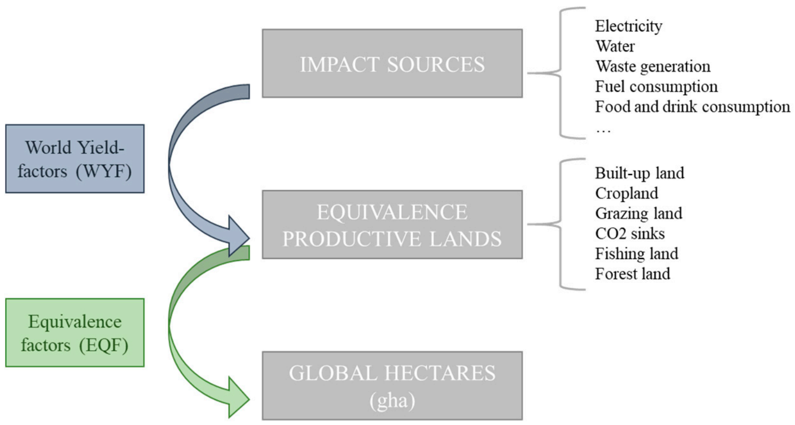

Figure 1. Ecological footprint calculation methodology.

To date, the most important institution applying the EF is the global footprint network (GFN) [31], which provides annual worldwide accounts of EF and biocapacity, and defines world yield-factors (WYF) and equivalence factors (EQF) every year [31].

Based on the GFN, the Earth's has been in overshoot since the 1970's, and, nowadays, it needs 1.7 Earths to overcome the demand for resources [31]. Initially, studies used EF to evaluate the impact of consumptions of nations and regions, then it started to be applied to smaller environments, like buildings, as shown in Table 1.

Table 1. Different contributions useful to implement ecological footprint (EF) by year.

	Authors	Implementation	Year
[26]	Wackernagel and Rees	Definition of EF, world yield-factors and equivalence factors	1996
[40]	Bicknell et al.	Definition of the link between economic activities and environment	1998
[36]	Simmons et al.	A component-based model of EF to measure the impact of different lifestyles of regions	2000
[41]	Lenzen and Murray	The EF has been used to define impacts for implementing meaningful policies	2001
[1]	Wood and Lenzen	Input-output analysis has been added to EF by developing a hybrid EF (HEF)	2003
[42]	Bastianoni et al.	Ecological footprint analysis for construction stage looking at the embodied energy of materials	2006
[39]	Acosta and More	Development of EF assessment (EFA) to monitor the impacts of buildings on the environment	2009
[43]	Jin, Xu and Yang	Integrating EF to system dynamics to overcome the problem of time	2009
[44]	Gottlieb et al.	Implement of EF Assessment for in-use stage	2010
[4]	Solìs-Guzman et al.		2012
[38]	Martìnez-Rocamora et al.	Implement of EF Assessment for construction stage	2016
[45]	Husain and Prakas	Association between EF and buildings life cycle (BLC)	2018
[37]	Brownell	Introduction of occupancy impact in the estimation of building EF index	2019

Many critics (e.g., [41,46–49]) argued that the calculation of EF oversimplifies the complex task of measuring sustainability, and that it was inadequate for regional design of policies [41]. In response to these issues, researchers proposed several modifications.

First, EF started being adapted to be used in the design of meaningful national and urban policies, linking economic activities and environmental impacts. Bicknell et al. [40] assessed the EF through the input-output analysis, allowing the calculation of consumptions by translating the demand of land through the WYF. Then, Lenzen and Murray [41] proposed an approach that reflects better the image of a footprint on land by describing the impact of human use of land on ecosystems. Their approach demonstrated EF's potential to expose inefficient resource use.

Afterwards, some studies implemented this approach to monitor the environmental impacts of buildings. Wood and Lenzen [1] developed a hybrid ecological footprint (HEF) for two buildings to enable the use of the results in urban policy formulation. They did not look at the impacts of all the six equivalence productive lands, but they limited their assessment to generic land disturbance and greenhouse gas emissions. Then, Bastianoni et al. [42] applied the EF on the construction of two Italian buildings. They introduced the use of embodied energy to translate the use of materials into equivalence productive lands. However, they do not implement a calculation model. Acosta and More [39] developed an ecological footprint assessment (EFA) to measure the ecological sustainability of organizations. They pictured a building's impact through the materials used and the energy spent. Since their application, the models to assess buildings' environmental impact were built on looking at the consumptions generated into the building, called impact sources [4,38,39,45,46]. However, these approaches were applied only once over the building's lifetime, so they were unable to track evolutions over time.

To overcome the limit of time, EF was later integrated with system dynamics [43]. Their objective was to define scenarios to formulate integrated policies for sustainable improvements. However, this approach is too complicated to be applied at the building level as it requires comparable or different scenarios of the analyzed building. Finally, Husain and Prakas [45] applied EF to BLC, which is a good compromise for plotting the sustainable progress over time. Nevertheless, the account of people during the in-use stage of the building is not relevant in this approach.

If we look at the impact sources that have been considered into the above mentioned studies at the building level, some deficiencies can be detected. Table 2 shows that the most common impact sources are water consumption [4,38,39,44,45], energy consumption [4,38,39,44,45], material consumption [4,38,39,44,45], waste generation [4,39,45] and user mobility [4,39,44,45]. None of the existing applications applied all the Impact sources together, except for Husain and Prakas [45]. However, they don't consider all the elements. For example, in developing food and drink, they just considered the consumption of food but disregarded drinks, and in implementing recycling potential, they only looked at the disposal stage of BLC, instead of considering all the waste produced in the in-use phase. Moreover, previous applications do not consider accurately the pressure that people and their behaviors have on EF.

In this regard, Brownell [37] emphasized the importance of evaluating the in-use phase of a building because it has the longest duration, compared to the other phases of a BLC (construction and disposal). He proposed a valuable theoretical framework including the estimation of: embodied footprint, which calculates the impact due to construction materials; operational footprint, which defines the impact of users; and influence footprint, which estimates the impact of building's utilization over time [37]. Brownell's approach to EF index is innovative as he emphasized that buildings do not stop consuming when unoccupied. Anyway, Brownell did not implement his idea into actual calculations but left it at a theoretical level. In this paper, we follow up on his proposal and develop it further.

2.2. Potential and Limitations of EF

The state-of-the-art suggests the potential of EF in showing the environmental impacts of buildings by condensing the human pressure on the environment into a single "figurative" quantity [35], which provides a snapshot of users' current demand [39] and evaluates the environmental pressure generated by the built environment [42]. EF can assess the human "responsibility" in the environmental impact of buildings by looking not only at resource consumption but also at the presence of people in the building [38]. EF provides a glimpse of users' current demand [39]. Finally, EF can potentially show variations in the sustainable performance of the built environment overtime [43,45].

Anyway, in its current state the EF index still presents some limitations if applied to buildings, for the following reasons:

- It is mainly applied as a static snapshot (e.g., [39,46]);
- It primarily includes energy and water consumption, along with waste and pollution generation, without considering the number of people occupying the building [4,38,39,44,45];
- None of the previous studies addressed all impact sources together.

In conclusion, a system is still missing for expressing the environmental impact of a building over its in-use stage by picturing the consequences of its actual functioning on the planet.

Table 2. Impact sources used in the evaluation of EF—literature review.

Authors	[39] **Acosta and More**	[44] **Gottlieb et al.**	[4] **Solìs-Guzman et al.**	[38] **Martìnez-Rocamora et al.**	[45] **Husain and Prakas**
Year	**2010**	**2012**	**2013**	**2016**	**2018**
BLC Stage	**In-use**	**In-use**	**Construction**	**In-Use**	**All**
Impact Sources	**Definitions**				
Built-up	Reveal the green space covered by buildings and parking lots	N.A.	N.A.	EF of land surface occupied by buildings	The land covered by buildings at the construction stage
Energy Consumption	Reveal the impact of the electrical and heat energy use	Capture the CO_2 emissions from electricity use	Reveal the amount of energy spent	EF of electricity and fuel consumed	Energy consumed in all BLC stages
Water	Reveal the impact of water demand	N.A.	Reveal the amount of water consumed	EF of water consumption	Water consumed in all BLC stages
Food and Drink	Reveal the impact of the creation and transport the product + their packaging	Capture the CO_2 emissions of food consumption	Reveal the amount of food consumed	EF of the food and drink used by manpower performing the activities of maintenance and cleaning	Food consumed by manpower in all stages
Mobility	Reveal the impact of the fuel used to travel	Capture the CO_2 emissions of travelling	Reveal the impact of travelling	N.A.	Travel of the manpower
Material	Reveal the impact of the creation and the transport of materials	Capture the CO_2 emissions of three types of materials used: paper, plastic, and cans	Reveal the amount of construction materials	EF of materials used for maintenance and cleaning	Material used in all BLC stages
Waste	Reveal the impact of solid waste	N.A.	Reveal the impact of solid waste	N.A.	Solid waste generated in all BLC stages
Recycling potential	N.A.	N.A.	N.A.	N.A.	Materials reused in the demolition stage

3. Goals and Approach

Based on the literature review and on the limits detected into the previous implementations of the EF index, the aim of the present work is to establish a new conceptual model for calculating the environmental impact of buildings. This model will seek to:

1. Evaluate the environmental impact of buildings within the in-use phase of the BLC as this represents the most enduring stage and the most resource-consuming;
2. Reveal the efficiency or inefficiency of buildings by looking at people occupancy;
3. Integrate all the impact sources used in previous research that have an impact on the in-use phase;
4. Integrate the "comprehensive method" and the "component method" into a combined model. The two methods allow the evaluation of impact sources through the embodied energy of products and materials, and then estimate EF addenda through WYF and EQF.

We called this new model integrated ecological footprint assessment (IEFA). The factors of the conceptual model and calculation method are presented below, along with some necessary assumptions that were established to proceed with the IEFA implementation. Later, we discuss the model through a test on an existing building. Discussion and conclusions present the results of the test and prospective developments to work on.

4. Model Design

4.1. IEFA Impact Sources

Based on the discussion of previous studies (see Table 2), IEFA gathers all impact sources that have been already applied in the literature, and introduces an additional source, occupant, which includes the occupancy data as a proxy for human pressure on the environment. This addition, which develops concepts elaborated by Wackernagel and Rees [26] and Bornwell [37], represents a marked innovation compared to previous models. According to Wackernagel and Rees [26] the level of sustainability of a resource is reduced if it is shared among several people. Sustainability depends on the assessment of user consumption per time interval [26]. Thus, it is not possible to assess the environmental performance of a product (a building) without acknowledging the fundamental variables of user consumption and time. Wackernagel and Rees [26] proposed to approximate an individual's need for land to 1.5 hectares per person; however, this serves only as a simple means for calculating individual EF. The IEFA model suggests using the occupant impact source to estimate simultaneous consumption by taking into account the number of hours spent in the building per individual.

Therefore, IEFA accounts for nine different Impact sources, as described in Table 3: built-up; energy consumption; water consumption; material consumption; food and drink; mobility; waste generation; recycling potential; and occupant.

4.2. Implementation through Equivalence Factors

As recommended in all EF calculation models to convert the Impact sources into addenda of IEFA, equivalence factors (EQF) available online at GFN [31] were used. EQF are scaling factors converting the actual areas of use of a single activity into global hectares' equivalence. GFN provides five EQF, corresponding to five of the six equivalence productive lands, i.e., built-up land, forest land, fishing land, pastureland, and cropland.

Our model is based on EQF provided by GFN in 2019 [31], as depicted in Table 4.

Moreover, the proposed model considers also the impact on CO_2 sinks, therefore further analysis was required to calculate the CO_2 sinks. According to Mancini et al. [34], carbon is estimated through the so-called absorption factors, which represent CO_2 emissions absorbed by oceans and land (cropland, forest and pastureland). 30% of the emission is absorbed by the ocean [50]. Among all sources of CO_2, human activities (and, therefore, buildings) account for one of the predominant causes of the fossil fuel in the atmosphere.

Table 3. Impact sources used in integrated ecological footprint assessment (IEFA) model.

References	Impact Sources	Definition	Data for Calculation	EQF Impacted
[38,39,45]	Built-Up	Impact coming from the surface land covered by the building	Surface of building	Built-up land
[4,38,39,44,45]	Energy Consumption	Impact in consuming energy to run the activities taking place in the building	Total energy consumed: electricity and fuel	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[4,38,39,45]	Water Consumption	Impact in consuming water	Total water consumed	Forest land
[4,38,39,44,45]	Material Consumption	Impact in consuming materials that serve the purpose to keep the building functional	The sum of all materials used for cleaning and maintenance	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[4,38,39,44,45]	Food and Drink	Impact in consuming food and drinks	The sum of all drinks and food consumed	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[4,39,44,45]	Mobility	Impact in travelling to the building from/to other destinations	The transport used to go to the building	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[4,39,45]	Waste Generation	Impact in generating solid waste produced by human activity within the building	The sum of all solid waste	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[45]	Recycling Potential	Benefit in recycling materials, food, drinks, water, and energy	The sum of all materials reused within the building	CO_2 sinks, forest land, fishing land, cropland, and pastureland
[37]	Occupant	Benefit in using the building simultaneously by several people	The number of hours spent in the building, and the number of users	CO_2 sinks, forest land, fishing land, cropland, and pastureland

Table 4. Equivalence factors, 2019 [31].

Equivalent Productive Land	Equivalence Factor (EQF) [gha/ha]
Built-up land	3.51
Forest land	1.26
Fishing land	0.37
Pastureland	0.46
Cropland	2.51

For the sake of simplicity, our model considers only fuel emission, which is an approximation for all CO_2 emissions. The absorption factor depends on the average carbon sequestration of ocean and land, as shown in Table 5.

Table 5. Absorption factors for CO_2 sinks conversion [34,50–52].

Component	Average Carbon Sequestration [t/tCO_2 year]	Total Hectares	Absorption Factor Components [tCO_2/ha]
Ocean	7×10^9 [52]	3.6×10^9 [53]	1.94
Forest	1.04×10^8 [51]	39×10^6 [51]	2.68
Cropland	8.4×10^6 [54]	40×10^6 [53]	4.76
Pastureland	11×10^6 [54]	11×10^6 [53]	1.76

To estimate the EQF for CO_2 sink, it is necessary to divide the EQF (Table 4) for each component (ocean, forest, cropland and pastureland) by the absorption factor components (Table 5), as shown in the following Table 6.

Table 6. Equivalence factors (EQF) for CO_2 sinks conversion [34,50–52].

Component	Correspondent EQF [gha/ha]	Absorption Factor Components [tCO_2/ha]	CO_2 Sink Factors [gha/tCO_2]
Ocean	0.37	1.94	0.19
Forest	1.26	2.68	0.47
Cropland	2.51	4.76	0.52
Pastureland	0.46	1.76	0.26

Then, forest, cropland and pastureland need to be combined to estimate the CO_2 sink factor for land. We applied the average, according to the following formula:

$$\text{CO}_2 \text{ sink factor for land } = \frac{(0.47 + 0.52 + 0.26)}{3} = 0.42\frac{gha}{tCO_2}, \quad (1)$$

Finally, as ocean absorbs 30% of the emissions and land 70%, we combined the two components, according to the following formula:

$$\text{CO}_2 \text{ sink factor } = (0.19 * 0.3 + 0.42 * 0.7) = 0.35\,\frac{gha}{tCO_2}, \quad (2)$$

4.3. Integrated Ecological Footprint Assessment Addenda

The proposed model develops an algebraic sum of the nine IEFA addenda. Each of the IEFA addenda needs to be previously calculated separately, which is possible by recurring to the formulas reported below. In addition to impact sources, and EQF, emission factors must also be used. Emission factors are coefficients able to convert the consumed material into tons of CO_2. We have used emission factors available online at the EU commission [53].

1. Built-up (BU) [33,38,45]:

$$\text{BU} = \text{total building surface area}\left(\frac{ha}{year}\right) \times \text{EQF of built up}\left(\frac{gha}{ha}\right) \quad (3)$$

2. Energy Consumption (EC) [4,38,39,44,45]:

$$\text{EC = Fuel Consumption EF + Electricity Consumption EF}, \quad (4)$$

$$\text{Fuel Consumption}\left(\frac{gha}{year}\right) = \text{Fuel Consumption}\left(\frac{GJ}{year}\right) \times \text{Emission factor}_{\text{fuel}}\left(\frac{tCO_2}{GJ}\right) \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (5)$$

$$\text{Electricity Consumption}\left(\frac{gha}{year}\right) = \text{Electricity Consumption}\left(\frac{kWh}{year}\right) \times \text{Emission factor}_{\text{electricity}}\left(\frac{tCO_2}{kWh}\right) \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (6)$$

3. Water Consumption (WC) [4,38,44,45,53]:

$$\text{WC}\left(\frac{gha}{year}\right) = \text{Water Consumption}\left(\frac{m^3}{year}\right) \times \text{Emission factor}_{\text{water}}\left(\frac{tCO_2}{m^3}\right) \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (7)$$

4. Material Consumption (MC) [4,38,39,44,45]:

$$\text{MC}\left(\frac{gha}{year}\right) = \text{Hour per use of material } i\left(\frac{h}{year}\right) \times \text{Emission factor}_{\text{material}}\left(\frac{tCO_2}{h}\right) \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (8)$$

5. Food and Drink (FD) [4,38,39,44,45]:

$$\text{FD}\left(\frac{gha}{year}\right) = \Sigma\ (\text{Energy land for item } i\left(\frac{gha}{t}\right) \times \text{total amount of item } i \text{ delivered in 1 year}\left(\frac{t}{year}\right)), \quad (9)$$

$$Energylandforitemi\left(\frac{gha}{t}\right) = \frac{associatedtotheembodiedenergy(tCO_2)}{tons(t)} \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (10)$$

6. Mobility (M) [4,39,44,45]:

$$\text{M}\left(\frac{gha}{year}\right) = \frac{Numberofpeople(unit)*Distance(km)}{Maximumcapacityofthetransport(unit)} \times \text{Average fuel efficiency}\left(\frac{t}{km}\right) \times \text{Emission factor}_{\text{ fuel}}\left(\frac{\frac{tCO_2}{t}}{year}\right) \times \text{CO}_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (11)$$

7. Waste Generation (WG) [4,39,45]:

$$WG\left(\frac{gha}{year}\right) = \text{Tons of waste } (t) \times \text{Emission factor}_{material}\left(\frac{tCO_2}{t}\right) \times CO_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (12)$$

8. Recycling Potential (RP) [45]:

$$RP\left(\frac{gha}{year}\right) = \text{Tons of reused materials } (t) \times \text{Emission factor}_{material}\left(\frac{tCO_2}{t}\right) \times CO_2 \text{ sink factor}\left(\frac{gha}{tCO_2}\right), \quad (13)$$

9. Occupant (O) [37]:

$$O\left(\frac{gha}{year}\right) = \text{Influence factor} \times (BU + EC + WC)\left(\frac{gha}{year}\right), \quad (14)$$

$$\text{Influence factor} = \frac{Spenthoursinthebuilding(h)}{Hoursinayear(h)}$$

BU, EC, WC, MC, FD, M, and WG are added together as they represent consumed resources, while RP and O are subtracted to the others. RP represents the amount of material reuse in the built environment. For example, if the building has a photovoltaic plant, the amount of electricity produced by the plant, which is a consumption, will be subtracted, as it has been produced within the building, and it has no impact on the environment. O represents the benefit of the simultaneous occupation of the building by multiple users. This is why it influences all those impact sources deriving from the consumption of resources related to the built environment: built-up, energy consumption, and water consumption. Of course, the greater the agglomeration of people, the greater impact on the environment. In fact, more people generate more waste and produce more carbon emissions. However, all emissions and consumptions are already considered in the calculation of IEFA thanks to the other addends. O serves the purpose of showing how the simultaneous use of some resources, if shared among numerous people, can be less impactful on the environment. This addendum assumes that when the light is on in a room and more people are present at the same time, electricity consumption must be divided between them and, therefore, globally it will have a lower weight because it is spent in a more efficient way and it avoids electricity consumption by the same people somewhere else in the world.

The overall IEFA result will be equal to the sum of all the above-mentioned components, as schematized in Figure 2:

$$IEFA = (3) + (4) + (7) + (8) + (9) + (11) + (12) - (13) - (14), \quad (15)$$

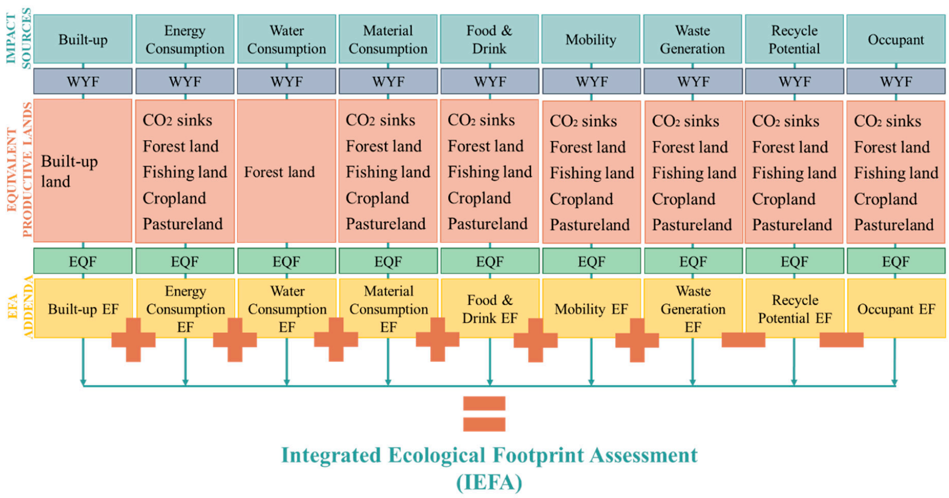

Figure 2. Integrated ecological footprint assessment (IEFA)—flowchart.

After defining the model and describing its theoretical implementation, we tested its applicability on an experimental case.

5. Application on a Case Study

The IEFA model was applied on the administrative headquarters of a multi-utility company located in the city center of Milan, Italy. The building was built in the early 1900's. It consists of a single C-shaped structure of five floors, with a gross external area of 4803 m^2. It hosts approximately 800 people, including visitors and workers.

To apply the formula described in the previous section, the facility management and human resources department collaborated with the researchers in data gathering. Data was collected through different sources, as summarized in Table 6. We were able to define all the impact sources, even though data was available from different years, between 2015 and 2018. The only addenda that was not possible to calculate is recycle potential EF, because the building does not present any systems for recycling or energy production.

Considering the feeding modalities of the building's plants, EF results from the combination of two factors, fuel consumption and electricity consumption. The only fuel used by the building's heating system is methane. Therefore, fuel declared in the consumption bills (13,279 m^3) was converted into kg, through methane density (0.656 kg/m^3) [53,55]. This result was converted into MJ through the energy density factor of 55.65 MJ/kg [55]. Electricity consumption is estimated using the emission factor of electricity of Italy, defined by EU commission, equal to 0.000343 tCO_2/MWh [56].

WC results as the combination of company's utility bills (9981 m^3), the energy intensity of drinking water, 0.78 kWh/m^3 [57], and the emission factor of electricity [56].

As the company has not developed a detailed maintenance program, but only a supply contract for out-of-service item replacements, MC is estimated according to the works that maintenance operators have concluded in a year of activity. A more detailed analysis has been possible for cleaning activities. A cleaning trolley has been defined through the data given by the company. Each product has been associated to the hours of use and the frequency in a year has been defined through company's data. After adding up the amount of materials used, we translate them into $kgCO_2$ through the embodied energy [39,58].

M is estimated by combining the distance from home of every worker, and which means of transport is used to reach the building. These data come from a survey of the company itself. For every means of transportation (car, bus, train, subway, tram, trolleybus, bicycle, foot, and motorbike), by using the index of conversion [59], expressed in $kgCO_2/Km$, we defined the footprint. Finally, we added all the results together for estimating the overall M.

As there were only food and drink vending machines in the building, we estimated FD through embodied energy (MJ/t) and CO_2 factors (tCO_2/t) [36,39] of the snacks and beverages sold. Then, we added everything together to evaluate the FD.

WG was the result of a month monitoring of the amount of rubbish produced by the workers. As it is an office building, three main types of waste were detected: plastic, paper, and unsorted waste (e.g., organic, wood of furniture, foam rubber, etc.). Through the density [60] of each component, and the waste emission factor of Italy [61], we estimated the WGEF.

O is estimated through the number of hours the building's users spend in the building. This data has been collected through the access system to the headquarters. Taking into consideration the total hours in a year, equal to 8760 h, we calculated the influence coefficient, which represents the percentage of time in a year the building is used. Finally, we applied Formula (14).

Based on the above-mentioned input data and formula, our calculations (see Appendix A) show that the overall IEFA for the company's headquarter sums up to 685.19 gha/year, as presented in Table 7.

Table 7. Source of data of case study.

Ecological Footprint Assessment Addenda	Source (see Appendix A for Details)	Impact Sources	Year	Resulting EF [gha/year]
BU	Drawings—plans	1.5975 ha	2018	4.01
EC	Electricity bills Fuel bills	2,658,830 KWh/year 13,279 m^3/year	2018	328.91
WC	Water bill	9981 m^3/year	2018	0.93
MC	Facility management bills and contracts	0.376 tCO_2/year	2015	0.13
FD	Contract with vending machine providers	65.69 t/year	2017	138.56
M	Employees' survey	People: 18 by car 108 by bus 262 by train 149 by subway 82 by tram 24 by motorbike 10 by trolleybus 15 by bicycle 1 on foot	2018	7.72
WG	1 month of monitoring by data collection	2 486.72 t/year	2019	224.55
RP	N.A.	N.A.	N.A.	0.00
O	Access monitoring through badge swipes	2 040 h/year	2019	0.93
TOTAL				**685.19**

Looking at the EF breakdown, the IEFA is, for the most part, caused by electricity consumption ecological footprint (EC), waste generation ecological footprint (WG), and food and drink ecological footprint (FD). EC affects the result by 39.07%, WG by 26.67%, and FD by 16.46% the total IEAF, as shown in Figure 3.

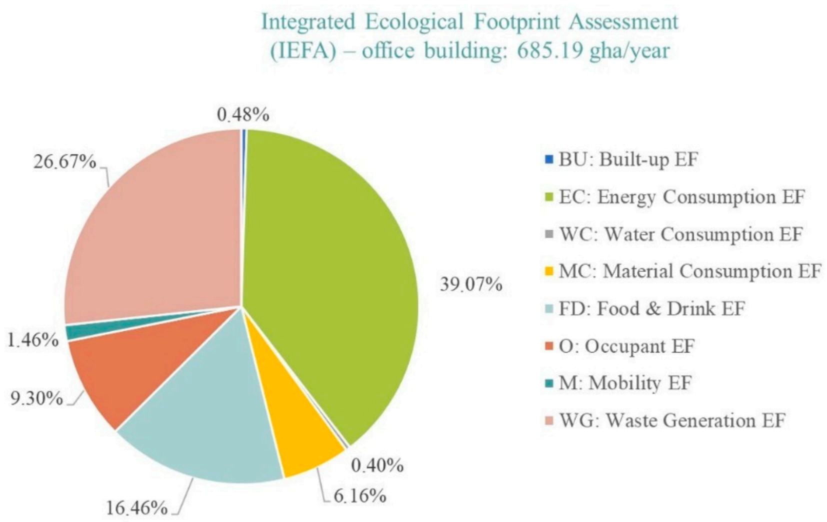

Figure 3. Influence of ecological footprint assessment addenda on the total for the analyzed building.

Due to the lack of similar applications, this result of IEFA for the analyzed office building cannot be compared nor interpreted through a benchmarking study. However, to grasp the magnitude of this company's footprint, one can compare the result of 685.19 gha/year to the area of a football field (which is equal to 0.7 ha). Thus, the case building needs 979 football fields to cover its demand in a year.

6. Discussion

The proposed IEFA model intended to assess the environmental efficiency of buildings through a synthetic indicator that depicts the buildings' demand for resources on Earth. IEFA evaluates the buildings' impact in the in-use phase of the BLC by looking at the influence of people behaviors and simultaneous occupancy. The model design has been inspired by Wackernagel and Rees [26], and Brownell [37] for the development of occupant impact source; and by Husain and Prakas [45] for the combination of the BLC with LCA. IEFA advances these pre-existing models by applying EF to the building in-use phase, proposing a calculation for Brownell's theoretical proposition, and using all the impact sources.

The nine Impact sources estimated in IEFA consider the consumption of resources (energy consumption EF, water consumption EF, food and drink EF, material consumption EF), the generation of waste (waste generation EF), the impact of travelling (mobility EF), the recycling potential (recycle potential EF), and the efficiency in consuming the same resource among multiple users (occupant EF).

To evaluate the accuracy IEFA, ideally it would be appropriate to apply it simultaneously with another standard, and then to look at the misalignments between the two indexes to check whether EF over- or under-performs. However, to the knowledge of the authors, no previous studies have applied EF together with other sustainability metrics. Therefore, the final result of IEFA, calculated for the administrative headquarters of an Italian company, was compared with the five studies [4,38,39,44,45] that informed the development of the model, as shown in Table 8.

Table 8. IEFA compared with six previous studies.

	Comparison	Type of Building	BLC Stage	Surface [m^2]	Users	Total EF [gha/year]	EF/User
	IEFA	Office Building	In-Use	4803	800	678.79	0.85
[39]	Acosta and More	School	In-use	378,539	32,479	16,590	0.51
[44]	Gottlieb et al.	School	In-use	19,600	1520	314	0.21
[4]	Solìs-Guzman et al.	Residential building	Construction	10,243	N.A.	2694	N.A.
[38]	Martìnez-Rocamora et al.	School	In-use	7187	139	67	0.48
[45]	Husain and Prakas	School	All	35,000	1480	4426	2.99

The IEFA applied to the case building resulted in 0.85 gha/person. This value resembles the same order of magnitude of previous studies, thus can be considered valid. Overall, it is slightly higher that the average values reported in most of the other references [38,39,44], which makes sense as IEFA considers nine impact sources, while the other sources included only five [38], seven [39], and just four [44] sources, respectively. In addition, IEFA considers all the food and drinks consumed and the materials used, while previous studies calculated just the food component and some materials (e.g., plastic, paper, and cans [44]). Only Husain and Prakas's [46] calculation results higher, even if it is still in a similar order of magnitude, because they have calculated the EF for a school related to all the stages of the BLC.

Despite limited possibility for comparing the proposed model with similar metrics and cases, it is worth highlighting its benefits compared to existing approaches and carbon metrics.

First, IEFA defines an organic system that integrates existing methods, and it bases the calculations on general parameters, shared worldwide. This overcomes the limit of the green certifications, which are relative models, developed on different building standards [38].

Second, EF does not produce a relative result, such as stars or percentage, but a simple and intuitive unit of measurement, global hectares (gha), which makes comparisons easy even for buildings located in different countries. In addition, this scientific result can be understood not only by the evaluators, but also by building managers, owners, and end users [36].

Third, the model proposes a systematic organization of IEFA addenda, which is useful for implementing calculations based on the "composition" approach, and for understanding where the main impacts are caused. Comparing the IEFA addenda allows to identify which factors most significantly affect EF and makes it possible to create strategies and to implement solutions for performance improvement. This partially prevents the proposed EF metric from being distorted or abused by building owners and policy makers. For example, it allows to detect if decision makers decide to reduce a large footprint only by decreasing water consumption but not energy demand or carbon emissions. This should theoretically discourage misleading strategies only aimed at gaining popularity and large agreement among the public. Moreover, gha express an intuitive quantity, which would enable the public to undertake a control function on environmental sustainability trends.

Fourth, IEFA assesses, through O, FD, MC and M, buildings' environmental impacts by considering users' behavior, which none of the previous studies have incorporated. In particular, the model includes the user variable by considering the number of people who occupy the building. This responds to the lack of applications considering the intensity of space utilization as a positive element in EF calculation. Even though O does not seem impactful in our analysis, it is worth noting that the more people are using the space, the smaller impact they are causing.

In practical terms, the IEFA model herewith proposed promises to be useful for a range of professionals, from executives to facility managers, but also for the end users of buildings. Facility managers can evaluate a building's performance over time, with the benefit of recognizing what factors are more impactful on biocapacity and require intervention. Executives can take advantage of this information when they aim at implementing strategies to reduce building consumption, waste, and pollution generation. Possible strategies span from technical/operative solutions to soft interventions on people's behavior and attitudes through policies or guidelines.

Taking this case study as an example, improving the electric plants and building envelop could potentially lead to reducing electricity consumption. At the same time, an organizational culture emphasizing the benefits of sustainability could lead to more responsible consumption. The EF, in fact, also depends on when the consumption takes place. For example, on a solar-rich grid, the EF of a building whose peak demand is in the middle of the day would be substantially different from one whose demand is relatively flat or peaks at night. This is coherent with the theory that building users contribute substantially. Users could alter the emission factor of a building, just by modifying their consumption habits and use practices. EF is meant to raise evidence of how even unconscious demand shifting would affect buildings' sustainability, thus it will support more conscious demand management and perhaps the implementation of automated systems to regulate energy demand (e.g., sensors for artificial lighting management, elevator activation, etc.). In the future, culture will be key to especially affect electricity consumption, food and drink consumption and waste generation. As FD in our company was mainly affected by hot beverages consumption, which amounts to 90% of the overall FD (Appendix A), some "coffee free" days could be introduced by company policies. In addition, providing the employees with their own mugs would allow for reducing waste production. Every coffee purchased from a vending machine corresponds to a plastic glass that affects WG, so reducing the use of single-use cups would influence the EF factor positively too.

7. Conclusions

Considering that people in the western world spend most of their time indoors it is important to implement indicators showing to what extent people's behavior can affect building's impact on the planet.

The calculation of greenhouse gas (GHG) emissions and lifetime energy, which are the most common indicators of the impact of man-made environments on natural environments, are very abstract and would benefit from being combined with a range of other measures that can support mitigation actions [4,38,44]. While multiple green certifications exist, there is the need to homogenize a wide range of different criteria and dimensions of buildings' sustainability. In this paper we proposed a first exploration of the potential of EF as a simple indicator of building's sustainability (i.e., IEFA). IEFA addresses current EF limitations by:

1. Evaluating buildings' environmental impact within the in-use phase of the BLC;
2. Revealing the environmental efficiency of buildings by looking at people occupancy;
3. Integrating all the impact sources used in previous studies;
4. Combining the "comprehensive method" and the "component method".

The application of a case study made it clear that users play a key role in the reduction of environmental impacts in the in-use stage. The extent to which they can contribute to EF depends not only on the activities that are undertaken in a building (e.g., office building), but also on their behaviors. Habits in waste generation and food and drink consumption were particularly impactful on IEFA in the case study.

Our experimental application shows that IEFA can provide important evidence to inform guidelines aimed at improving buildings' sustainability in the in-use phase. Focusing on the in-use stage might highlight that a low energy building can be energy inefficient in the provision of services, such as food and beverage.

IEFA provides a measure that represents over-consumption and can encourage a more sustainable culture. Gha makes the model potentially comparable to the hectares of production and waste assimilation by city or region, so that these benchmarks could set an overall budget or target of sustainable consumption by specific territorial areas. For instance, in 2012 there were approximately 12.2 billion global hectares of production and waste assimilation on Earth, while consumption totaled 20.1 billion global hectares, meaning about 65% more was consumed than produced [31]. How would this translate at scale for a city as Milan or for the Lombardy region? Some more research would be necessary to translate this approach down to the neighborhood, city, or regional level.

Still the proposed model presents multiple limitations that might hinder its implementation and expansion. These limitations have mainly to do with: (i) data provision; (ii) absence of benchmarks; and (iii) lack of standards for calculation. Inventory quality is a major element for the consistency of results related to IEFA. Generally speaking, a harmonization approach should be performed in future implementations of the model, as in the LCA harmonization by Heath and Mann [61]. A similar approach could be used also to develop a meta-analytical procedure, based on several EF approaches, which simplifies the direct comparison of results. Our test uses data from surveys, and measurements done by the company in different years; however, data should be gathered on only one year of analysis and should be consistent for all data sources. Second, the absence of benchmarks makes comparisons impossible. In future applications, a cross-company analysis should be developed. Third, the absence of calculation standards might have generated errors and imprecisions. Major difficulties have been encountered when avoiding double counting. For example, the embodied factor needed for calculating food and drinks EF (Appendix A) takes the wasted packaging into account already. Therefore, this waste should not be included in waste generation EF. At the current time, a system for helping building managers, or whoever performs the calculations in this kind of accounting, does not exist. In addition, in the proposed model, a weighting system of addenda has been neglected. In future applications, a system to understand which addendum is most important due to its impact on Earth would be beneficial. These limits can be partially solved by implementing technology (i.e., installing sensors). A real time estimation of IEFA will improve the effectiveness of building management.

Finally, even though we contend that EF is a more easily understandable metric than green rating systems, a survey could be submitted to verify whether this has a beneficial effect on people's responsibility toward the environment. Future implementations must look at how different sustainability metrics impact, or not, human behavior. Theoretical frameworks could be developed by elaborating on Daniel Kahneman's [62] works on the psychology of choice for appraising how we might expect the EF metric to over- or under-perform other metrics. A crucial question yet to be answered is: do gha, number of Earths or football fields induce people to implement sustainable policies and adopt sustainable behaviors more effectively than other carbon metrics or energy consumption measures?

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Built-Up Ecological Footprint		
Company data	**EQF**	**Result [gha/year]**
SQM: 1.6 ha	2.51	4.01

Energy Consumption Ecological Footprint			
Fuel Consumption—Methane			
Company Data	**Conversion Data [53]**	**EQF**	**Result [gha/year]**
13,279 m^3/year	Density of methane: 0.656 kg/m^3	0.35	971
Electricity Consumption			
Company data	**Conversion Data [55,56]**	**EQF**	**Result [gha/year]**
2,658,830 KWh/year	Emission factor of electricity: 0.000343 tCO_2/KWh	0.35	319.19
TOTAL Energy Consumption Ecological Footprint			328.91

Water Consumption Ecological Footprint			
Company data	**Conversion Data [56,57]**	**EQF**	**Result [gha/year]**
9981 m^3/year	Energy Intensity of drinking water: 0.78 KWh/m^3 Emission factor of electricity: 0.000343 tCO_2/KWh	1.26	3.36

			Material Consumption Ecological Footprint			
			Cleaning			
Product—Company Data	**$kgCO_2/kg$**	**kg/y**	**$kgCO_2$/year [39,58]**	**tCO_2/year [39,58]**	**gha/tCO_2**	**MCcleaning [gha/year]**
Cleaning trolley	2.858	2.8	8.0024	0.008002	0.35	0.00280084
Wide mop	8.909	11.977	106.703093	0.106703	0.35	0.037346083
Dust cloth (3)	9.601	0.701	6.730301	0.00673	0.35	0.002355605
Buckets (2)	2.858	0.35	1.0003	0.001	0.35	0.000350105
Mop or broom sticks (4)	7.247	1.968	14.262096	0.014262	0.35	0.004991734
Mops	8.909	5.301	47.226609	0.047227	0.35	0.016529313
Broom	7.754	0.9	6.9786	0.006979	0.35	0.00244251
Dustpan	2.858	0.135	0.38583	0.000386	0.35	0.000135041
Large garbage—bag	2.096	2.5	5.24	0.00524	0.35	0.001834
Trash bags	2.096	16.667	34.934032	0.034934	0.35	0.012226911
Wiper blade	7.446	0.106	0.789276	0.000789	0.35	0.000276247
Wiper blade runner	2.394	0.28	0.67032	0.00067	0.35	0.000234612
Wiper tool	2.858	0.06	0.17148	0.000171	0.35	0.000060018
Wiper tool fleece	8.909	0.05	0.44545	0.000445	0.35	0.000155908
Disposable gloves	2.096	1.25	2.62	0.00262	0.35	0.000917
Paper hand towel roll (120 m)	0.675	23.262	15.70185	0.015702	0.35	0.005495648
Ostrich feather duster	2.858	0.22	0.62876	0.000629	0.35	0.000220066
Antistatic duster	2.858	0.46	1.31468	0.001315	0.35	0.000460138
Bleach (5 L)	0.374	116.279	43.488346	0.043488	0.35	0.015220921
Neutral cleaner (1.5 L)	0.374	34.884	13.046616	0.013047	0.35	0.004566316
Bath descaler (750 mL)	0.374	3	1.122	0.001122	0.35	0.0003927
Floor cleaner (1 L)	0.374	45.455	17.00017	0.017	0.35	0.00595006
Furniture cleaner spray (450 mL)	0.374	2.695	1.00793	0.001008	0.35	0.000352776
Mop cleaner spray	0.374	3	1.122	0.001122	0.35	0.0003927
Soapy cleaner (1 L)	0.374	5.988	2.239512	0.00224	0.35	0.000783829
Glass cleaner (750 mL)	0.374	9.036	3.379464	0.003379	0.35	0.001182812
Ink remover (750 mL)	0.374	17.442	6.523308	0.006523	0.35	0.002283158
Liquid soap refill (5 L)	0.374	76.923	28.769202	0.028769	0.35	0.010069221
Air freshener	0.374	12.048	4.505952	0.004506	0.35	0.001577083
			TOTAL			0.131603352
			Maintenance: Cleaning			
Product—Company Data	**$kgCO_2/kg$**	**kg/y**	**$kgCO_2$/year [39,58]**	**tCO_2/year [39,58]**	**gha/tCO_2**	**MC [gha/year]**
Cleaning trolley	2.858	2.8	8.0024	0.0080024	0.35	0.00560168
Trash bags	2.096	16.667	34,934032	0.034934032	0.35	0.024453822
Wiper blade	7.446	0.106	0,789276	0.000789276	0.35	0.000552493
Wiper blade runner	2.394	0.28	0,67032	0.00067032	0.35	0.000469224
Wiper tool	2.585	0.06	0.17148	0.00017148	0.35	0.000120036
Wiper tool fleece	8.909	0.05	0.44545	0.00044545	0.35	0.000311815
Disposable gloves	2.096	1.25	2.62	0.00262	0.35	0.001834
Machinery fat	0.743	76.923	57.153789	0.057153789	0.35	0.040007652
			TOTAL			0.073350723

Maintenance: Repair					
Product—Company Data	**Time/Year**	**Tons of Components**	**tCO_2/year [39,58]**	**gha/tCO_2**	**MC [gha/year]**
Light bulbs	200	420	0.258	0.35	37.926
Electrical cables	290	98.86	0.258	0.35	8.565858
Bolts	300	42.64	0.258	0.35	3.850392
Water tubes	5	14.53	0.258	0.35	1.312059
TOTAL					51.654309
TOTAL Material Consumption Ecological Footprint					51.85

Food and Drink Ecological Footprint					
Product—Company Data	**Embodied Energy MJ/t [39,58]**	**Emission Factor [39,58]**	**gha/tCO_2**	**t/year**	**FD [gha/year]**
Mineral water	7.77	0.83	0.35	21.77	6.324185
Fruit juices	32.21	2.43	0.35	1.24	1.05462
Cold drink (like tea)	55.16	6.01	0.35	2.332	4.905362
Taralli (bread)	14.05	1.49	0.35	0.311	0.1621865
Chips	39.44	3.72	0.35	0.116	0.151032
Biscuits	26.35	2.72	0.35	0.276	0.262752
Chocolate confectionery	36.05	11.73	0.35	0.097	0.3982335
Non-chocolate confectionery	38.06	4.64	0.35	0.136	0.220864
Tea	55.16	6.01	0.35	12.996	27.337086
Coffee	128.92	13.62	0.35	12.996	61.951932
Drinking chocolate	60.51	7.31	0.35	12.996	33.250266
Ice-cream	38.15	7.26	0.35	0.428	2.541
TOTAL					138.55951

Mobility Ecological Footprint								
Mobility Ecological Footprint—From Milan								
Way of Transport	**N° People**	**N° of Working Day/Year**	**Average Distance**	**Max Transp. Capacity**	**EFF [59]**	**Index of Conversion [L/km] [59]**	**gha/tCO_2**	**M [gha/year]**
Car	2	240	5	1	0.0024	0.0659	0.35	0.1328544
Bus	98	240	5	95	0.0025	0.0614	0.35	0.066506
Train	0	240	5	450	0.000343	3	0.35	0
Subway	115	240	5	1,200	0.000343	3	0.35	0.041417
Tram	82	240	5	262	0.000343	3	0.35	0.135262
Trolleybus	10	240	5	166	0.000343	5	0.35	0.0433916
Bicycle	15	240	5	1	3×10^{-10}	144	0.35	0.0002722
Foot	1	240	5	1	3×10^{-10}	90	0.35	0.0000113
Motorbike	11	240	5	1	0.0024	0.05	0.35	0.5544
							TOTAL	0.974115

Mobility Ecological Footprint—From the Province of Milan								
Way of Transport	**N° People**	**N° of Working Day/Year**	**Average Distance**	**Max Transp. Capacity**	**EFF [59]**	**Index of Conversion [L/km] [59]**	**gha/tCO_2**	**M [gha/year]**
Car	8	240	20	1	0.0024	0.0659	0.35	2.1256704
Bus	10	240	20	95	0.0025	0.0614	0.35	0.027145263
Train	102	240	20	450	0.000343	3	0.35	3.918432
Subway	34	240	20	1 200	0.000343	3	0.35	0.0489804
Tram	0	240	20	262	0.000343	3	0.35	0
Trolleybus	0	240	20	166	0.000343	5	0.35	0
Bicycle	0	240	20	1	3×10^{-10}	144	0.35	0
Foot	0	240	20	1	3×10^{-10}	90	0.35	0
Motorbike	12	240	20	1	0.0024	0.05	0.35	2.4192
							TOTAL	8.539428

Mobility Ecological Footprint—From the Lombardian Region								
Way of Transport	**N° People**	**N° of Working Day/Year**	**Average Distance**	**Max Transp. Capacity**	**EFF [59]**	**Index of Conversion [L/km] [59]**	**gha/tCO_2**	**M [gha/year]**
Car	8	240	20	1	0.0024	0.0659	0.35	2.1256704
Bus	0	240	20	95	0.0025	0.0614	0.35	0
Train	160	240	20	450	0.000343	3	0.35	0.614656
Subway	0	240	20	1 200	0.000343	3	0.35	0
Tram	0	240	20	262	0.000343	3	0.35	0
Trolleybus	0	240	20	166	0.000343	5	0.35	0
Bicycle	0	240	20	1	3×10^{-10}	144	0.35	0
Foot	0	240	20	1	3×10^{-10}	90	0.35	0
Motorbike	0	240	20	1	0.0024	0.05	0.35	0
							TOTAL	2.740326
TOTAL Mobility Ecological Footprint								12.25387

Waste Generation Ecological Footprint			
Company Data	**Conversion Data [60,61]**	**EQF**	**WG [gha/year]**
2 486.72	0.258 tCO_2/t	0.35	224.551

Occupancy Ecological Footprint			
Company Data	**Influence Index**	**BU + EC + WC**	**O [gha/year]**
2 040 h/year	0.23	336.28	224.551

TOTAL IEFA for the administrative headquarters, BU + EC + WC + MC + FD + M +WG − O = 685.19 gha/year.

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