

Influence of energy mix on the life cycle of an eco-neighborhood, a case study of 150 countries



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ABSTRACT

In recent years, the destruction of the ecosystem, due to the strong emission of greenhouse gas into the atmosphere by humans has led to significant damage to wildlife, human health, and flora. This has significantly changed the human life cycle. Nowadays, the environmental damage costs are applied for the countries strongly impacting pollutant emission. To this end, developing countries receive annual compensation from the countries considered to be the most polluting. So far, decision-makers seem to be unaware that, at the scale of an eco-neighborhood, some emerging countries produce also a significant amount of CO₂. The main purpose of this research is to quantify and to compare the effect of the energy mix of 150 countries on three environmental impacts generated by an eco-neighborhood: greenhouse effect, energy demand, and biodiversity damage. To perform this comparison, the same neighborhood design is applied to 150 countries, but four parameters are adapted to each country: energy mix, local climate, building materials, and occupants' mobility. In addition, this research evaluates the induced environmental costs of the neighborhood over a life cycle of 100 years and examines the impact of mobility and photovoltaic panel on these environmental costs. The different environmental impacts were evaluated by the Pleiades ACV simulation software under four phases (construction, use, renovation, and demolition), before being translated into environmental costs. Among the four local parameters (energy mix, local materials, climate, and transport), the energy mix has the most significant effect on the three studied environmental impacts. The results show that the countries having a higher concentration of renewable energy sources produce lower CO₂ than others. Domestic and material wastes are also one of the main sources of greenhouse gas emissions and biodiversity damage in a sustainable neighborhood. The biodiversity damage is high in Sub-Sahara Africa, and MiddleEast, but low in the USA, Brazil, European Union, Russia, and Australia. The implementation of photovoltaic panels in a sustainable neighborhood mitigates, on average, 15.9% of carbon dioxide emissions and 21.2% of primary energy demand; but, unfortunately, this solution increases up to 25.0% the biodiversity damage.

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1. Introduction

The greenhouse effect is considered a natural phenomenon causing a rise in the temperature on the surface of our planet. Human activities affect the chemical composition of the atmosphere and lead to the emergence of an additional greenhouse effect, largely responsible for the current climate change [1]. According to the Intergovernmental Panel on Climate Change

(IPCC), two-third of the energy from the sun is absorbed by the atmosphere, the soil, and the ocean. The remaining third is directly reflected back to space by clouds, aerosols, the atmosphere, and the earth's surface [2]. Human activities have a direct implication on energy demand and the degradation of biodiversity. Energy consumption in the building sector is an important part of global energy consumption [3]. In fact, buildings consume almost 40% of all energy and contribute to almost 30% of annual global greenhouse gas emissions [4]. Observing, the massive growth of new constructions in economies in transition, some researchers have shown that if nothing is done, greenhouse gas emissions from buildings will be more than double over the next few decades [5]. The energy

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consumed during the life cycle of a building can be divided into operational energy, intrinsic energy, and decommissioning energy [6]. Each phase of the life cycle of a building affects the environment and must be studied to produce a high-performance, energy-efficient building [6]. The urban mobility of occupants has an important influence on onCO₂ emission and energy demand in the neighborhoods. Encouraging the displacement of the population with public transports, such as bus and train, could help to reduce significantly these emissions [7]. Designing energy-efficient buildings are first and foremost about reducing energy requirements to a minimum, without compromising comfort. To do this, the implementation of passive strategies can be a solution [8,9].

Environmental risk assessment is central to maintaining the life cycle of humankind. The decline of biodiversity is a global concern that needs to be addressed urgently. Globally, several scientists explained that the world's biodiversity is suffering from alarming damages. These ones are the result of growing human pressure on land use, agriculture, urbanization, tourism, forestry, etc. [10–12].

Since the 1970s, a general awareness has emerged of environmental problems. At the neighborhood scale, the Life Cycle Assessment (LCA) method is part of clearly validated scientific methods. LCA of buildings is even standardized at the European level. It is currently the only scientifically sound approach to carry out an environmental assessment at the neighborhood scale. It allows a quantitative study of the environmental impacts of constructions over the whole of their life cycle [13].

Buyle et al. [11] explained that impact assessment is the quantification of environmental effects, based on the inventory. Three steps are necessary: the selection of impact categories according to the purpose of the study, aggregation of the results of the impact category inventory, and the calculation of the indicators corresponding to each impact category. Colombert et al. [14] showed that the urban population is becoming aware of the need to preserve biodiversity and green spaces. Olivier-Solà et al. [15] found that it is highly likely that the environmental and energy issues we are currently dealing with at the building level will soon be transferred to the urban scale. Lotteau et al. [16] explained that the neighborhood life cycle analysis is complex, multifunctional, and changing and that its life is long. These previous studies raise many new issues regarding how to apply the LCA method at the neighborhood scale, especially regarding the definition of the functional unit or the consideration of temporal aspects. Moreover, no standard dictates the procedure to follow at this scale. In 2006, Popovici [17] proposed a definition of the neighborhood according to three elements: buildings, public spaces, and networks, considering a life cycle from cradle to the end of life. Stephan et al. [18] demonstrate that energy use during the operational phase is the primary contribution to environmental impacts over the entire life cycle of a neighborhood. Indeed, it accounts for almost 40% of primary energy consumption (PEC) and more than 42% of greenhouse gas emissions (GHG). By comparing several urban developments of different densities, Norman et al. [19] conclude that mobility contributes much more significantly to total energy consumption and GHG emissions in a low-density urban development than in the case of dense development. By comparing four scenarios, based on different types of residential buildings, Trigaux et al. [20] showed that the contribution of road infrastructures accounts for 1%–6% of total impacts.

The different environmental impacts generated important costs each year. Environmental cost assessment methodologies allow quantifying them. Some of these methods were updated on the basis of the methodologies developed previously by Debacker et al. [21] and DeNocker et al. [22]. Niemelä et al. [23] showed that the optimization of heat pump systems greatly reduces the

environmental impact costs compared to the building envelope efficiency. The same result was found by Atmaca [24]. Moreover, several scientific papers have already proposed different methods of optimizing the Life Cycle Cost (LCC) to explore energy efficiency measures [25–28]. Tokarik and Richman [29] suggested that several optimization methods can be used to mitigate the LCC of a Toronto house up to 33%.

However, the results of all these studies strongly depended on climate. A lot of studies in the literature have already been focusing on life-cycle analysis at the building scale and very little at the neighborhood scale, focusing mainly on the analysis of only one environmental parameter or life cycle cost. Other studies focus solely on optimizing environmental impacts with the implementation of photovoltaic panels. More recent studies are rather oriented on the optimization of heating pumps. In addition, maintenance, demolition of residences, and recycling of materials are often neglected in LCA studies on the built environment. It is important to note that all of these studies mainly focus on the issues of one country/region. These studies have great local interest. However, it is time to scale up these studies and focus on the world scale. Problems related to climate change, greenhouse gas emissions, biodiversity degradation, and energy demand should be solved on an international scale. Every country should feel concerned and be aware of the extreme environmental damage, the necessity, and the urgency to find solutions. In this study, we pushed thinking further. There are a total of 12 types of environmental impacts for an LCA. This study focuses only on three factors of LCA (Energy, Carbon, and Biodiversity) because they are the most significant and the most well-known of the twelve.

The main purpose of this research is to quantify and to compare the impact of climate, energy mix, local building materials, installation of PV panels, and mobility behaviors on three environmental impacts including greenhouse gas effect, energy demand, and biodiversity damage generated by an eco-neighborhood over its life cycle in 150 countries. Unlike previous studies that only focused on a single life cycle stage (e.g., renovation or use), all four phases including construction, use, renovation, and demolition were considered in this study.

2. Research methodology

We carried out the environmental analysis of a sustainable neighborhood located in Belgium (Europe) over 100 years, and then, we adopted the same design in 149 other countries, while keeping four parameters specific to each country: energy mix, local climate, building materials, and occupants' mobility. In addition, we calculated the costs related to three environmental impacts: greenhouse effect, energy demand, and biodiversity degradation. Finally, we varied different design parameters to quantify their effects on the environmental costs of the neighborhood. Overall, this methodology is divided into five main sections (a) neighborhood selection and site modeling; (b) LCA of the selected neighborhood; (c) modeling the same neighborhood in 149 other countries with adaptation of the four local parameters and life cycle assessment; (d) calculation of the cost of the three studied environmental impacts; (e) applying one scenario for mitigating some environmental costs.

The following sections (2.1–2.6) will describe some methodological choices: the case study, the chosen countries and databases, the environmental database and the environmental indicators studied, the LCA simulation software used, the environmental cost calculation method, the improvement scenario tested.

2.1. Initial analysis of the eco-neighborhood

This neighborhood is initially located in the Liege city in Belgium, and the same design is adapted in 149 countries represented in the world. The Sart-Tilman eco-neighborhood in Liege is one of the privileged places of Belgium, where the concepts of a sustainable neighborhood have been applied. This eco-neighborhood offers different types of buildings (terraced and semi-detached houses, apartment buildings, etc.). A majority of the built surface is dedicated to housing, but we also find spaces dedicated to commercial functions or the liberal professions and small businesses. In total, we counted 40 small apartments, 45 larger homes, 11 single-family duplex homes, and 6 complementary functions (businesses and shops). Private parking spaces are planned near the buildings. All the dwellings located on the ground floor have a private garden. An aerial view of the studied neighborhood is showed in Fig. 1.

In this neighborhood, the buildings were designed with respect to the passive standard, which imposes very low energy consumption. Moreover, this new neighborhood meets almost all the criteria of a sustainable neighborhood, following the references published by the University of Liege and other international Organizations [30,31]. The site is strongly served by public transport linking it to the center of Liege, thanks to the proximity of the university. The neighborhood has a built density of 40 dwellings per hectare. Outdoor spaces are landscaped with more than 30% "green" or "blue" surfaces and separate water management for rainwater and wastewater. Rainwater recovery systems and tanks are also implemented.

In this research, only the neighborhood residential part was studied. The calculated environmental impacts correspond to the residential eco-district of 3.5ha comprising 1ha of roads, driveways and parking lots, 17800 m² of green space, 19740 m² of floor space, housing around 219 inhabitants, studied on a life cycle of 100 years. Given the construction standards in Belgium compared to those of other countries, it is clear that Belgian buildings would hardly exist in Asian cities, the Middle East, Africa, and South America. For this, firstly, we have made a sensitivity study. Thus, in this study, we take into account country-specific standards for the choice of local materials. In the literature, it is seen that the density of living space per person is very specific to each country, the inhabitants of Asian countries occupying very little space, and the inhabitants of North America and Australia occupying very large spaces per person. To remedy this problem, in this study, in the case of developed countries in Europe, North America, some Asian countries and



Fig. 1. The studied eco-neighborhood, near the University of Liege, in Belgium (See these videos: www.youtube.com/watch?v=FDzdAaMy_3Ywww.youtube.com/watch?time_continue=81&v=hdX2abFvebo).

Australia, we maintained 219 occupants in all the neighborhood, while in the case of others Asian country, Middle East, Africa, South America, we have fixed 438 (219x2) occupants (this technique allowed us to reduce the space occupied per person in these countries).

2.2. Design of the same eco-neighborhood in other countries

The same eco-neighborhood is built in 150 capitals located in 150 countries. The choice of the capital, for representing each country was not random; indeed, in most of these countries, the capital was considered as the most populated region of the country, with the highest pollution rate and energy consumption. This strong population concentration has a significant influence on all the environmental impacts.

We simultaneously applied four parameters for adapting this neighborhood in each country: the energy mix of each country, the local climate of each country, typical building materials used in each country, and occupants' mobility. Only the four parameters that influence building performance were selected because several studies have shown that these different parameters have a more significant impact on the different environmental impacts. In addition, it is practically impossible to consider all the parameters existing at the neighborhood level. An example of a case in five countries located in five continents is showed in Table 1.

The International Energy Agency (IEA) database [32] and the Energy Information System of each country were used to gather the information on the energy mix and electricity mix. On the Pleaides-ACV software, it was possible to freely select the different energy components mix (in %) or electricity mix (in %), such as nuclear, fuel, coal, gas, and renewable energy; then, assigning their corresponding values.

The information on the local climate of each country was evaluated with the most recent Meteonorm software version. Meteonorm is defined as a meteorological database with climatological data for every location on the globe [33]. The fixed database in Meteonorm 7.3.1 contains approximately 6200 cities, 8325 weather stations, and 1200 Design Reference Year sites.

The information on the construction materials was evaluated on the basis of 2018–2020 standard thermal regulation of each country, but also from information issue to the UN-habitat [65], and some literature reviews (for some African and Asian countries, without recent building standards). Regarding inhabitant mobility, the data was freely selected on Pleaides software [66]. These data are based on a different rate of occupants commuting daily: 80% in developed countries (USA, Japan, Germany, France, UK, etc.) and 50% in developing countries (Cameroon, Madagascar, Haiti, Thailand, etc.). The distance of the weekly commute between home and trade is 1000m; distance from the public transport network is 500m, distance from the daily commute to work is on average between 5000m and 10000m. Presence of bike path: yes; public transportation: bus, subway, and tram [66].

2.3. Environmental database and studied indicators

The environmental data used come from the ECOINVENT database developed by different research institutes based in Switzerland. These data include, for each process and material, a life cycle inventory that contains all material and energy flow into and out of the system [34]: (i) resources consumed (water, energy, etc.); (ii) emissions in the different natural environments: air, water or soils (ammonia in water, metals in the soil, CO₂, etc.); (iii) waste created (inert, toxic or radioactive). We used version 2.2 (2012) of the ECOINVENT database. This version was completed by the latest version, ECOINVENT 3.5 (2018). The development of this database

Table 1
Example of input parameters taken in five countries.

Continents	Europe	Africa	America	Asia	Oceania	Source
Countries	Belgium	Madagascar	United States	China	Australia	
Capitals	Brussels	Antananarivo	Washington	Beijing	Canberra	
Energy mix (2016)	-Nuclear: 52% -Hydraulic: 17%	-Coal: 20.7% -Oil: 65.5%	-Nuclear 9% -Renewable energy:11%	-Nuclear: 10% -Renewable energy:1.7%	-Coal 6.8% -Gas 22%	[32]
Local climate (According to Köppen climate classification)	-Coal:4% -Oil:0% -Gas: 27% Temperate oceanic climate (Cfb)	- Hydraulic: 13.8% Tropical wet and dry climate (AW/AS)	-Coal:14% -Oil: 37% -Gas:29% -Oceanic climate (Cfb) -Mediterranean warm/cool-summer climates (Csb) - Humid continental climate(Dfb)	-Coal:63.7% -Oil: 19% -Gas:5.6% Humid continental climate (Dwa)	-Oil: 36% -Hydraulic:20% -Nuclear: 15.2% Temperate oceanic climate (Cfb)	[33]

follows processes that have been verified several times to make sure they are reliable and the contents of this database have been verified and validated by international experts. The ECOINVENT Centre is recognized as an international leader in environmental sustainability data and it is well known for the transparency of its methods [35].

In this study, we assessed three (03) environmental impacts of the studied neighborhood: the greenhouse effect (via the Global Warming Potential, GWP); Cumulative Energy Demand, and Biodiversity damage [36–38]. These different environmental indicators are presented in Table 2.

2.4. LCA simulation software

In this study, we used a combination of all the new IZUBA energy software. Indeed, the interface of the most recent version (Pleiades software, version 4.19.1.0) is divided into 6 modules: Library, Modeler (called ALCYONE for the old software version), BIM, Editor (called COMFIE-PLEIADES), Results, and ACV (nova-EQUER). It is important to notice that each one has a precise function. All of them are regularly used by numerous international research laboratories and have been clearly validated by the scientific community [14,39,40].

Modeler, ALCYONE software, is a graphical input tool. It allows the description of the geometry of a building, to represent its solar masks and to define the composition of the walls. Also using this software we defined the zoning of the building where the thermal behavior is homogeneous [14]. This software is essentially made up of five components: Generals (Construction Data, Project Library, LCA Association, Weather and Horizon); Plan; 3D; Calculation. Some physical characteristics of the studied neighborhood are shown in Tables 3 and 4.

Editor, COMFIE-PLEIADES software, allows the performance of dynamic thermal simulation for buildings [14,39]. The geometry created via “Modeler” can be imported from the information entered concerning the materials, the occupation scenarios, and the meteorological data, the software evaluates the heating and air conditioning needs. It is possible to disaggregate the results based

on the thermal zone or by a period of time. This neighborhood was regrouped in 10 blocks with heating requirements shown in Table 5.

ACV module, nova-EQUER, is the environmental quality assessment tool. The requirements calculated in “Editor” are exported and additional inputs are provided to complete the LCA. It includes data such as the energy mix, the mobility of users, the constitution of outdoor spaces, and networks. The software then performs the LCA of the buildings and neighborhood and presents results in the form of radars compiling the different impacts with the possibility of visualizing the part of each phase of the life cycle and comparing different variants of the same project [39]. This module is essentially made up of:

2.4.1. Building/neighborhood data

The original data come from the Pleiades, this thermal/ACV coupling allows to automatically recover all the characteristics of the building: data on the structure of the building and the elements involved in thermal calculations and/or energy consumption. These data are then supplemented with specific LCA data: all elements that are not part of the thermal study; general and administrative data concerning the current operation and the building or neighborhood; specific or adjusted seizures for energy, water, waste, and transport.

2.4.2. (ii) Software organization

The Pleiades interface is structured around five axes:

- Library: Environmental Impact Data Libraries, General Calculation Characteristics. In this research, we fixed: the surplus of materials at the site 5%, default typical service life of families of element: interior and exterior doors 30 years, global equipment 20 years, glazing 30 years, coating 10 years; the distance of transport: site of production towards building site 100 km, site towards inert discharge finally of life: 20 km.
- Project: Project management with structure data for any type of project and use of the building with the EQUER engine. In this research, we fixed: Loss of electrical network

Table 2
Average LCA results of the eco-neighborhood (in Liege city) in terms of calculated impacts.

Environmental indicator	unity	Value over 100 years	Value/inhabitant Per year	Value/m ² per year
Energy	GJ	3232.62	1.115	0.035
Greenhouse effect	t CO ₂ eq	92419.00	31.869	1.010
Biodiversity damage	PDF*m ²	154146.62	53.154	1.685

Table 3
Wall composition.

Element	component	E(cm)	$\rho * e(\text{kg/m}^2)$	λ (w/m.k)	R($\text{m}^2 \cdot \text{K/W}$)
Coated exterior wall	exterior coating	1.5	26.0	1.150	0.01
	Expanded polystyrene	32.0	8.0	0.032	10.0
	Limestone silico block	15.0	270.0	0.136	1.10
Barded outer wall	ceiling	1.3	11.0	0.325	0.04
	Cement fiber cladding	2.0	36.0	0.950	0.02
	Air blade	1.2	0.0	0.080	0.15
	polyurethane	24.0	7.0	0.025	9.60
	Limestone silico block	15.0	27.0	0.136	1.10
High floor	ceiling	1.3	11.0	0.325	0.04
	PDM sealing	–	–	–	–
	Polyurethane	40.0	12	0.025	16.00
	Concrete slab	25.0	325	1.389	0.18
Intermediate floor	Ceiling	1.3	11	0.325	0.04
	Chappe + coating	8.0	144	0.700	0.11
	polyurethane	1.0	0	0.030	0.33
	Aerated concrete	8.0	48	0.210	0.38
	Concrete slab	25.0	325	1.389	0.18
Low floor	Ceiling	1.3	11	0.325	0.04
	Chappe + coating	8.0	144	0.700	0.11
	polyurethane	25.0	8	0.025	10.00
Internal wall	Concrete slab	25.0	575	1.750	0.14
	Ceiling	1.3	11	0.325	0.04
	Limestone silico block	15.0	270	0.136	1.1
	Expanded polystyrene	4.0	1	0.032	1.25
	Limestone silico block	15.0	270	0.136	1.10
	ceiling	1.3	11	0.325	0.04

(e) Thickness, ($\rho * e$) the mass per unit area, (λ) thermal conductivity and (R) thermal resistance.

Table 4
Wall surface states.

		Property			
Location	coating	ξ	A	P(%)	
External face	Red brick	0.92	0.68	20	
Floor	concrete	0.88	0.9	30	
External roof	gray gravel	0.95	0.85	15	
Internal face	White paint	0.91	0.2	80	
Ceiling	White paint	0.91	0.2	80	

Emissivity (ϵ), absorptivity (α), and reflectivity (ρ) of the different coatings used.

Table 5
Heating requirements of different neighborhood buildings in the basic and high configuration of a floor.

Buildings	Heating requirements($\text{kWh/m}^2 \cdot \text{year}$)	
	Initial situation	First floor
A3	15	14
B2	12	12
B3	14	13
D1	19	20
D2	20	20
D3	20	21
D4	18	19
C1	12	11
C2	13	12
C3	13	11
Mean	15.6	15.3

Table 6
Monetary indicators for the European Committee for Standardization indicators [40].

Environmental Indicator	Unit	Value €/unit
Greenhouse gas	kg CO_2eq	0.05
Biodiversity damage	PDF. $\text{m}^2 \cdot \text{year}$	0.30–0.59
Energy demand	kWh	0.2

CEN (European Committee for Standardization); ECC (European Consumer Centers); PDF (potentially disappeared fraction).

from 9% to 40% according to country. Water system yield: 80%, hot water consumption 40L/day/person; cold water consumption 100L/day/person; Selective collection of glass: yes; sorted glass: 90%; incinerated waste 40%; recovery to incineration: yes; substituted energy: gas or fuel oil (depending on the country); recovery yield: 80%; selective collection of paper: yes; sorted paper: 80%; distance from the site to the garbage dump: 20 km; distance from the site to the incinerator: 10 km; distance from the site to the recycling center: 100 km.

- (c) Experimentation: Specific seizures PEBN E + C-; (at this stage, we introduced all the same experimental data as building structure, location, climate, etc.)
- (d) Calculation and results: Start the calculations and consult the results(after having evaluated all the impacts from each of the constituents of the district (examples: buildings, road, garden transport, etc.), we combine all these elements to assess the impacts related to the district).
- (e) Neighborhood: Neighborhood Management.

2.5. Environmental cost calculation method

The three environmental impacts will be translated into environmental costs, which make them comparable to each other. The cost calculation is based on the method Monetization of the MMG (Global method monetize) updated in 2017 [40], which is based on the methodologies developed previously by Debacker et al. [21] and De Nocker et al. [22]. Monetary values of each environmental indicator have been determined in this methodology [40] for three regions: Western Europe, Belgium, and the rest of the world. Note that the error margin related to the monetary value is low. The tables below show the conversion values of the environmental impacts of environmental costs.

Overall, the environmental cost is very important during the operation phase (71.1%). The maintenance cost is estimated to be around 3.7% of the total environmental cost. These findings confirm the results found by Trigaux et al. [41].

2.6. Mitigation of impacts

In this study, we applied one scenario to study the mitigation potential of one sustainable strategy on the calculated environmental impacts and costs. This strategy consisted of applied photovoltaic panels combined with better inhabitants' mobility behaviors.

In the initial scenario, all the electricity used came from the electricity grid of each country, and the production impacts were taken into account. In this new configuration, we will have a photovoltaic system on all the roofs on the site. Installed photovoltaic panels cover a total area of 580 m² equivalent to a peak power of 82857.14w. It must be noted that our homes use electricity only for light and to power household appliances. The installation will consist of monocrystalline photovoltaic solar panels. The sensors will be placed using support on the roof terrace. They will be oriented toward the south in the case of countries located in the northern hemisphere (Russia, Canada, China, United States, India, Kazakhstan, etc.), and toward the north in the case of countries located in the southern hemisphere (Angola, Botswana, Burundi, Comoros, Lesotho, Madagascar, Malawi, etc.); they will also be inclined at 37° for the countries located in the temperate and cold zones and inclined at 45° for the countries located in the hot zone. This allows us to have optimal inclination in all the countries. We have then performed the thermal simulation of each building and completed the final LCA of the neighborhood.

Let us now look at the impact of mobility on the neighborhood's environmental record. In our basic scenario, we considered a significant use of the car for daily commuting. We will compare this scenario with a second one, where the site is considered urban, perfectly integrated with public transport networks, and at a short distance from the shops of primary needs. Let us recapitulate the mobility hypotheses: (i) Initial scenario: 80% of the occupants commute daily in developed countries and 50% of the occupants commute daily in developing countries; the distance from home to work of 5–10 km is carried out daily by car; the distance from home to shops of 1 km is done weekly by car. (ii) new scenario or "Urban Site" scenario: 100% of the occupants make the trip daily in all the countries; the distance from home to work of 2–5 km is done daily by bus; the distance from home to shops of 0.5–1 km is carried out weekly by bike or on foot. Finally, both scenarios have been combined to obtain a mixed scenario having a significant effect on the three environmental impacts assessment.

This scenario was mainly applied to the case of 31 representative countries, selected among the 150 studied countries. These selected countries are located in the 5 continents (Fig. 9), covering the three climatic zones (Fig. 10), and covering the 7 different types of the climate of the world (Fig. 11). These countries were also selected under the base of their very significant energy mix and local building materials.

3. Results and analysis

This section analyzes the environmental impacts and costs of the reference scenario and a mitigation scenario. Then, the parameters that most influence the different environmental impacts are highlighted.

3.1. Environmental impacts over 100years

Figs. 2–4 show the results of the three environmental impacts assessment of studied neighborhood, adapted in 150 countries over a period of 100 years. Fig. 2 shows that the greenhouse effect is the most significant in some countries such as Australia, China, Poland, Madagascar, Mongolia, etc. This rate is low in countries such as

Denmark, Costa Rica, Finland, United Kingdom, Sweden, Switzerland, and Brazil. According to IEA [32], the percentage of renewable energy in the energy mix is of 43.0% in Denmark, 47.0% in Costa Rica, 29.6% in Finland, and 33.3% in Brazil (based on their energy mix in 2016). These percentages explain the low carbon concentration emissions in these countries compared to other countries. In addition, it is interesting to notice the carbon rate emission is moderate in the USA, Germany, Cameroon, and Argentina. These results show that countries such as the United States, Germany, and Russia emit average carbon content. This result is not a surprise, because, despite the rate of fossil energy use considered very high in these countries, it is offset by the implementation of sustainable or green energy sources. The heating of buildings is often supplied in these countries by nuclear energy and cooling by solar energy.

As shown in Fig. 3, primary energy demand is low (between 450000 GJ and 550000 GJ) in Brazil, Mali, Norway, and Singapore; the energy demand is moderate in USA, Namibia, Germany, and India, and very significant (more than 750000 GJ over 100 years), in Australia, Canada, Kazakhstan, and South Africa.

The degradation of biodiversity is very high in Africa and the Middle East because of the non-renewal of waste. In these areas, there are several highly polluted sites. Industrial and petroleum wastes are often rejected on the African coast. On the contrary, it is seen that in most developed countries such as USA, the European Union, Russia, and Australia, biodiversity damage is the lowest (see Fig. 4).

Overall, among the four applied parameters (energy mix, local material, climate, and transport), the energy mix has the most significant effect on the three studied environmental impacts.

3.2. Applied energy mix

Fig. 5 shows the analysis of three environmental impacts per square meter living space per year coming from a neighborhood adapted in several regions in the world. As shown in Fig. 5a, the average of the greenhouse effect of an eco-neighborhood (including buildings, road construction, and daily mobility) located in the 150 studied countries is around 72.1 kg CO₂/m².year and 60.31 kg CO₂/m².year in the 34 OECD countries. The greenhouse effect is higher than the average in countries such as Canada, China, India, and Australia, but also in southern Asia, Africa, and the Middle East. Contrary to certain results published by the IPCC, which stipulates that on a global scale, the developed countries emit an important quantity of greenhouse gases. It is also found in this research that at the scale of the sustainable neighborhood, greenhouse gas emissions are lower in the European Union than in Africa.

Fig. 5b shows that the average primary energy demand of an eco-neighborhood (including buildings, road construction, and daily mobility) is around 255.4 kWh/m².year in the 150 countries. The energy demand is around to 319.1 kWh/m².year in Canada, and 369.4 kWh/m².year in Australia. This energy demand is 8.8% and 12.1%, higher in the European Union, and Africa, respectively, than the average of other studied countries. However, it is found that this energy is 3.2% and 28.2% lower in the Middle East and Denmark, respectively, compared to the average in all the studied countries.

In Fig. 5c, it is interesting to notice that biodiversity damage is very low in Germany (1.8PDF.m².year) and the highest in Madagascar (13.62 PDF.m².year). These findings confirm the report of the United Nation which mentioned Madagascar as one of the countries in the world where fauna and fuel are in perpetual disappearance [42].

The effects of the energy mix on the environmental impacts in different countries are an innovative subject in recent research. They are evaluated nationally and consider different economic

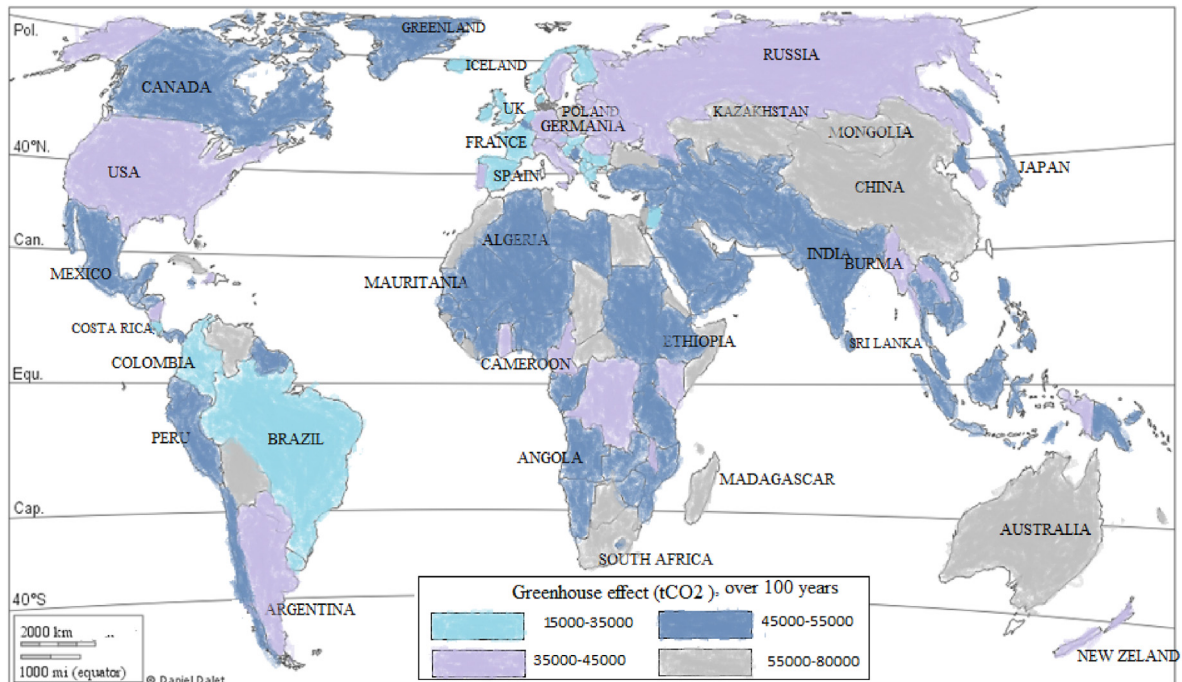


Fig. 2. Greenhouse effect assessment of a sustainable neighborhood, designed in 150 countries over a period of 100 years.

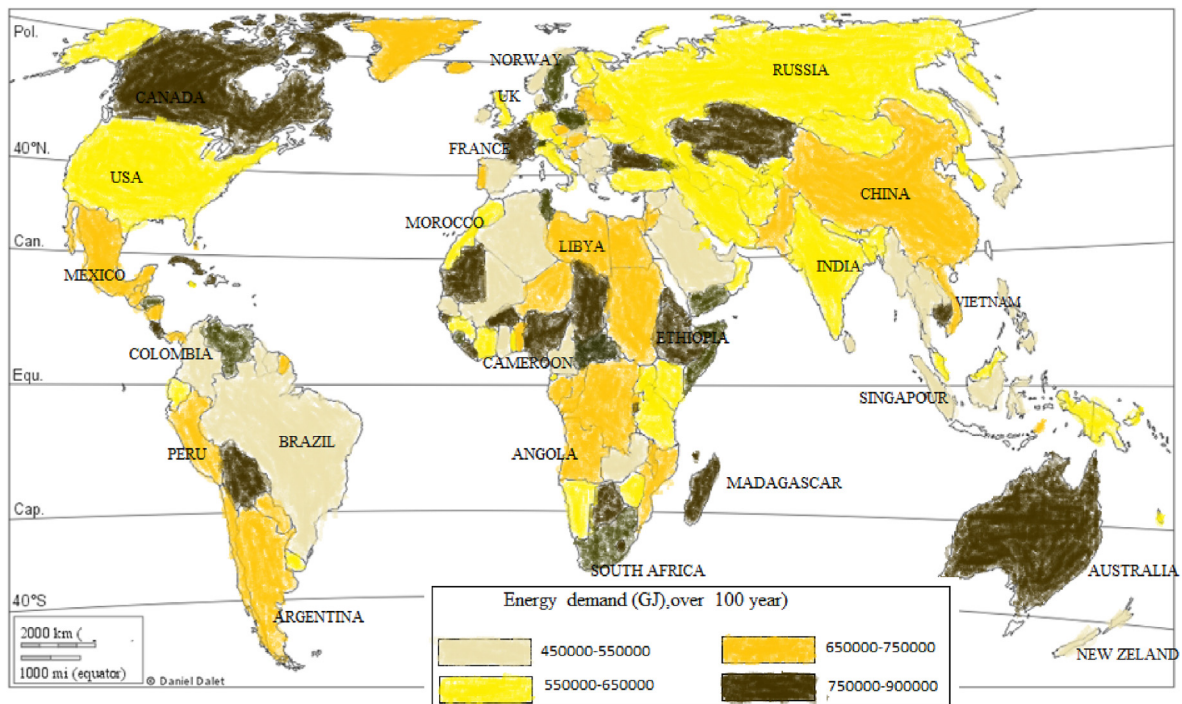


Fig. 3. Primary energy demand assessment of a sustainable neighborhood, designed in 150 countries over a period of 100 years.

problems of the countries, the variations of the energy supply, and the changes in the profile of demand [43–45]. Other studies on European countries explain how a sudden change in the energy mix towards fossil energy sources will lead to significant increases in emissions per occupant, nationally, and globally, even without increasing energy consumption [46–49].

Overall, compared to the mean of biodiversity damage (around 10.71PDF.m².year), the observed damage is 14.8% higher in Africa

and 16.9% higher in South Asia than the average value in the 150 countries. On the other side, biodiversity damage is 62.8% lower in the European Union than the average of all the studied countries. The average biodiversity damage is only 4.87 PDF.m².year in the countries member of G7.

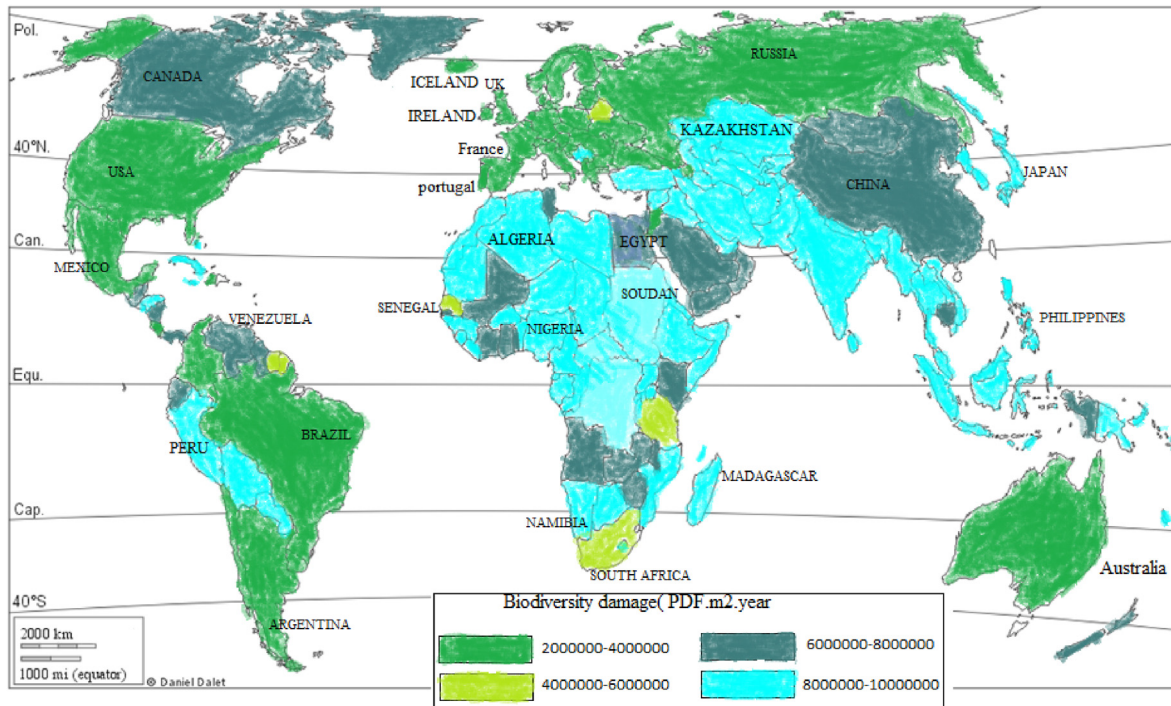


Fig. 4. Biodiversity damage evaluation of an eco-neighborhood, designed in 150 countries over a period of 100 years.

3.3. Mitigating of environmental impacts

To reduce environmental impacts, we have coupled two scenarios as detailed in section 2.6. The results are shown in Figs. 6–8.

Fig. 6 shows the significant effect of implementing the photovoltaic scenario on the carbon rate. Overall, the implementation of this method allows mitigating the greenhouse effect by up to 15.2%. Indeed, the greenhouse effect is reduced by 9.5% in the hot zone, 18.2% in the temperate zone, and 15.9% in Africa. In addition, the carbon rate is mitigated up to 58.9% in Mexico, 25.4% in Australia, and 37.7% in Belgium. Despite this, it is seen that the implementation of the photovoltaic panel increases the greenhouse effect from 36.7% in Iran, 15.6% in Singapore, and 5.8% in India. This may be due to the materials used in photovoltaic panels which are more suited to the temperate climate. These results show that the yield associated with the rate of carbon reduction is greater in the temperate zone than in the hot zone.

As shown in Fig. 7, primary energy demand is mitigated to 21.2% by adopting this new scenario. The saved energy is up to 18.9% in the temperate zone, 22.1% in the tropical climate regions, and 23.0% in Africa. In addition, this new method allows mitigating energy demand to 11.7% in Brazil, 4.4% in Russia, 29.7% in New Zealand, and 41.1% in Cameroon. These results showed that the implementation of the photovoltaic panel has the most significant effect (produce a high yield) in the countries with a tropical and arid climate, such as Singapore (26.8% of saving energy), Qatar (41.3%), etc. This result confirms those found by Laleman et al. [50] who explained that in regions with low solar radiation, the potential of photovoltaic electricity is not very high. However, this potential is 4 times higher compared to a wind farm. But, 10 times lower than that of electricity produced by a coal power plant. Overall, the PV-systems yield varied according to the countries. Jungbluth and Tuchschnid [51] estimated this yield around 725 kWh/kWp/year in some countries such as the UK and Belgium and 848 kWh/kWp/year in Switzerland.

As shown on Fig. 8, overall, the biodiversity damage increases up

to 24.9% in all regions by implementing the new scenario. This biodiversity damage increases to 23.8% in the European Union, 42.2% in Africa, and 30.9% in some oceanic countries, such as New Zealand, Fiji, Papua New Guinea. It is interesting to see that biodiversity damage increases to 105%, 118%, and 126%, in the USA, Australia, and southern Africa, respectively. However, it decreases in some countries such as Brazil (0.07%), Mexico (59.6%), Canada (62.5%), Argentina (22.9%), Chile (53.6%), etc. These results show that the significance of the biodiversity index varies according to the regions.

Global results show that installing photovoltaic panels in the eco-neighborhood mitigates carbon rate and primary energy demand. However, it increases the biodiversity damage in the temperate, hot, and polar climate zones. The energy yield of photovoltaic panels is the most significant in the countries having a tropical climate (see Table 6).

3.4. Environmental costs

Table 8 shows the values of the three environmental impacts and environmental costs calculated under the base of two scenarios coupled over one year of life, the case of 30 countries distributed in five continents, and covering different climate types.

According to the results shown in this table, the average spending cost per country regarding greenhouse gas emissions is estimated at 24509€/year. The 15.5% of this cost can be saved, after implementing the photovoltaic and urban scenario. The average spending cost per country regarding biodiversity loss is estimated at 19108 €/year. This cost increases in mean to 14.7% by applying the new scenario (Photovoltaic + urban mobility). It is interesting to notice that:

(a) In UK (Europe), carbon cost decreases to 11.1% while biodiversity damage cost increases to 43.6%; (b) in USA (America), carbon cost decreases to 7.0%, while biodiversity damage cost increases to 105%; (c) in China (Asia), carbon cost increases to 1.9%, while biodiversity decreases to 33.2%; (d) in Qatar (middle east),

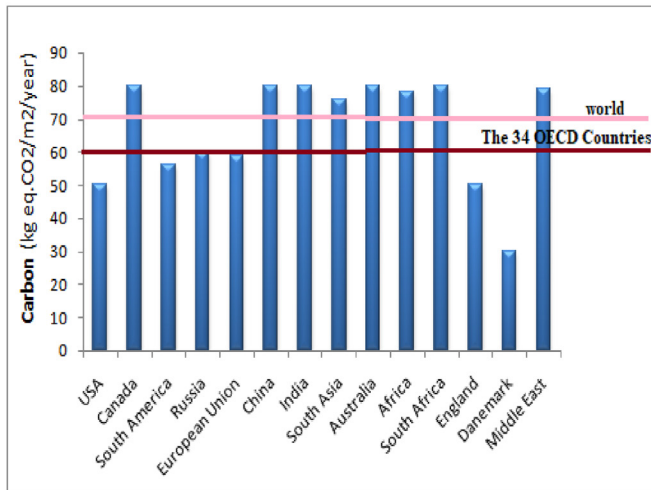


Figure 5a. Greenhouse effect for a sustainable neighborhood distributed in the world per square meter living space per year

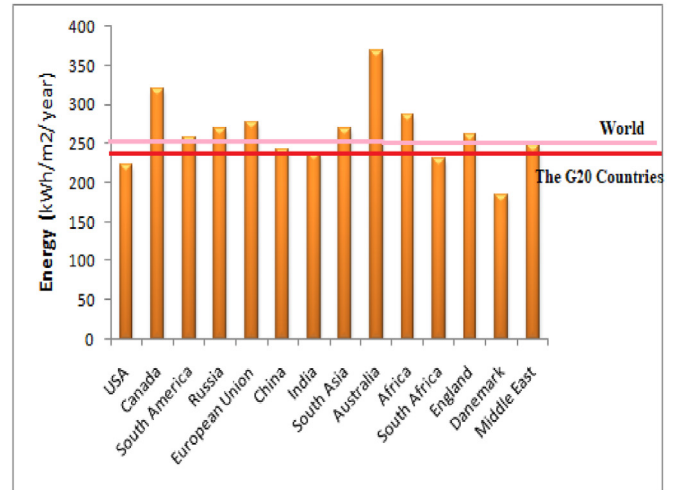


Figure 5b. Primary energy demand for a sustainable neighborhood distributed in the world per square meter living space per year

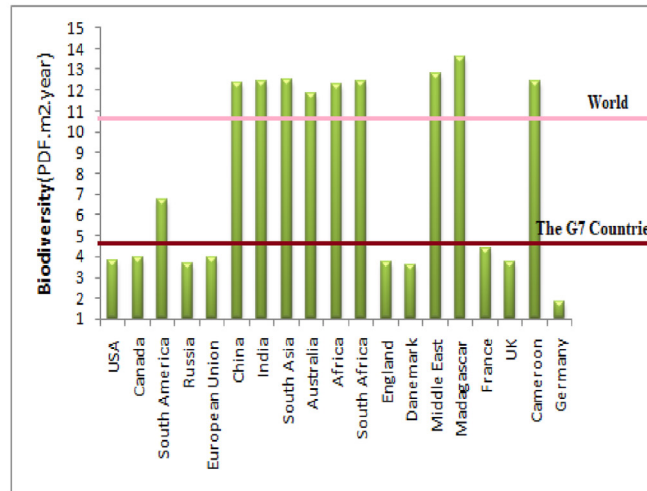


Figure 5c. Biodiversity damage for a sustainable neighborhood distributed in the world per square meter living space per year

Fig. 5. Assessment of three environmental impacts coming from a sustainable neighborhood distributed in some countries in the world.

carbon cost decreases to 18.6%, while biodiversity damage cost increases to 131.3%; (e) in Madagascar (Africa), carbon cost increases to 0.4%, while biodiversity damage cost increases to 40.1%; (f) and in Australia(Oceanic), carbon cost decreases to 25.4%, while biodiversity damage cost increases to 118.5%. These results may be compared to the conclusion of Zhou et al. [52] which showed that CO₂ emissions vary in the same direction as energy, however, increasing more slowly than energy.

Table 9 gives the distribution of the three environmental impacts by region and their cost.

On Table 7, we see that the environmental cost and impact of the greenhouse effect are more important in central and northern Asia, and less important in Northern European. This can be explained by the fact that in most countries in North and Central Asia, the percentage of fossil fuel energy consumption (oil, coal, etc.) is above 80%. While in Northern Europe, USA, and Australia, the proportion of fossil energy in the energy mix is very high, but some portion of it is slightly offset by green energy sources or renewable energy sources, which reduces the carbon content of an eco-neighborhood. In addition, biodiversity damage is low in the countries of the European union and very important in the countries of Africa union.

3.5. Environmental components

Fig. 9 shows the frequency of the different environmental components in the generation of the greenhouse gas effect, in 28 representative countries located in the five continents of the world (Europe, America, Africa, Asia, and Oceanic).

Overall, in an eco-neighborhood, the materials selected during the construction phase have a very low pollution rate. However, some materials can pollute enormously after a few years of use. For example, some types of insulations are manufactured under basic of petrol waste.

The greenhouse gas rate produced by waste or material degradation was 50.7% in Germany, 29.9% in Belgium, 38.5% in France, and 33.8% in Iceland. At the neighborhood scale, electricity production is the main cause of greenhouse gas emissions in the USA(49.9%), Spain (49.2%), Argentina(47.5%), Mexico(42.3%), in Italy(41.7%), Russia(38.8%), and Canada(33.2%). However, in Africa and Asia, electricity and waste are the two main environmental components of greenhouse gas emissions. Globally, it is found in this research that the main sources of greenhouse gas emissions in the different countries are: electricity production and waste.

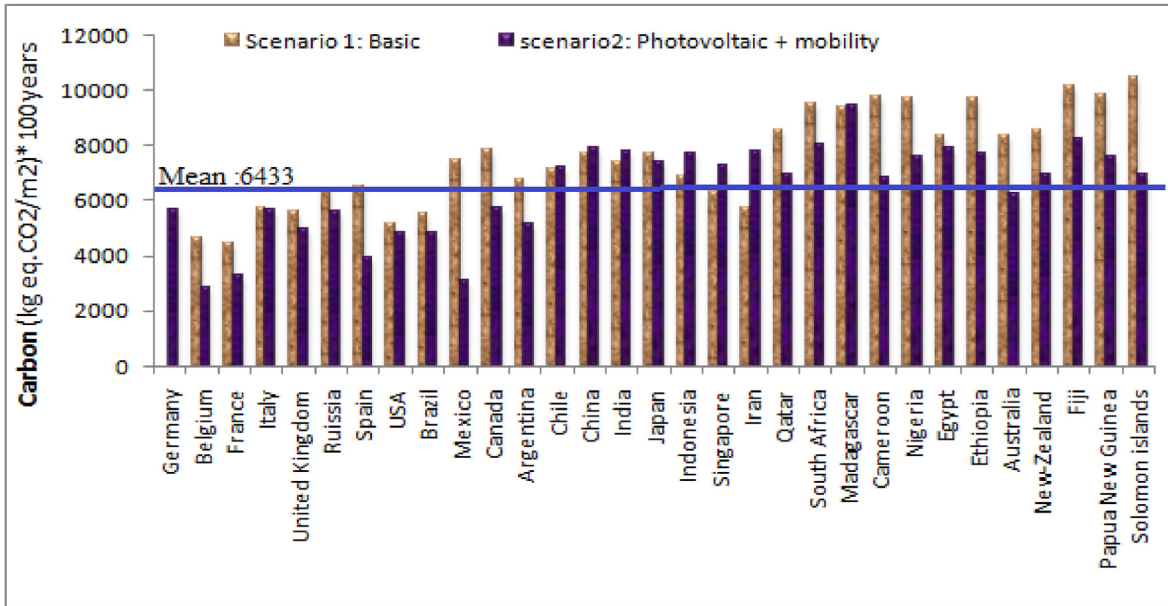


Fig. 6. Comparative diagram of the Carbon Impact of the "Initial" and "Photovoltaic" Scenarios (Functional Unit: Entire neighborhood).

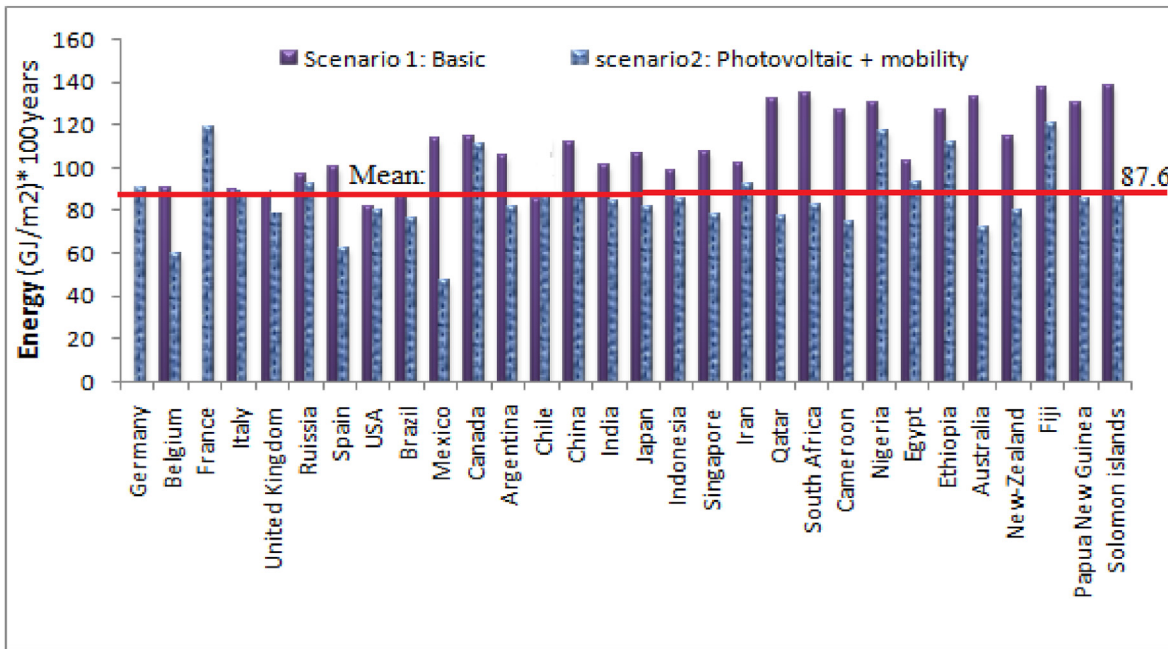


Fig. 7. Comparative Diagram of the Primary Energy Demand of the "Initial" and "Photovoltaic" Scenarios (Functional Unit: Entire neighborhood).

Transportation has also a significant effect on the environmental impact. The studied buildings have high energy performance and thus low heating consumption compared to old buildings, whither heating and cooling energy demand is very high. As shown on Fig. 10, "electricity" is the main component of energy demand (37.5%) in all the three studied zones (temperate, hot and cold). It is interesting to notice that electricity demand is over 50% in some countries such as USA, Spain, and Argentina. Only 5.0% of the total energy demand is associated with transportation in this eco-neighborhood. Fig. 11 shows the percentage of the different environmental components in the generation of the biodiversity demand, for representative countries located in the seven climate

types of the world (polar climate, oceanic, continental, Mediterranean, equatorial, tropical, and arid). Overall, one of the main components having a significant effect on the biodiversity damage is the waste (36.1%). Only 1.1% of biodiversity damage comes from "transportation" in the seven climate types distributed in the world.

In a temperate climate, material wastes contribute to 85.3% of biodiversity damage in Belgium, 78.5% in the UK, 76.2% in Germany, and 67.5% in France. While in tropical and equatorial climates, domestic and material wastes contribute up to 66.7% of biodiversity damage in Nigeria, 63.4% in Madagascar, and 68.3% in Singapore. In the USA, 77.2% of biodiversity damage is related to the building

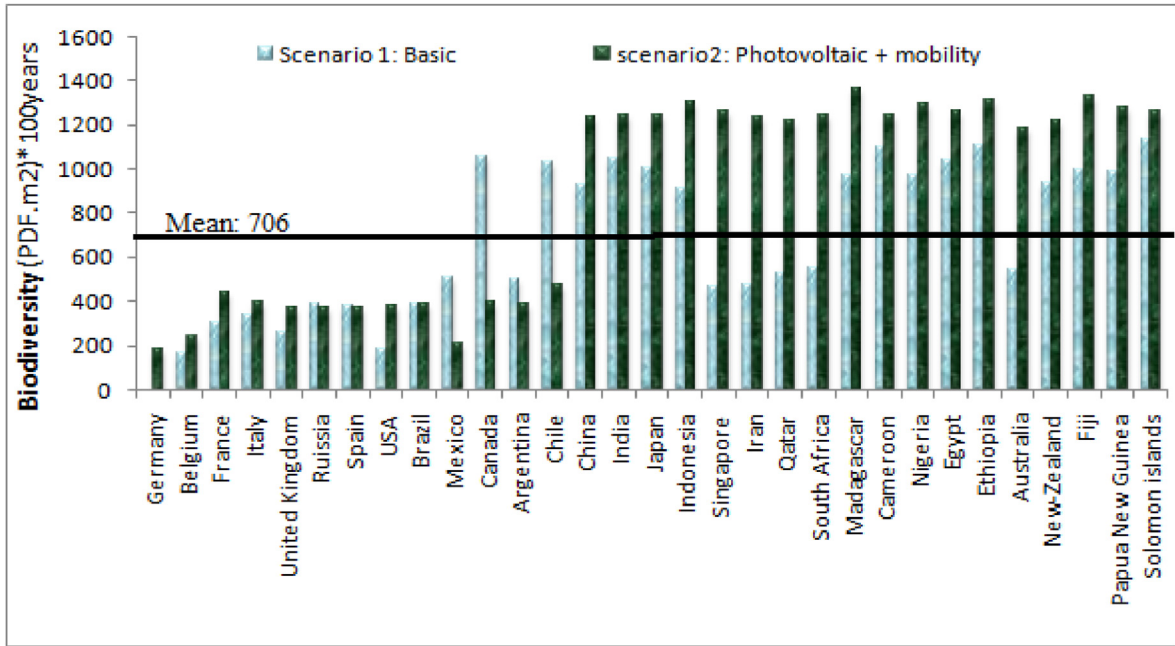


Fig. 8. Comparative Diagram of the biodiversity demand of the "Basic" and "Photovoltaic" Scenarios (Functional Unit: Entire neighborhood).

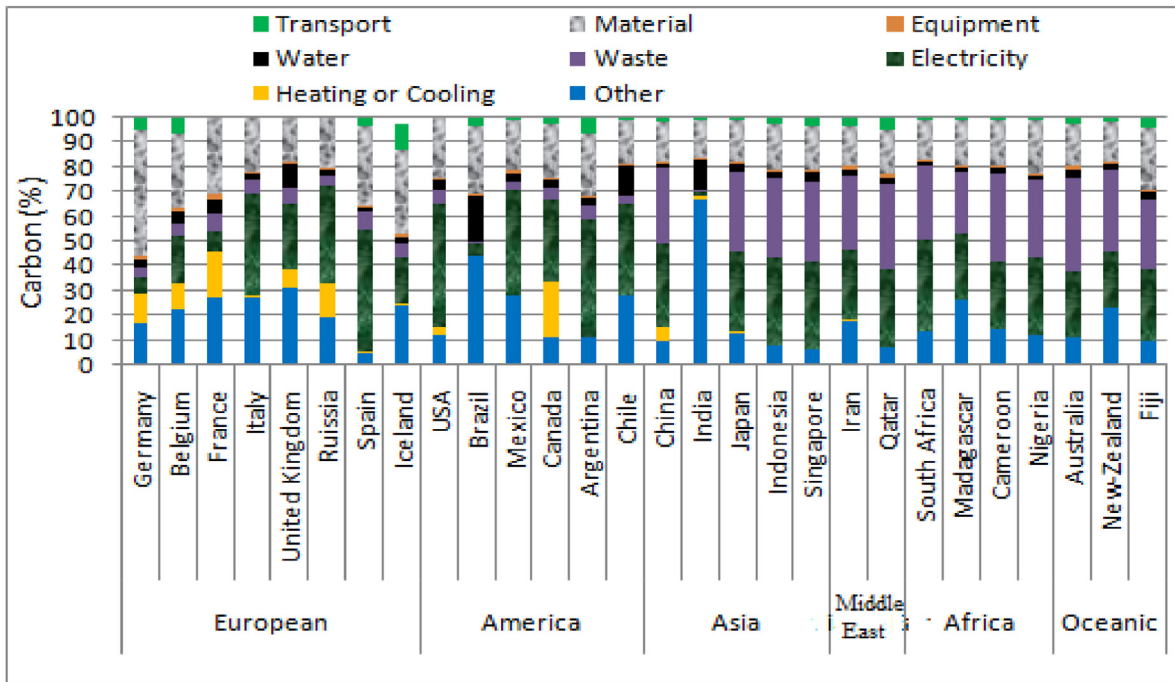


Fig. 9. Frequency (%) of the different environmental components in the generation of the greenhouse effect, for some countries located in the five continents of the world.

materials and 11.9% to electricity production. However, in Japan, waste material produces 69.4% of biodiversity damage.

Fig. 12 shows the deviation of three impacts in some regions of the world. This analysis allows us to understand in depth the rate of environmental impact in each region. Why one region is more impacted than the other. The deviation of energy and carbon impacts is very high in central Europe. Indeed, the results show, at the eco-neighborhood scale, that the carbon emission in Poland is higher than in the central European region. This can be due to the high use rate of fossil fuel energy in their energy mix (more than

83%, according to IEA [32]). In addition, deviation from biodiversity damage is more significant in southern America. Indeed, it is seen that biodiversity damage is very high in Bolivia, Peru, and Paraguay, but, low, in Brazil and Argentina.

These results show that most of the environmental impacts of buildings come from waste and electricity production. These results are similar to those found by Blengini [53].

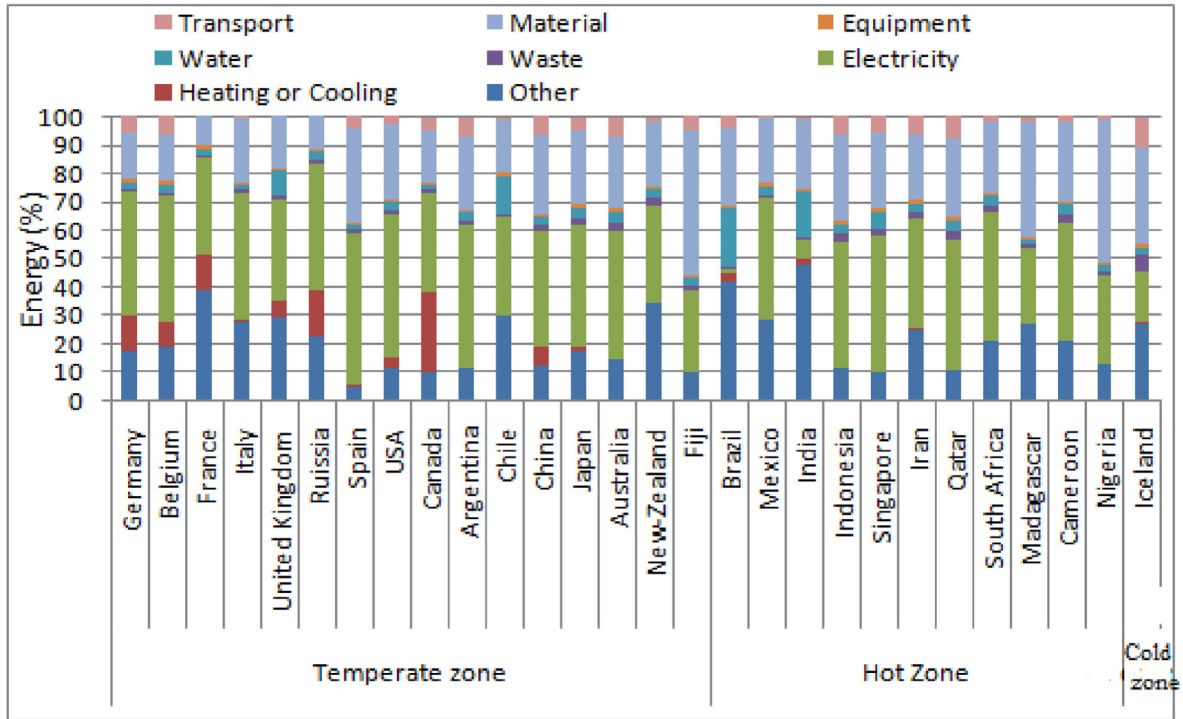


Fig. 10. Frequency (%) of the different environmental components in the generation of the energy demand, for some countries located in the three climate zones of the world.

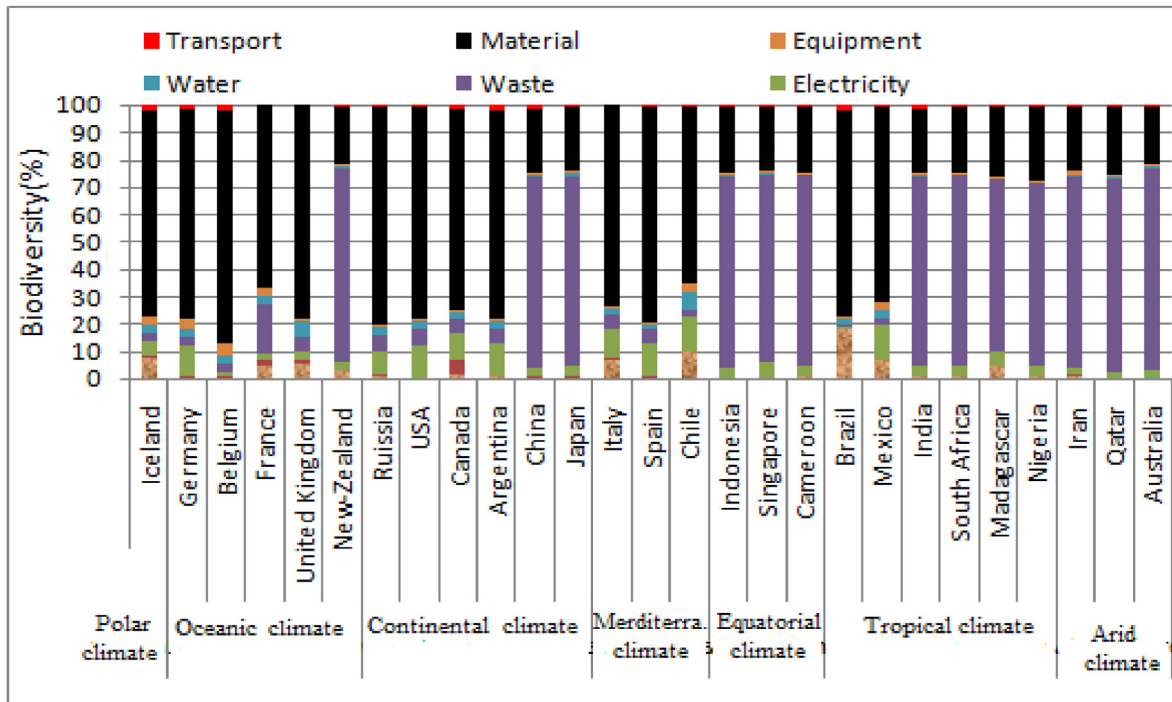


Fig. 11. Frequency (%) of the different environmental components in the generation of the biodiversity demand, for some countries located in the seven climate types of the world.

4. Discussions

In 2013, the United Nations [54] stated that more than 50% of the world’s population lives in cities. This rate will increase by up to 70% in the next decade. In addition, the building sector is one of the most consumer-intensive sectors in terms of natural resources,

especially fossil fuels. It induces enormous environmental impacts. In developed countries, the construction sector is responsible for 42% of final energy consumption [55], 35% of greenhouse gas emissions [56], and 50% of all-material extractions [57]. This research shows the significant impact of the energy mix on the different environmental impacts. This conclusion confirms the

Table 7
Environmental cost of each phase of the eco-neighborhood in Belgium.

Environmental impacts	Year	Construction (in €)	Operation (in €)	Maintenance (in €)	Dismantling (in €)
Greenhouse effect	2017	4166	9179	409	47
	2020	12499	27537	1227	140
	2030	54162	119326	5316	605
	2050	137488	302904	13494	1535
Energy	2020	215714	701031	35447	3879
	2030	934763	3037824	153606	16807
	2050	2372859	7711399	389922	42663
	2080	4530004	14721762	744423	81448
Biodiversity damage	2020	28855	3481	1303	26
	2030	125036	15084	5646	114
	2050	317403	38291	14331	289
	2080	605952	73100	27360	553
Total(%)	–	24.8	71.1	3.7	0.4

results found by Rossi et al. [48,49] who showed that the energy mix of one country has a significant impact on CO₂ emissions. These researchers showed how a shift in the energy mix towards renewable sources yields important reductions, even without reducing energy consumptions.

Our study shows that the carbon emission rate is very high in China, Australia, Mongolia, Madagascar, and South Africa. These results are normal because more than 80% of the energy consumed in these countries is produced by fossil fuels such as coal, oil, etc. In countries such as Brazil, Costa Rica, Denmark, Sweden, Finland, and the UK, the emission rate is low because of the large-scale implementation of renewable energy in the production of consumed energy. In addition, in Germany, Russia, and the USA, the rate of greenhouse gas emissions is moderately important because heating and electricity are for the most part produced by gas, nuclear, and renewable energies. Most fossil fuel energy in these three countries is used to supply industries.

In Europe, in 2008, only 8.5% of energy consumption comes from renewable and clean resources [58]. The 2014 climate-energy package sets new targets for 2030: 40% reduction in greenhouse gas emissions compared to 1990, 27% renewable energy in the energy mix; and 27% energy efficiency. More than 27% of the energy consumed in Denmark and Costa Rica is renewable which explains their low carbon emission on the neighborhood scale.

Overall, the influence of energy mix over the environmental impacts varied in each country: in France, 74% of nuclear in the energy mix, produces very low CO₂; in Germany, and Denmark, much higher renewable energy in the energy mix than most countries produces lower CO₂ than average; in Poland, 90% of fossil energy in the energy mix produces much higher CO₂; in China, 64% of coal accentuates the pollution rate. The implementation of renewable and nuclear energies will radically alter grid emissions in the world. These findings confirm the researches of Sharif et al. [59] who showed that the use of nonrenewable energy has still, positive impacts on environmental damage, while renewable energy has a negative effect on environmental damage and allows to mitigate environmental hazards.

Energy demand is very high in Canada, Australia, and South Africa, but moderate in Brazil, Norway, Cameroon, and Singapore. This confirms some of the results found by Berardi [60].

In Madagascar, 70% of the energy consumed comes from coal. While in Chad, more than 40% of energy is used for cooling. Overall, in this study, heating energy in countries located in temperate and polar areas and cooling for hot-zone countries is very low compared to those found in other works [48]. This is due to the fact that our study took place exclusively in an eco-neighborhood. Indeed, in this kind of neighborhood, they implement various passive design strategies in the design of their buildings. The mean

value for the neighborhood located in 150 countries is 0.25 kg of CO₂/kWh.

The results show that biodiversity damage is high in Sub-Sahara Africa, and Middle East (more than 8 millionsPDFm².year), but, lower in USA, Brazil, European Union, Russia, and Australia (less than 2 millionsPDFm².year). Globally, the causes of biodiversity degradation are direct and indirect. But, they are largely the result of uncontrolled human expansion and predominance. It should be noted that certain chemical pollutants emitted during the production of nuclear energy and the waste discharged into the environment during the refining of petroleum have a significant effect on the destruction of the environment. These chemical pollutants emitted are also often toxic to human beings.

Following the involvement of humans in the destruction of the environment (industry, deforestation ...), in recent years, biodiversity has become a world heritage of humanity and the majority of people agree that it must be protected and amplified.

Stamatiou and Dritsakis [61] showed that there is a great relationship between CO₂ emissions, energy consumption, and economic growth in each country. This finding is confirmed by some results of this research. Indeed, the implementation of a photovoltaic panel on a sustainable neighborhood mitigates 15.9% of CO₂ and 21.2% of energy; but, unfortunately, biodiversity damage increased by 25.0%. According to Nian [62], one of the aims of the solar photovoltaic systems (PV) is mainly to mitigate carbon emissions of energy systems. Globally, PV systems give nearly zero carbon emission when in operation, but the manufacturing phases produce carbon emissions. There was no study to deeply investigate the impacts of PV systems on the biodiversity damages. Carbon emissions from photovoltaic panels and nuclear energy production are low during the operational phase. However, their life cycle is not free of carbon emissions. In fact, the manufacture of PV systems requires a significant amount of materials such as metal, petrochemicals, contributing to the pollution of the environment [63]. Material wastes and electricity are the two main components that affect carbon dioxide emissions and energy consumption in a sustainable neighborhood. The waste shows a more significant effect on biodiversity degradation. It is seen that all fossil fuel energy sources do not increase the negative environmental impacts in the same way. Indeed, the type of fossil energy sources used to produce electricity greatly influences the environmental impact. If we impose a new energy and electricity mix for all the studied countries, including for example 27% of renewable sources (on the basis of the objectives set in the European Union in 2014, horizon 2030), we observe a direct reduction of greenhouse gas emissions between 15% and 40% and reduction of the total primary energy demand of 10%–30%. The results showed that, at the sustainable neighborhood scale, the ECC of the greenhouse effect is 35.6%,

Table 8
Comparison of the three environmental impacts and costs calculated over one year on our reference scenario.

Continents	countries	Greenhouse effect(kg CO ₂ e/q/year)				Energy demand(kWh/year)				Biodiversity demand(PDF.m ² .year)			
		Basic		Photovoltaic + mobility		Basic		Photovoltaic + mobility		Basic		Photovoltaic + mobility	
		LCA	ECC(in €)	LCA	ECC (in €)	LCA	ECC (in €)	LCA	ECC (in €)	LCA	ECC (in €)	LCA	ECC (in €)
European	Germany	372270	18613.5	339460	16973	1656336.1	331267.2	1526047.2	305209.4	12117.72	7149.44	23357.52	13780.93
	Belgium	304630	15231.5	276010	13800.5	1660858.3	332171.7	1593450	318690	10727.78	6329.39	22901.29	13511.76
	France	292060	14603	217900	10895	2170869.4	434173.9	1887647.22	377529.4	20077.9	11845.96	28719.24	16944.35
	Italy	377920	18896	371580	18579	1661236.1	332247.2	1636533.33	327306.7	22039.44	13003.24	26319.12	15528.28
	UK	366920	18346	325420	16271	1715161.1	343032.2	1611238.88	322247.7	17029.63	10047.48	24454.19	14427.97
America	Russia	425530	21276.5	370180	18509	1767333.33	353466.7	1693230.55	338646.1	25842.34	15246.98	24247.85	14306.23
	Spain	426090	21304.5	260680	13034	1833138.88	366627.8	1140038.888	228007.8	25208.71	14873.13	24479.08	14442.66
	USA	341730	17086.5	317820	15891	1490122.22	298024.4	1464891.66	292978.3	12180.01	7186.21	24978.28	14737.18
	Brazil	365600	18280	316610	15830.5	1584058.33	316811.7	1399094.4	279818.9	25536.64	7660.992	25534.62	7660.4
	Mexico	493740	24687	402560	20128€	2076305.55	415261.1	1708875	341775	33649.49	10094.84	26929.1	8078.73
	Canada	518260	25913	377170	18858.5	2100008.33	420001.7	2022911.1	404582.2	69336.5	40908.53	25979.64	15327.98
	Argentina	443530	22176.5	341050	17052.5	1936288.88	387257.8	1487450	297490	32997.4	9899.22	25430.39	7629.11
	Chile	469130	23456.5	47500	2375	2073016.66	414603.3	1563769.4	312753.9	67653.89	20296.2	31395.93	9418.78
	China	510460	25523	520320	26016	2051986.11	410397.2	1598247.22	319649.4	61030.57	18309.15	81297.2	24389.16
	India	486390	24319.5	514100	25705	1846147.22	369229.44	1549205.5	309841.1	68736.05	20620.8	81938.31	24581.5
Asia	Japan	508230	25411.5	489280	24464	1952113.88	390422.8	1500852.77	300170.6	65909.55	38886.6	81935.39	48341.9
	Indonesia	453640	22682	487640	24382	1803394.44	360678.9	1489833.3	297966.7	60147.57	18044.25	81865.95	24559.78
	Singapore	415650	20782.5	480810	24040.5	1960866.66	392173.3	1435263.8	287052.8	30644.21	9193.26	83284.33	24985.3
	Iran	376210	18810.5	514840	25742	1863983.3	372796.7	1681958.3	336391.7	31270.97	9381.3	81524.25	24457.3
	Qatar	561770	28088.5	457340	22867	2409533.3	481906.7	1415516.66	283103.33	34654.65	20446.24	80186.82	47310.22
	South Africa	624970	31248.5	527400	26370	2467238.8	493447.8	1508552.7	301710.5	36080.17	10824.054	81642.23	24492.6
	Madagascar	620460	31023	622800	31140	2272436.1	454487.22	2414002.77	482800.6	63973.27	19191.96	89621.8	26886.54
	Cameroon	643200	32160	447990	22399.5	2319786.1	463957.22	1366175	273235	72245.24	21673.57	81922.94	24576.88
	Nigeria	638970	31948.5	498630	24931.5	2379411.1	475882.2	2145458.33	429091.6	63988.74	19196.61	85300.61	25590.18
	Egypt	552810	27640.5	522110	26105.5	1885786.11	377157.2	1704691.6	340938.3	68556.67	20566.98	83115.62	24934.68
Africa	Ethiopia	638570	31928.5	507580	25379	2313519.4	462703.9	2043580.55	408716.1	72669.34	21800.79	86144.3	25843.3
	Australia	550670	27533.5	410720	20536	2433569.4	486713.8	1322666.6	264533.3	35614.14	21012.34	77836.22	45923.36
	New Zealand	565520	28276	459580	22979	2087488.8	417497.8	1465583.3	293116.7	61865.27	18559.58	79969.88	23990.96
	Fiji	668040	33402	543710	27185.5	2465169.4	493033.9	2209038.8	441807.8	65470.38	19641.11	87710.42	26313.12
	Solomonislands	692410	34620.5	456990	22849.5	2533758.3	506751.7	1580527.77	316105.5	74453.59	22336.1	82914.82	24874.44

Table 9
Cost and environmental impacts in some regions in the world.

Region	Contribution <i>usedcountries</i> <i>totalcountries</i>	Greenhouse effect (tCO ₂ eq/year)			Energy demand (GJ/year)		Biodiversity demand		
		Mean LCA	Mean	Total	Mean LCA	Total	Mean LCA	Mean	Total
			ECC (in €)					ECC (in €)	
Northern Africa	6/7	544.44	27222	3266.6	6718.3	40309.8	82346.6	48584.5	494079.8
Northern European	7/10	282.96	14148	1980.77	6135.9	42951.2	25151.9	14839.6	176062.1
Northern America	12/24	448.1	22405	4928.87	7073.1	77803.3	59198.8	34927.3	640187.5
Northern Asia	1/4	636.9	31845	636.9	8267.4	8267.4	85127.5	50225.2	85127.5
Southern Africa	11/13	510.7	25535	5617.4	6709.9	73809.1	78929.8	46568.6	868228.4
Southern European	9/18	347.2	17360	3124.3	5570.0	50130	31811.4	18769	286302.9
Southern America	9/12	368.8	18440	3319.5	6108.2	54973.9	44344.1	26163	399096.6
Southern Asia	13/19	484.6	24230	6429.3	5929.3	77080.9	82101.6	48439.9	1067321.2
Central Africa	7/8	508.5	25425	3559.8	6977.5	48842.6	84518.2	49865.7	591627.4
Central European	6/9	458.7	22935	2752.5	7536.3	45217.6	27206.2	16051.7	163236.8
Central America	4/7	435.9	21765	1743.6	7267.9	29071.5	67841.9	40026.72	271367.6
Central Asia	1/5	636.9	31845	636.9	8267.4	8267.4	85127.5	50225.2	85127.5
West Africa	15/16	509.1	25455	7636.7	6761.6	101424.9	82282.8	48547	1234241.6
West European	6/7	374.6	18730	2247.9	6647.1	39882.9	26238.6	15480.8	157431.9
West Asia	12/14	516.9	25845	6203.1	5786.6	69439.9	74743.6	44099	896923.6
East Africa	10/11	527.9	26395	5279.5	7281.6	72815.8	833776.8	49193	833776.8
East European	6/10	554	27700	3032.2	7867.2	47203.4	27079.8	15977	162478.9
East Asia	4/6	500.2	25010	2000.6	5694.8	22779.4	81775.1	48247	327100.5
European Union	22/28	384.8	19240	8465.8	6556.3	144238.8	26550.1	15664.6	584102.9
Africa union	49/51	520.2	26010	—	6889.8	—	—	—	—
Middle East	14/16	508.3	25415	7116.3	5781.9	80947.1	72071.8	42522.4	1009005.9
Caribbean America	4/15	521.93	26096.5	2087.7	7505.9	30023.7	72733.2	42912.6	290932.9

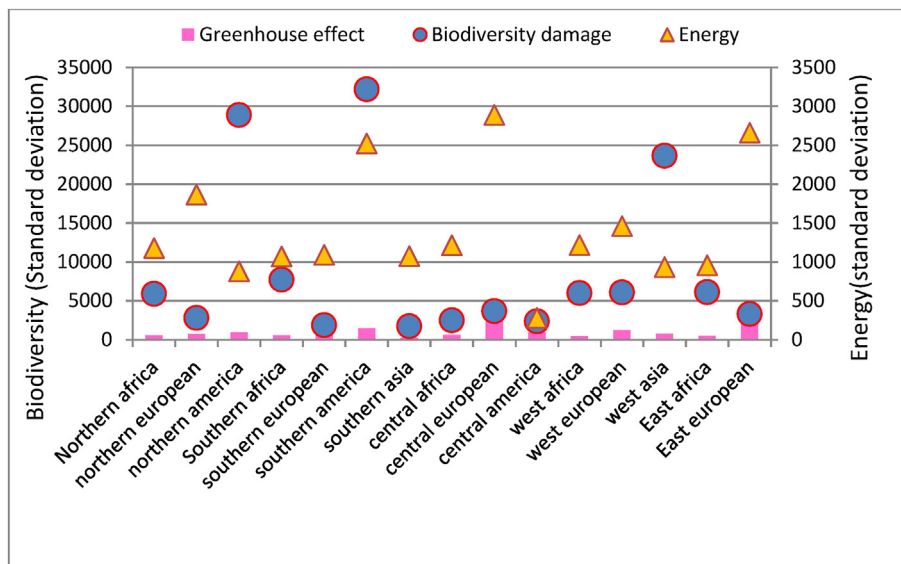


Fig. 12. Standard deviation of the three environmental impacts of an eco-neighborhood in some regions of the world.

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