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Life Cycle Assessment of Waste Products of a Green-Neighbourhood

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Abstract

This research aims to quantify and to compare the effect of the energy mix of 150 countries on the waste products generated by an eco-neighbourhood. To perform this comparison, the same neighbourhood design is applied to in 150 countries, but four parameters are adapted to each country: energy mix, local climate, building materials and occupants' mobility. The life cycle of the neighbourhood was assessed over 100 years. This environmental impact was evaluated by the Pleiades simulation software under four phases (construction, use, renovation, and demolition). Among the four local parameters (energy mix, local materials, climate, and transport), the energy mix has the most significant effect on the waste product emission. In this sense, the results showed that the most important quantity of waste products (35.3% of the total) is generated during the demolition phase. What is more, the application of photovoltaic panels in eco-neighbourhood increases up to 12% of the total waste product emission over 100 years. Globally, in the 150 Countries, 80% of waste products come mainly from building materials and domestics and the waste product emission per occupant was between 10 and 20% higher in developed countries (USA, Japan, Canada, France, Germany, etc.) than in poor or developing countries (Madagascar, Cameroon, Vietnam, Haiti, Costa Rica, Afghanistan, etc.). Finally, the waste generation concentration of an occupant of an eco-neighbourhood was estimated to be around of 322 kg per year.

Graphical Abstract

Keywords Life cycle assessment · Waste products · Eco-neighbourhood · Countries

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Statement of Novelty

Nowadays the effect of environmental pollution by multiple wastes released by humans is known. This waste directly affects human health and destroys the ecosystem. It will be better to conduct such studies on a global scale, to propose a common strategy to all countries. The majority of studies in the literature uses known models and apply them in the case of a specific region for the evaluation and reduction of waste emitted into the environment. The case of waste analysis atthe scale of a sustainable district has not yet been developed,much less on the scale of several regions. The behaviour of individuals varies from country to country. But a study of global sensitivity makes it possible to better understand the position of each country and to take joint decisions. Overall, it is recognized that one of the main objectives of environ- mental policies in each country is to integrate environmental sustainability into the economy and growth. But how to do it? Nowadays, politicians are wondering about issues relatedto the environment, and also to the different mechanisms ofdaily waste management.

Introduction

Increasing urbanization has a significant impact on environ- mental degradation, with the emission of waste produced by humans. By 2050, according to the European Union [1],a minimum of 70% of the world's population should livein cities. This strong population growth expected in 2050 could accelerate the production of urban waste. For a long time, sustainable development policy has been recom- mended by many international organizations and applied in several countries. This policy in several of its articles recom- mended the total recycling of the waste emitted. Since 1990, the design of eco-neighbourhoods has steadily increased in many parts of the world, especially in developed countries. Several researchers have suggested that the implementationof sustainable neighbourhoods may be one of the solutions to reduce waste emission into the atmosphere. Housing policy has gradually given way to a climate policy, as it is now part of multiple approaches. So, political power, what- ever its level, can no longer be content today to program the creation of new neighbourhoods without striving to meet more needs as individual as well as collective, present and future. The quantity of waste released into the environmenthas increased considerably, following the strong mechaniza-tion and new technologies. Nowadays, waste management in the neighbourhoods or cities is becoming a major concern for both city officials and the occupants. The potential for recovery or processing of any product and material must bevalued. Waste released in a neighbourhood can be a resource in agriculture [2]. The waste management is done by the chain: first inside houses, followed by neighbourhoods, andcities [3, 4]. Nematchoua and Reiter [5] explained that a sus-tainable neighbourhood incorporates, upstream of its design, many criteria, such as waste treatment through the selectivecollection of waste, sorting, recycling, composting, etc.

Overall, the economic impact of waste is mainly influ-
enced by food losses [6, 7]. According to environmental- ists, incineration with energy recovery and composting are among of best-recommended management waste method.

It is advisable to recycle the waste and use, the local non- industrial composting technique, which has no impact on the environment [8–11]. In Belgium, food accounts for 12% (15,000 tons) of trash contents per year [12]. Food waste has an impact on the entire cycle of the chain, from the producerto the consumer [13]. Indeed, 1 kg of food thrown at the endof the chain amounts to producing a much larger mass of waste linked to the cumulative loss, at each stage of produc-tion [14]. They explained that even though waste manage- ment techniques are established and mastered in developed countries, it continues to be a subject of concern in many countries. The European Union in its approach towards sustainable development had fixed several objectives such as: Reduce household waste thanks to the compost and the recycling of the materials. "Recovery" of 58% of packaging materials in the year 2000; and increase the use of recycled materials in aggregates from 35 million tons to 50 million tons in 2005 [15, 16].

Life cycle assessment (LCA) is the main method pro- viding more precise information on environmental impacts related to waste management. Indeed, this methodology facilitates the comparison of waste treatment channels [17]. LCA allows studying the effects of a product on the envi- ronment, human health and the different resources. Rod- ríguez et al. [18] proposed a model of Integrated Waste Management to optimize the collection and treatment of solid waste. They assessed the total cost of different types of environmental waste. The results showed the effective- ness of biological treatments compared to heat treatments. Finnveden [19] proposed different aspects of the life-cycle analysis of solid waste management systems and showed thatthese aspects condition optimal waste management. Studiesconducted by Cherubini et al. [20] were applied on LCA of four waste management methods: biogas-free landfill, biogas landfill, waste sorting, and waste incineration. The results showed that the new waste treatment technology can limit the different environmental impacts, also, the energy pro- duced with waste can cover 15% of the total energy used in Rome. Winkler and Bilitewski [21] compared six models of waste optimization developed in Europe and America. The results showed a significant difference between the differ- ent models of waste life cycle analysis. After analysing fivewaste treatment strategies, Hong et al. [22] found that waste incineration has the highest potential for acidification, while, the discharge, has the highest potential for eutrophication and global warming potential. Yay [23] explained that LCA is the most recommended tool to help administrators' betterplan an integrated waste management approach that delivershighly reliable environmental results.

In 2020, Doaemo et al. [24] suggested 3 core waste man-
agement hierarchy systems to support sustainable develop- ment for Lae City by reviewing existing opportunities and challenges associated with the current municipal solid waste management system and the associated policies. The result shows that a zero waste campaign for resource recovery involving all stakeholders can be implemented since the organic content of municipal solid waste generated in Lae City reaches 70%. In addition, the discharge of municipal solid waste to the dedicated landfill site can be minimized ifthe policies are strengthened and the proposed way to avoidwaste is strictly implemented. Baquero et al. [25] developed a methodology to estimate bio-waste generation at municipal level taking into account the characteristics of the region, the Municipal Solid Waste management applied, and different socio-economic variables that define the level of ruralityof a municipality. A model to estimate the bio waste gen- eration for each type

of municipality has been developed using Multiple Linear Regression Analysis. Significant influ- ence of socio-economic variables on bio-waste generation was observed for the rural municipalities.Roy and al. [26] evaluated the performance of the existing Solid Waste Man-agement system as an eco-friendly component of Nirala, a planned residential area of Khulna city. When they were applying the TOPSIS method, a low level of community par- ticipation was found to be the reason behind the deplorablecondition of the Waste Management system in Nirala city. In 2021, Colangelo et al.[27] assessed the environmental impacts coming from five mixtures of concrete, with simi- lar mechanical properties and workability, but with a differ- ent amount of recycled coarse aggregate and natural coarse aggregate (0–30–50–70–100%). The results showed that mixtures obtained by recycled coarse aggregates have better environmental impacts than the only one formed exclusivelyby natural coarse aggregates and results improve when the amount of recycled coarse aggregate is higher.

All these different researches [25–27] are very important, however, they focus on the case study of a region. Nowa- days the effect of environmental pollution by multiple wastes released by humans is known. This waste directly affects human health and destroys the ecosystem. It will be better to conduct such studies on a global scale, to propose a com- mon strategy to all countries. The majority of studies in the literature uses known models and apply them in the case of a specific region for the evaluation and reduction of waste emitted into the environment. The case of waste analysis atthe scale of a sustainable district has not yet been developed,much less on the scale of several regions. The behaviour of individuals varies from country to country. But a study of global sensitivity makes it possible to better understand the position of each country and to take joint decisions. Overall, it is recognized that one of the main objectives of environ- mental policies in each country is to integrate environmental sustainability into the economy and growth. But how to do it? Nowadays, politicians are wondering about issues related to the environment, and also to the different mechanisms of daily waste management. Decision-makers must assess the technical, environmental, and economic aspects of waste management. Environmental impact assessment (EIA) and inventory analysis are good examples of these techniques. Indeed, the life cycle assessments can provide a more in- depth framework, assess waste management strategies, and identify environmental impacts and hotspots regarding waste treatment hierarchy. This research can also help decision- makers understand the benefits associated with more effi- cient waste treatment. Various research gaps are detailed and presented for a reader review. As far as the authors are aware, no work of this type has been attempted in the past. Thus, the principal objective of this research is to analyse the impacts of the energy mix and Photovoltaic panels on thequantity of waste produced in an eco-neighbourhood. The different simulations details are given in the next paragraph.

The research methodology

The environmental analysis of a sustainable neighbour- hood located in Belgium over 100 years was carried out and adopted the same design in 149 other countries while adapting four parameters specific to each country such as: energy mix, local climate, building materials and occupa- tional mobility.

Overall, this methodology is divided into four main sec- tions (a) neighbourhood selection and site modelling; (b) life cycle assessment (LCA) of the selected neighbourhood; (c)modelling the same neighbourhood in 149 other countries and to define the life cycle assessment; (d) to apply one sce-nario for mitigating the health damage.

In this sense, the methodological carried out in this research is based on the choice of the case study, the analysis of the environmental database and the environmental indica- tors, the use of LCA simulation software, and the improve- ment scenario tested.

Initial analysis of the eco-neighbourhood

The Sart-Tilman eco-neighbourhood in Liege is one of the privileged places of Belgium, where the concepts of a sustainable neighbourhood have been applied. This eco- neighbourhood offers different types of buildings (terraced and semi-detached houses, apartment buildings, etc.). A majority of the built surface is dedicated to housing, but it can be also found spaces dedicated to commercial functions or the liberal professions and small businesses. In all, it can be observed 40 small apartments, 45 larger homes, 11 single-family, duplex homes and 6 comple- mentary functions (businesses and shopping centres) and private parking spaces are planned near the buildings. All the dwellings located on the ground floor have a private garden.

In this neighbourhood, the buildings were designed with respect to the passive standard, which imposes very low energy consumption. Moreover, this new neighbour- hood meets almost all the criteria of a sustainable neigh- bourhood, following the references published by the Uni- versity of Liege and other international Organizations [28, 29]. The site is strongly served by public transport linking it to the centre of Liege, thanks to the proximity of the university. The neighbourhood 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. Rainwa- ter recovery systems and tanks are also implemented.

In this research, only the neighbourhood residential part was studied. The environmental impacts calculated to corre- spond to the functional unit "residential eco-district of 3.5 hacomprising 1 ha of roads, driveways and parking lots, 17,800m^2 of green space, 19,740 m^2 of floor space, housing around219 people, studied on a life cycle of 100 years.

Design of the same eco-neighbourhood in othercountries

As it was explained before, the same eco-neighbourhood was simulated in 149 capitals located in 149 countries. Thechoice of the capital, for representing each country was notrandom. Indeed, in most of these countries, the capital was considered as the most populated regions of the country, with the highest pollution rate and waste products.

In this sense, four parameters were simultaneously applied for adapting this neighbourhood in each country such as: the energy mix of each country, the local climate of each country, building materials of each country and occupant mobility.

The information on the energy mix and electricity mix, was obtained from the International Energy Agency [30] and the Energy Information System of each country. With the Pleiades software, it was possible to freely select the different energy components mix (in %) or electricity mix (in %) such as: Nuclear, fuel, coal, gas and renew- able energy. More details of Pleiades software are shownin Izuba Energy Web site (https://www.izuba.fr/). At the same time, the information on the local climate of each country was evaluated with the most recent Meteonorm software version. Meteonorm was defined as a meteoro- logical database with climatological data for every loca- tion on the globe [31]. The fixed database in Meteonorm
7.3.1 contains approximately 6200 cities, 8,325 weather stations, and 1200 Design Reference Year sites.

The information on the construction material was evalu-ated on the basis of 2018–2020 standard thermal regu-lation of each country, but also from information issue to the UN-habitat, and some literature reviews (for some Africa and Asia countries, without recent building stand- ards). Regarding inhabitant mobility, the data were freely selected on Pleiades ACV software. These data are pre- sented as follows;

- Type of site: Suburbs
- 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 andtrade (1000 m);
- Distance from the public transport network (500 m),
- Distance from the daily commute to work (5000–10,000 m).
- Presence of bike path: yes;
- Public transportation: bus, subway and tram.

Finally, it was supposed that there is no war in any country,such as Libya, Syria, Mali, Niger etc. because, at the time ofwar, the behaviour of the population varied anytime.

Environmental database and studied indicators

The environmental data used comes from the ECOIN- VENT database developed by different research institutes based in Switzerland. These data include, for each process and material, a life cycle inventory that contains all mate- rial and energy flows into and out of the system [32]. The software version 2.2 (2012) of the ECOINVENT database was employed and complemented by the latest version, Ecoinvent 3.5 [33]. In this sense, it is interesting to highlight that the development of this database follows processes thathave been certified several times as reliable and the contentsof this database have been verified and validated by inter- national 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 (Ecoinvent [33]).

Environmental impacts are possible adverse effects caused by a development, industrial, or infrastructural pro- ject or by the release of a substance into the environment. Some of the major environmental issues that are causing immense concern are environmental pollution, air pollution, water pollution, garbage pollution, noise pollution, deforest- ation, resource depletion, climate change, etc. In this sense,this study is centred on only one environmental impact: waste products [34–36] due to the impact of waste on the environment, like air pollution, affect health. For instance, three million people die each year from air pollution, either5% of annual global deaths, according to the recent report of the World Health Organization

(WHO). At the same time, air pollution is also responsible for allergies and respiratory diseases and the emission of waste generates the productionof CO_2 which accelerates the global warming of the Earth.

Table 1 Wall composition

Element	Component	e(cm)	ρ*e(kg/m^2)	λ (w/m.k)	R(m^2.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
	Ceiling	1.3	11.0	0.325	0.04
Barded outer wall	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
	Ceiling	1.3	11.0	0.325	0.04
High floor	PDM sealing	–	–	–	–
	Polyurethane	40.0	12	0.025	16.00
	Concrete slab	25.0	325	1.389	0.18
	Ceiling	1.3	11	0.325	0.04
Intermediate floor	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
	Ceiling	1.3	11	0.325	0.04
Low floor	Chappe + coating	8.0	144	0.700	0.11
	polyurethane	25.0	8	0.025	10.00
	Concrete slab	25.0	575	1.750	0.14
Internal wall	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

Thickness (e),the mass per unit area (ρ*e),thermal conductivity (λ) and thermal resistance (R)

LCA simulation software

In this study, all the new IZUBA energy software resourceswere combined. Indeed, the interface of the most recent ver-sion (Pleiades ACV software, version 4.19.1.0), is divided into 6 modules: Library, Modeller (called ALCYONE for the old software version), BIM, Editor (called COMFIE-PLEI-ADES), Results, and ACV (nova-EQUER). It is important to notice that each one has a precise function and that all ofthem are regularly used by numerous international research laboratories and have been validated by the scientific com- munity [37–39].

Modeller or ALCYONE software is a graphical input tool. It allows the description of the geometry of a build- ing, to represent its solar masks and to define the composi- tion of the walls. It is also via this software that we define the zoning of the building where the thermal behaviour is homogeneous [39]. This software is essentially made up of five components: Generals (Construction Data, the Project Library, LCA Association, Weather and Horizon); Plan; 3D and Calculation. Finally, some physical characteristics ofthe study neighbourhood are shown in Table 1 as modelling. Editor or COMFIE-PLEIADES software allows to define the performance of dynamic thermal simulation for build- ings [38, 39]. The geometry created via "Modeller" can be imported from the information entered concerning the mate- rials, the occupation scenarios and the meteorological data. Finally, the software evaluates the heating and air condition- ing needs and it is possible to disaggregate the results by thermal zone or by a period of time.

ACV module or nova-EQUER is the environmental qual-ity assessment tool. The requirements calculated in "Editor "are exported and additional inputs are provided to com- plete the LCA. It includes data such as the energy mix, the mobility of users, the constitution of outdoor spaces and networks for example. The software then performs the LCA of the buildings and neighbourhood 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[38]. This module is essentially made up:

(i) Building/neighbourhood data

The original data comes from the Pleiades, this thermal/ACV coupling allows to automatically recover all the characteristics of the building, data about the structure of the building and the elements involved in thermal calculations and the needs and/ or energy consumption.

These data are then supplemented with specific LCA data like: all elements that are not part of the thermal study, general and administrative data con- cerning the current operation and the building or neighbourhood and the specific or adjusted seizuresfor energy, water, waste and transport.

(ii) Software organization

The Pleiades interface is structured around five axes and the input data was defined for this particularcase study as:

(a) Axe1: environmental impact data libraries and gen- eral calculation characteristics. In this research it were fixed: surplus of materials at the site 5%, default typical service life of families of element: interior and exte- rior 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.
(b) Axe2: Project management with structure data for any type of project and use of the building with the EQUER engine. In particular, in this research it were fixed these values: Loss of electrical network from 9to 40% according to country; water system yield: 80%,hot water consumption 40 l/day/person; cold water consumption 100 l/day/person; a 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 and distance from the site to the recycling centre: 100 km.
(c) Axe3: Specific seizures PEBN E + C-
(d) Axe4: Start the calculations and consult the results.
(e) Axe5: Neighbourhood Management.

The waste scale

The scales used in this study were detailed in Table 2. In this sense, several studies in the literature recommend that, when LCA is applied as a decision-making tool for a specific geographic region, the functional unit is chosen as the total waste produced in this region in a given time (i.e., in a year).In this research, the functional unit is the total annual and per capita amount of waste generated by this eco-district in each region. Finally, it is interesting to highlight that, according to Eriksson et al., the system boundaries must account for time, space and the functional unit chosen as a basis of comparison.

Mitigation of impacts

In this study, one scenario to study the mitigation potential of one sustainable strategy on the calculated environmental impact was applied. This strategy consisted of applying pho-tovoltaic panels combined with inhabitant mobility.

In the initial scenario, all the electricity used to come from the electricity grid of every country, and the produc- tion impacts were taken into account. This new configurationwill have a photovoltaic system on all the roofs on the site. Installed photovoltaic panels cover a total area of 580 m^2, equivalent to a peak power of 82,857.14 W. It must be noted that the selected homes use electricity only for light andto power household appliances. What is more, the selected installation will consist of mono crystalline photovoltaic solar panels with sensors placed using support on the roof terrace. For the countries located in the temperate zone the photovoltaic panels (PV) were oriented at 37° towards the southern hemisphere, whereas, for the countries located in the hot zone, the PV were inclined at 45° towards northern hemisphere. This procedure, will let us to have an optimal inclination in all the countries. After this, it was performed the thermal simulation of each building, and completed the final LCA of the neighbourhood.

Finally, it let us look at the impact of mobility on the neighbourhood's environmental record. It is interesting to highlight that, in the basic scenario, it was considered a significant use of the car for daily commuting. This sce- nario will be compared with a second one, where the site isconsidered urban, perfectly integrated with public transportnetworks and at a short distance from the shops of primary needs. These are the mobility hypotheses employed in this study:

Table 2 The scales used in thisstudy

Intensity	Meaning
0–100	Low
100–200	Slightly low
200–300	important
300–400	Slightly high
400–500	high

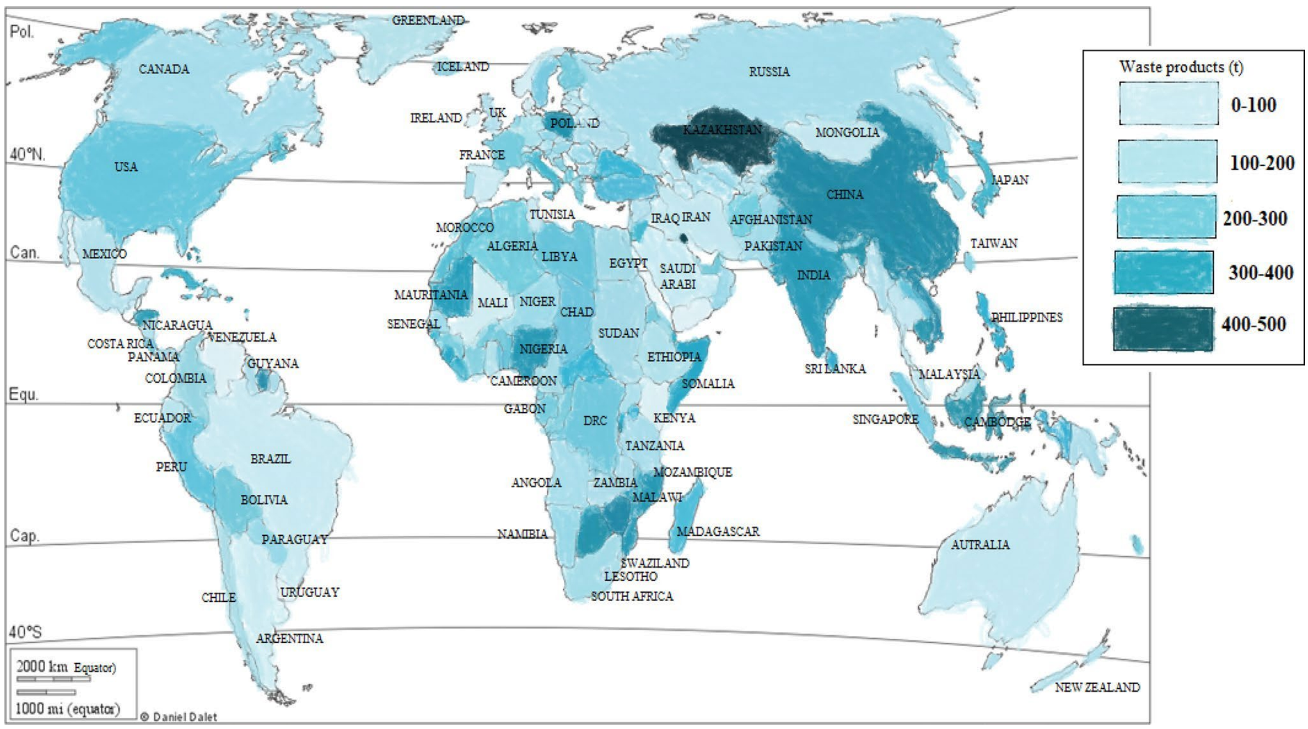
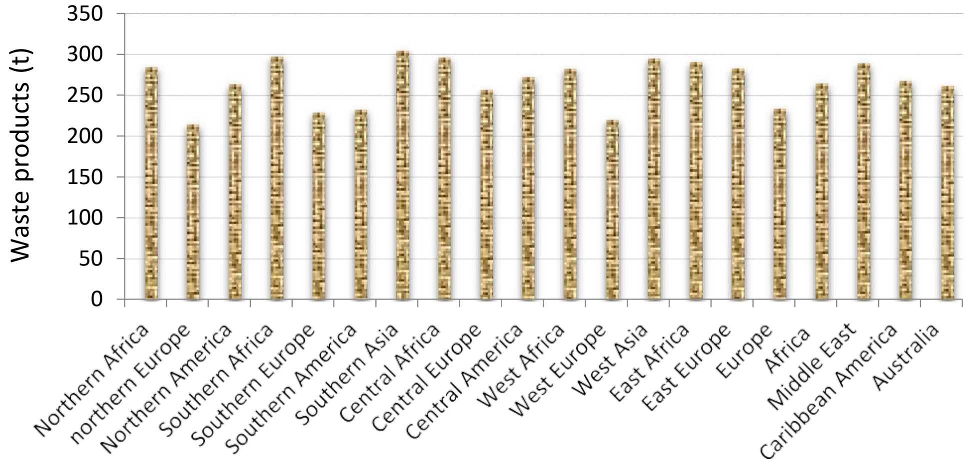


Fig. 1 Waste product assessment generated by an eco-neighbourhood designed in 150 countries

Fig. 2 Waste product evaluationgenerated by an eco- neighbour-hood designed in some regions



(i) Initial scenario: Eighty per cent of the occupants commute daily, the distance from home to work on 5–20 km is carried out daily by car and the distance from home to shops of 1–5 km is done weekly by car.

(ii) New scenario or" Urban Site" scenario: One hundredper cent (100%) of the occupants make the trip daily,the distance from home to work on 2–5 km is done daily by bus and the distance from home to shops of0.5-1 km is carried out weekly by bike or on foot.

Finally, both scenarios have been combined for obtaining amixed scenario affecting more significant on the three environmental impact 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, covering the three climatic zones and were also selected on the base of their very significant energy mix andlocal building materials. Results and discussions

This section is divided into four sub-sections. The first one section analysis the waste products in the different countries,the second section analysis the influence of new scenario onthe waste products, the third section analysis the different waste product components and the fourth section analysis the different life cycle phases and the waste products per occupant in each region.

Analysis of the waste products

Figures 1 and 2, show the waste product assessment com- ing from a green-neighbourhood designed in 150 countries and some regions of the world every year. In Fig. 1, it can be observed that the waste products are "High (between400 and 500tons/year)", in Kazakhstan. The waste prod- ucts are "Slightly high (300-400tons/year), in China, India, Poland, Nigeria, Somalia, Botswana, and Mozambique. These, are "important (200-300tons/year)", in USA, Japan, Madagascar, Peru, Nicaragua, Libya, Cambodia, France, etc. Moreover, the waste products are "Slightly low (100- 200tons/year)", in Canada, Russia, Australia, Cameroon, and Mongolia; but, "low (0-100tons/year)", in some coun- tries such as: Mali, Kenya, Ireland etc. In consequence, it can be deduced that the countries having important fossil energy, produce the most waste products. That is the caseof China and Kazakhstan where the 63.7% of the energy mix are constituted of coal (IES, 2016). Indeed, during the extraction, transportation, processing and storage of oil, such as coal, there is a release of large quantities of waste into theenvironment. At the same time, some countries that producenuclear energy, such as France (42% of energy mix) and Belgium (48%) in 2016 (IES, 2016), emit a great number ofwaste products. Despite this, it is Poland one of the world countries producing a large amount of waste. This result is not surprising, given that its energy mix consisted of 56.5%coal and 27.0% of oil in 2016.

In Fig. 2, it can be observed that the average waste prod-uct emission is 283.7tons/year in the countries located in North Africa, 214.3tons/year in North Europe and 262.3tons/year in North America. These results showed thatthe waste products are more significant in North Africa thanin North Europe. Although fossil fuels are more widely usedin Northern Europe countries, the percentage of this fossil energy in the energy mix used is lower in Northern Europe than in North Africa.

The majority of countries located in North Africa are oilproducers. Indeed, oil extraction processes generate a significant amount of waste that can harm human health. Also,it is seen that the waste products are more important in SouthAsia (304.2tons/year) than in South Africa (297.2tons/year)and more important in South America (232.4tons/year) thanin south Europe (228.9tons/year). It is interesting to notice that waste products are 13% more significant in Africa thanin Europe. So, at the scale of the neighbourhood, the averagewaste products are the highest in Asia countries and the leastin Europe countries.

The Europe countries are among the most polluters inthe world. However, many conventions are adopted within Europe to reduce the pollution rate, as the package (40%, 27%, 27%), fixed in 2014. Despite this, Africa and Asia remain highly dependent on fossil fuels. In addition to this, large quantities of industrial waste are released by the devel- oped countries on the Asian and African maritime coasts. These highly polluting degradations affect the health of thepopulation and destroy the ecosystem.

Analysis of scenario impacts

As shown in Fig. 3, the introduction of a photovoltaic panelallows to increase up to12% of total waste products. Over- all the waste products varied according to the continent,

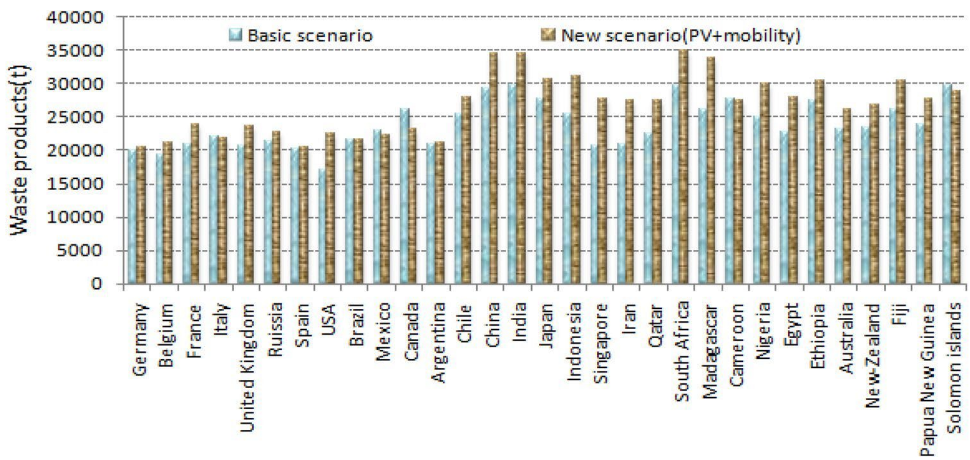


Fig. 3 Comparative Diagram of the waste product impacts of the "Initial" and "Photovoltaic" Scenarios (Functional Unit: Entire neighbourhood) over 100 years

Table 3 The waste products insome countries per living area

Country	Initial LCA of waste prod-ucts (kg/m^2)	LCA of waste product after apply-ingPV scenario (kg/m^2)	Comments
France	30	40	Increase to 33%
Germany	30	30	Stable
Spain	30	30	Stable
Italy	30	30	Stable
UK	30	40	Increase to 33%
Canada	40	40	Stable
USA	30	30	Stable
Brazil	30	30	Stable
China	40	50	Increase to25%
Russia	30	30	Stable
India	10	50	Increase to 400%
Cameroon	40	40	Stable
Madagascar	40	50	Increase to25%
Ethiopia	40	50	Increase to25%
Australia	40	40	Stable
Japan	10	50	Increase to 400%
Average	32.25	39.38	Increase to 26%

indeed, these increases to 6.5%, 4.7% and 22.1% in Europe, America and Asia, respectively. Applied Photovoltaic panel, increase up to 16.7% and 11.2% of waste products in Africaand Oceanic. These results showed that the influence of thenew scenario is more significant in the countries located in Asia and Africa than other continents (Europe, Oceanic andAmerica).

The waste products also varied according to the countries,for example: an increase of 12.3% in Australia; 14.4% in the UK and France; 17.9% in China; 30.1% in Madagascar; 31.4% in Iran; 32.3% in the USA and 34.0% in Singapore. The countries as Russia, Belgium and the UK generate a low waste quantity by using gas as one of the main heat- ing sources. These results show that the photovoltaic panel generated an important waste quantity. In this sense, Bilimo-ria and Defrenne [40] affirmed that the waste rate increaseswith applying photovoltaic panel. Overall, more than 90% of photovoltaic waste in Europe is emitted by the followingcountries: Belgium, France, Germany, Italy, Spain, Slovakiaand the United Kingdom. In consequence, the mix of nuclearand renewable energies is essential to reduce the share of fossil fuels (coal in mind) in the majority of world electric-ity production.

In 2018, while coal (and other fossil fuels) is the most widely used sources of electricity production in the world, the development of low-carbon energies (nuclear and renew-able energies) is indispensable and unavoidable.

While panels contain small amounts of valuable materialssuch as silver, they are mostly made of glass, an extremely low-value material… In addition, some governments may classify solar panels as hazardous waste, due to the small amounts of heavy metals (cadmium, lead, etc.) they con- tain. Solar panels are composed of photovoltaic (PV) cells that convert sunlight to electricity. When these panels enterlandfills, valuable resources go to waste. And because solarpanels contain toxic materials like lead that can leach outas they break down, landfilling also creates new Wastes. Table 3 shows the waste products by living area.

From this table it can be observed an increase of up to 26%, per living area, applying the PV scenario. The averagewaste concentration is estimated to be from 32.25 kg/m^2.yearin an eco-neighbourhood. These results seem to be smaller than those found in some research. It is normal and very logical that it is smaller than those of neighbourhoods with more conventional habitats because this study takes place inan eco-neighbourhood. Indeed, the construction materials are over 70% recycled.

Analysis of waste sources

Figure 4 shows the frequency of some waste sources. The different waste components in the 30 representative coun- tries in the 150 countries are: transport and heating (0.8%); electricity (6.3%); domestic waste (21.6%); water (8.2%); building material (58.4%) and equipment (2.5%). So, domes-tic wastes and building materials are the main sources of waste products. In an eco-neighbourhood, daily mobility and building heating have the least influence on the waste quantity. In Europe, the building material wastes were esti-mated to be 72.1% in Spain, 68.6% in Italy, and 70.5% in Belgium. In America, this one was estimated at 68.1% in Brazil, 66.3% in the USA, and 64.7% in Canada. However,

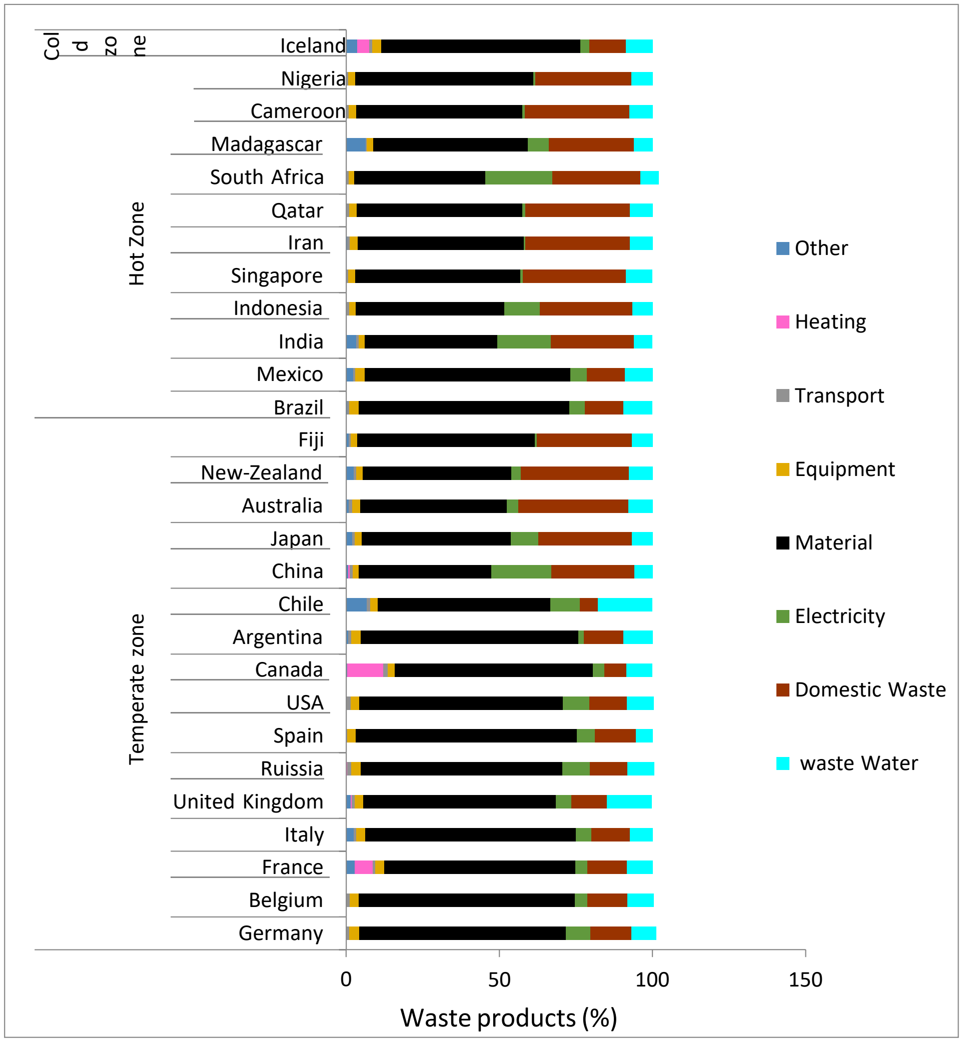


Fig. 4 Percentage of the different environmental components in the generation of the waste products, for some representative countries located in the seven (07) climate types of the world

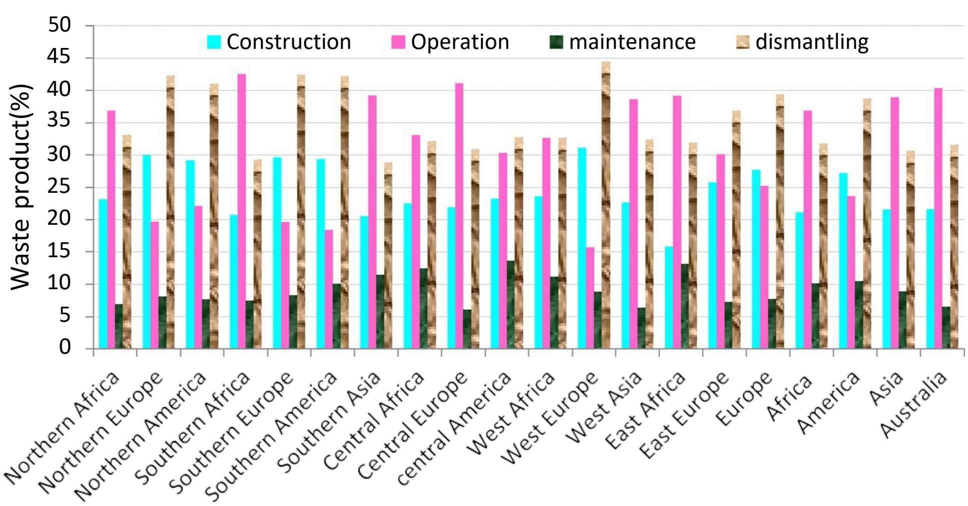


Fig. 5 Waste product concentration generated by each phase of life cycle at the eco-neighbourhood scale designed in some regions

in Asia, they were off 43.3% in China and India, then 48.7% in Japan. Finally, in Africa, the building material wastes were off 42.7% in South Africa, 58.1% in Nigeria, 54.1% in Cameroon, and 50.4% in Madagascar. It is very important to notice that: in the cold zone (Iceland and Greenland), the heating building, and electricity produce 4.0 and 2.9% of waste products, respectively. In the warm zone (Madagascar, Brazil, Nigeria, Singapore, Iran etc.), electricity and water produce 6.5% and 7.3% of waste, respectively. While in tem-perate zones (USA, Canada, France, China, Germany, etc.), this one produces 7.2% and 9.1% of the wastes, respectively. The analysis of these results shows that electricity produces the most waste in the temperate zone. Nevertheless, the heat-ing building generated the most important waste quantity in the "Cold zone". In the temperate zone, some countries as France and Belgium depend enormously on nuclear electricity.

Nuclear energy has many advantages: it is stable, low pol- luting and predictable. The waste emission rate is reduced between 10 and 25% by replacing virgin or non-recycla- ble building materials with recycled ones. In addition, an increase in the waste recycling rate, up to 80%, can reduce CO_2 emissions by up to 30%. These results are almost simi-lar to those found by Parkes et al. [41].

Analysis of different phases

Figure 5 shows the waste products concentration gener- ated by the different phases. In the 150 countries, it can be observed that the 24.4% of total waste are produced during the construction of the neighbourhood; 31.2%, during the operation phase; 9.1%, during the renovation phase; and 35.3% of waste during the demolition of the neighbour- hood. These results show that the dismantling phase of the neighbourhood is the most significant. In Europe, the con- struction and operation phases represent 27.7% and 25.3% of total waste generated, respectively; while the renovation and demolition represent 7.7%, and 39.4%, respectively. InAfrica, the construction and use phases generated 21.1% and36.8% of the wastes, respectively, while the renovation and demolition represent 10.1%, and 31.8% of waste, respec- tively. Also, in the America countries, the construction andoperation phases represent 27.2%, and 23.6% of total waste,while the renovation and dismantling generated 10.5% and 38.7% of this one, respectively. Finally, in Asia, the con- struction phase represents 21.6% of total waste, the utiliza- tion phase 38.9%, the renovation phase 9.1% and the demoli-tion phase 35.3%.

On one hand, these previous results show that the con- struction and demolition phases generated more waste in Europe than in the three other continents. At the same time,the Operation phase produces the more important waste quantity in the countries located in Asia, than, these of threeother continents (Africa, Europe and America). Finally, therenovation phase produces the most wastes in America andAfrica.

On the other hand, in Fig. 6 it can be observed that, in the 150 countries, the average of waste products is of 402 kg/ inhabitant/year and that the total waste quantity generated by the occupant is expected to be 5.22 tons in 2030 and 13.25tons in 2050. The waste products generated per inhab-itant per year for the countries located in European are overthe average of the world. While these ones are under the average of the world for the countries located in Africa and Asia continents. The wastage rate produced by an inhabit- ant is estimated to be around 435 kg per year in Europe andaround 358 kg per year in Africa.

We also can see that the waste emission rate per inhabit- ant per year is over of the average world in China, USA, Madagascar and Canada, but, under of the average world,in Germany, Senegal and Australia.

The European Environment Agency [42, 43] reported thatthe waste rate sent by an inhabitant from a conventional or standard neighbourhood was estimated to be around 450 kg

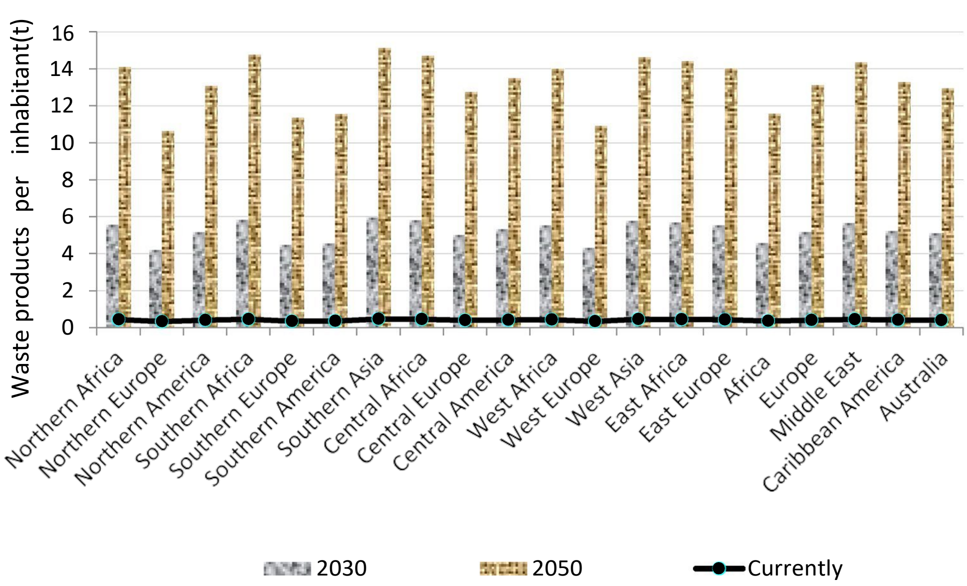


Fig. 6 Waste products generated by each occupant living in eco-neighbourhood on two periods (presently and future)

per year in Europe. The results found in this research are almost 10% lower than those ones. So, the waste products are lower in the sustainable neighbourhood than in the con-ventional neighbourhood. To move towards the "zero waste"goal it is important to avoid what can become or produce wastes.

Conclusions

This research focuses on the life cycle assessment of waste products of an eco-neighbourhood initially located in Bel- gium. The same neighbourhood was simulated in 149 othercountries by respecting some parameters own at each coun-try such as the use of different materials, the heating/cool- ing systems, the energy mix, the buildings insulation thick-nesses, mobility and the climate-related to the temperatures.It was found that the energy mix, own in each country has the most significant effect on the waste products. Indeed, countries heavily dependent on fossil fuels (petroleum, coaletc.) emit more waste from the exploitation, transport, stor-age and processing of these energy sources. Some countriessuch as China, Poland and the majority of African countrieshave a high concentration of waste. This is not surprising given that these countries are still more than 80% dependenton fossil fuels. The dismantling phase of the neighbourhoodproduces the most significant quantity of waste. During thisbuilding phase, most of the building materials are broken, and useless, they can only serve as waste.

The huge quantities of waste regularly produced by humans and released into the environment contribute to environmental pollution by destroying flora and fauna. Nature is unable to bear all the pressure of human reacts symmetrically on different forms with the birth of floods, drought, tornado, cyclone etc. For this, recycling makes it possible to recover all this waste. The waste concentration does not vary in the same way with the introduction of the photovoltaic panels in each of the world regions. Those ones increase the most of waste rate in African countries.In fact, in Africa, most photovoltaic panels are very poorly maintained.

Sustainable neighbourhoods can be recommended as a model of the neighbourhood with a low wastage rate when they are compared to the more conventional neighbourhood. In all regions of the world, new neighbourhoods must be more ecological and adapted to the new climate. To limit the polluting waste emitted during the building demolition phase, future buildings must be constructed with recyclable materials. To reduce daily waste it is recommended to limit packaging, put waste in the right place to properly sort it, to use compost, to limit the use of batteries and to reduce paperwork. Finally, another future study will focus on the analysis of waste on the health of the inhabitants at the neighbourhood scale.

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Declarations

Conflict of interest The authors declare no competing interests.

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