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RESEARCH ARTICLE

Simulation of the photochemical ozone production coming from neighbourhood: A case applied in 150 countries

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Abstract: The main objective of this research is to Evaluate, analyse, to compare and discuss the photochemical ozone production coming from one neighbourhood initially located in Belgium. Which the same neighbourhood design is applied in 150 countries, by applying four parameters adapted to each country such as: energy mix, local climate, building materials and occupants' mobility. In addition, this research evaluates the induced environmental costs of the neighbourhood over a life cycle of 100 years in some countries located on the five continents. The results show that in the case of sustainable neighbourhoods, the photochemical ozone production is 14.3% higher in the Low than High income countries. Photovoltaic panel has a significant effect on the photochemical ozone production; indeed, it allows to reduce between 5-10% of this one. By 2030, if each of the 150 studied countries, increases up to 30% the renewable energy rate in its own energy mix, to the current examples of countries such as: Denmark, Finland, Sweden, Switzerland, Costa Rica, DRC, Nepal, Tajikistan . . . , so, Photochemical Ozone Production will decrease from 32% to 45% depending on the region. An average of 56% of photochemical ozone potential (POP) is produced during the operational phase of the neighbourhood.

Keywords: simulation, ozone, inventory, eco-neighbourhood, countries, environmental impact

1 Introduction

Since 1960, the world population has grown rapidly, so that today, this population is estimated around seven billion people. This population will reach 9 billion by 2030. As a result, a strong pressure of the human on the environment, generating global warming of the planet. Human activity alters the composition of the atmosphere and causes the destruction of the ozone layer[1].

Unlike other gases, ozone is not emitted directly by natural processes or by human activities. It results solely from photochemical reactions. The stratospheric containing 90% of the total amount of ozone is the main reservoir of the troposphere ozone[1]. Ozone is a secondary pollutant, which means that it is not directly produced by automobile traffic, industry, *etc.*, but rather that it is formed, under the action of solar radiation, on the basis of several "precursor" pollutants.

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Since the beginning of the 20th century, the ozone content of the troposphere has increased, mainly for transport reasons. However, it is seen that the speed and rate of increase vary from one region of the world to another[2]. Globally, troposphere ozone acts differently on the environment and human health than stratospheric ozone, which protects us from ultraviolet radiation[3]. Indeed, it is the same molecule, but, its impacts vary according to the content in the air and altitude[4]. The study of ozone concentration is subject to continuous monitoring by global and local observing networks.

Some gas, such as nitrogen oxides (NO_x) or volatile organic compounds (VOCs), common pollutants, have the capacity to produce ozone and other air pollutants in the presence of solar radiation[5]. Ozone is needed in the upper atmosphere to protect the Earth's surface from ultraviolet radiation. However, troposphere ozone causes crop damage and increased cases of asthma and other respiratory conditions[5]. The summer pollutions (smogs), covering the big agglomerations are the most obvious highlighting of the high emissions of gases, which contribute to the creation of photochemical ozone at low altitude. The use of fuel in engines is the main cause of nitrogen oxide emissions[6]. Most organic compounds are used in paints and other coatings. The Potential for Troposphere Photochemical Ozone Creation (POCP) impact category allows us to measure the relative capacity of a gas to generate ozone in the presence of nitrogen oxides and solar radiation[5,6].

According to Andersson *et al*.[7], the concentrations of photochemical ozone creation potentials (POCP) vary according to the calculation method and the chemical environment (NO_x). Reeves *et al*.[8] Showed that much of the mid and lower North Atlantic troposphere is in a state of slow photochemical O_3 destruction. Several researchers such as Anenberg *et al*.[9], Brauer *et al*.[10], and Lim *et al*.[11] found that the rate of ozone-related deaths accounted for between 5 and 20% of all deaths from the atmospheric pollution. In a report published in 2012, the Organization for Economic Cooperation and Development (OECD)[12] said that by 2050, if no law is proposed, the first environmental cause of premature mortality in the world should be air pollution. Brhland Crutzen[13] suggested a reaction, for exciting the oxygen formation from ozone photolysis, as one of the solution to the problem of ozone intensity evaluated to be above 45 km. Recent research of Nematchoua and al.[14] in Belgium, showed that the photochemical ozone production is 75% higher in standard than sustainable neighbourhoods. European Directive 2001/81/EC (known as the "NEC" Directive) imposes emission ceilings for atmospheric pollutant precursors of troposphere ozone (VOC and NO_x) not to be exceeded from 2010. These ceilings expressed in kiloton's (kt), are applicable until 2019. The maximum values imposed for Belgium were 139 and 176 kt, respectively for VOCs and NO_x[15].

The main purpose of this research is to evaluate, analyse and compare photochemical ozone potential generated by a neighbourhood initially located in Belgium, which the same model has been designed in 150 countries, by considering for each country: local climates, local energy mix, local use of materials and local mobility behaviours. Thus, the present study concerns a whole neighbourhood and it is not limited to the case of a country, but it will be studied in 150 countries, with very different climates and energy mix. The quantification and analysis of photochemical ozone impact related to the implementation of photovoltaic panels on the neighbouring roofs are also not limited to a specific region or climate; almost all the climatic zones of the world through 150 countries have been studied. This work did not focus on a single life cycle stage (for example, renovation or use) like some previous studies, but all four phases (construction, use, renovation, and demolition) have been evaluated. Methodology, results and discussions are presented in the next sections.

2 The research methodology

Environmental analysis of a sustainable neighbourhood located in Belgium (Europe) have been carried out over 100 years, and then, the same design have been adopted in 149 other countries, while keeping four parameters specific to each country: energy mix, local climate, building materials, and occupants' mobility. In addition, the costs related to three environmental impacts have been calculated: greenhouse effect, energy demand and biodiversity degradation. Finally, different design parameters have been varied to quantify their effects on the environmental costs of the neighbourhood. Overall, this methodology is divided into five main sections:

(1) Neighbourhood selection and site modelling;

(2) LCA of the selected neighbourhood;

(3) Modelling the same neighbourhood in 149 other countries with adaptation of the four local parameters and life cycle assessment;

(4) Calculation of the cost of the one studied environmental impacts;

(5) Applying one scenario for mitigating some environmental costs.

The following sections (2.1 to 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-neighbourhood

This neighbourhood have been initially located in the Liege city in Belgium, and the same design have been adapted in 149 countries represented in the world. 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 also spaces dedicated to commercial functions or the liberal professions and small businesses have been found. In total, 40 small apartments, 45 larger homes, 11 single-family duplex homes and 6 complementary functions (businesses and shops) can be counted. Private parking spaces are planned near the buildings. All the dwellings located on the ground floor have a private garden.

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. Rainwater recovery systems and tanks are also implemented.

In this research, only the neighbourhood residential part was studied. The calculated environmental impacts correspond to the residential eco-district of 3.5 ha comprising 1 ha of roads, driveways and parking lots, 17800 m^2 of green space, 19740 m^2 of floor space, housing around 219 inhabitants, studied on a life cycle of 100 years.

2.2 Design of the same eco-neighbourhood in other countries

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

Four parameters were simultaneously applied for adapting this neighbourhood 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. Figure 1 shows the different investigation places.

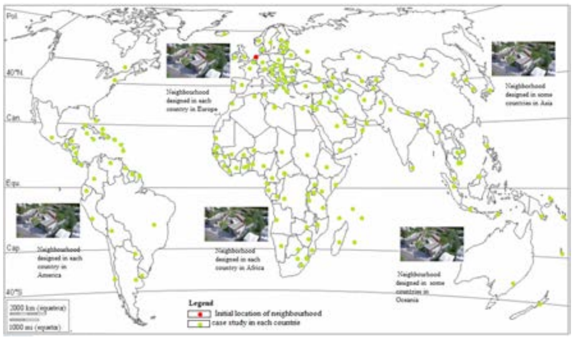

Figure 1. Geo-location of studied sites of design of eco-neighbourhood in the 150 analysed countries

The International Energy Agency (IEA) database[16] 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. The Meteonorm is defined as a meteorological database with climatological data for every location on the globe[17]. The fixed database in Meteonorm 7.3.1 contains approximately 6,200 cities, 8,325 weather stations, and 1,200 Design Reference Year sites.

The information on the construction materials was estimated on the basis of 2018-2020 standard thermal regulation of each country, but also from information issue to the UN-habitat, and some literature reviews (for some African and Asian countries, without recent building standards). Regarding inhabitant mobility, the data were freely selected on Pleaides ACV software. 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.*). Distance of the weekly commute between home and trade is 1000 m; distance from the public transport network is 500 m, distance from the daily commute to work is on average between 5000 m and 10000 m. Presence of bike path, public transportation: bus, subway and tram. These are the standard values suggested by this software.

2.3 Environmental database and studied indicators

The environmental data used to 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 flows into and out of the system[18]: (i) resources consumed (water, energy, *etc.*); (ii) emissions in the different natural environments: air, water or soils (ammonia in water, metals in the soil, CO_2, *etc.*); (iii) waste created (inert, toxic or radioactive). The version 2.2 (2012) of the ECOINVENT database was used. This version was completed by the latest version, ecoinvent 3.5 (2018). The development of this database 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[19]. The (01) environmental impacts of the studied neighbourhood and the production of photochemical ozone (via the Ozone Depletion Potential, ODP) were assessed[20–22].

2.4 LCA simulation software

In this study, a combination of all the new IZUBA energy software was applied. Indeed, the interface of the most recent version (Pleaides 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-PLEIADES), Results, and ACV (nova-EQUER). It is important to notice that each module has a precise function. All of them are regularly used by numerous international research laboratories and have been clearly validated by the scientific community[23–25].

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. By using this software, the zoning of the building where the thermal behaviour is homogeneous[23] were also defined. This software is essentially made up of five components: Generals (Construction Data, Project Library, LCA Association, Weather and Horizon); Plan; 3D; Calculation. This neighborhood was regrouped in 10 blocks with heating requirements showed in Table 1.

Table 1. Heating requirements of different neighborhood buildings

Buildings	Heating requirements (kWh/m^2.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

Editor, COMFIE-PLEIADES software, allows the performance of dynamic thermal simulation for buildings[23,24]. The geometry created via "Modeller" can be imported from the information entered concerning the materials, the occupation scenarios and the meteorological data, the software evaluate the heating and air conditioning needs. It is possible to disaggregate the results based on thermal zone or by a period of time.

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 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[24]. This module is essentially made up of:

(1) Building/neighbourhood 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 neighbourhood; specific or adjusted seizures for energy, water, waste, and transport.

(2) Software organization

The Pleaides ACV interface is structured around five axes:

(a) Library: Environmental Impact Data Libraries, General Calculation Characteristics. In this research, the following parameters have been fixed: 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; distance of transport: site of production towards the building site 100 km, site towards inert discharge finally of life: 20 km.

(b) Project: Project management with structure data for any type of project and use of the building with the EQUER engine. In this research, the following parameters have been fixed: Loss of electrical network from 9% to 40% according to country. Water system yield: 80%, hot water consumption 40 L/day/person; cold water consumption 100 L/day/person; Selective collection of glass: yes; sorted glass: 90%; incinerated waste 40%; recovery to incineration; 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 centre: 100 km.

(c) Experimentation: Specific seizures PEBN E+C-;

(d) Calculation and results: Start the calculations and consult the results.

(e) Neighbourhood: Neighbourhood Management.

Several of this hypothesis are found in standard ISO14040[38], and ISO14044[39].

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[25], which is based on the methodologies developed previously by Debacker *et al*.[26] and De Nocker *et al*.[27] Monetary values of each environmental indicator have been determined in this methodology[25] for three regions: Western Europe, Belgium and the rest of the world. Note that the error margin related to the

Table 2. Environmental cost of each phase of the eco-neighbourhood in Belgium

Environmental impacts	Year	€ /unit	Construction	Operation	Maintenance	Dismantling	ECC
Photochemical product	2030	€/dwelling	157.1	98.1	13.8	8.6	269.8
		€/m^2	0	0.4	0	0	0.4
		€/inhabitant	7.2	4.5	0.6	0.03	12.2
	2050	€/dwelling	398.9	248.8	35.1	2.2	684.9
		€/m^2	0	1.1	0	0	1.1
		€/inhabitant	18.2	11.3	1.6	0.1	31.2

monetary value is low. Table 2 shows the conversion values of the environmental impacts in environmental costs.

2.6 Mitigation of impacts

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

In the initial scenario, all the electricity used to come from the electricity grid of each country, and the production impacts were taken into account. In this new configuration, a photovoltaic system will be on all the roofs on the site. Installed photovoltaic panels cover a total area of 580 m^2 equivalent to a peak power of 82857.14 W. It must be noted that 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 northern hemisphere and toward the north in the southern hemisphere; 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 an optimal inclination in all the countries. The thermal simulation of each building has been then performed and completed the final LCA of the neighbourhood.

The impact of mobility on the neighbourhood's environmental record has now to be looked at. In the basic scenario, a significant use of the car for daily commuting has been considered. This scenario will be compared 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. The mobility hypotheses are: (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 on 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 on 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 materials.

2.7 Scenario

The different projections were conducted under the basis of scenario A2 established by the IPCC[34]. The A2 scenario is at the higher end of the SRES emissions scenarios (but not the highest), and this was preferred because, from an impacts and adaptation point of view, if one can adapt to a larger climate change, then the smaller climate changes of the lower end scenarios can also be adapted to. A low emissions scenario potentially gives less information from an impacts and adaptation point of view. In addition, the current actual trajectory of emissions (1990 to present) corresponds to a relatively high emissions scenario. The hourly data of the last thirty years of temperature, relative humidity, wind speed, sunshine were used in this circumstance.

3 Results and analysis

This section gives some details regarding the origin and cost of photochemical ozone production at the scale of the neighbourhood. POCP is calculated based on ethylene as the reference substance. The United Nations Economic Commission for Europe has defined the characterization factors for the POCP. They are calculated for two scenarios: a relatively high NO_x background concentration and a relatively low background concentration[1].

The indicator of formation of photo-oxidants is as showed in Equation (1):

$$\text{Photo - oxidant formation} = \sum_i POCP_i \times m_i \quad (1)$$

With m_i = mass of substance; i released in kg.

The indicator is therefore expressed in kg of ethylene equivalent (C_2 H_4). Photochemical production results from the dissociation of nitrogen dioxide (NO_2) by ultraviolet radiation. This reaction constituting the main source of atomic oxygen (O) in the lower layers of the atmosphere as showed in Equation (2):

$$NO_2 + hv \rightarrow O + NO \quad (2)$$

Atomic oxygen combining with molecular oxygen (O_2) to form ozone, as shown in Equation (3):

$$O + O_2 \rightarrow O_3 \quad (3)$$

And the production of ozone is however limited by its reaction of nitric oxide: as shown in Equation (4):

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (4)$$

Ozone production is very dependent on sunshine. The photochemical cycle of formation and destruction of ozone has a non-linear character and hence its complexity. The Figure 2 showed different intensity of photochemical ozone production. The Figure 1 shows the different Intensity of Destruction of Troposphere Ozone. The Figure 2 showed different intensity of photochemical ozone production. It is seen toward this picture the different intensity of destruction of Troposphere Ozone.

In Figure 2 (1) and Figure 2 (2), it is seen a strong human pressure on nature, the environment tends to gradually deteriorate, as a direct consequence: the thickness of the ozone layer becomes more fragile. In Figure 2 (3), Figure 2 (4) and Figure 2 (5), it is seen that the ozone layer is further destroyed by the strong pressure of global warming, lets through, the ultraviolet rays of any kind.

Figure 2 (7) and Figure 2 (8) show the future state of degradation of the layer, in case the temperature will increase between 3-5 ° C in the next decade according to estimates by the IPCC.

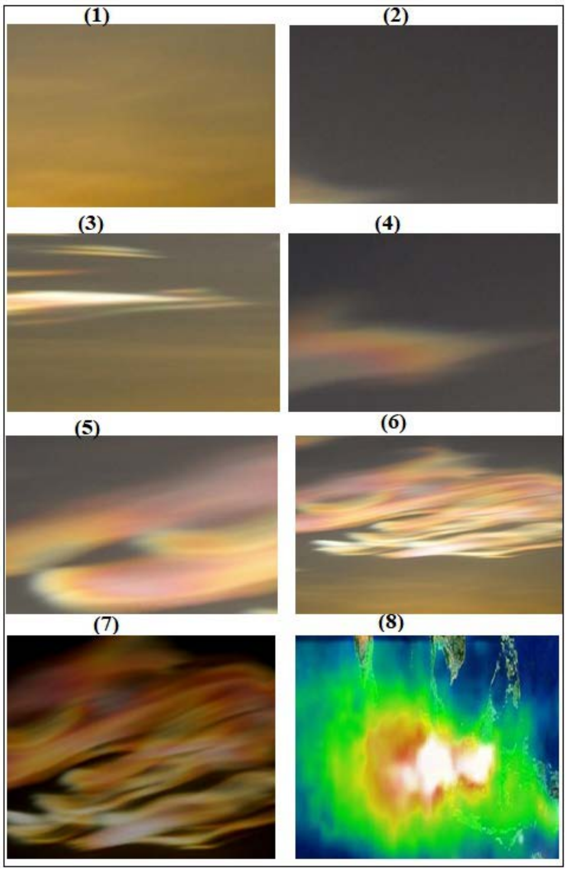

Figure 2. Global Warming and Intensity of Destruction of Troposphere Ozone[28,29]

3.1 Analysis of Photochemical ozone production

In the Figure 3, it is seen that in Northern America, the 56%, and 28% of photochemical ozone production are issued for operation, and construction phases, respectively. In Northern Africa, Asia and Europe, an average of 58%, and 31.5% of this one is produced during operation, and construction phases. In addition, in southern America, and Asia, retrofit phase produces the 12% of total photochemical ozone.

These results show that the majority of photochemical ozone production was issued during “operation or use phase”. These findings further enhance the results of some specialists in the field[30,40]. These results show that the majority of photochemical ozone production was issued during “operation or use phase”. This is not surprising, indeed, during the operational phase, which the duration of the life cycle of buildings is estimated at 100 years in this study, the occupants pollute the atmosphere enormously.

It is seen that the pollution rate is very high in developed countries, especially in the USA and in the European Union. This may be due to the behaviour of the occupants. Indeed, the ecological footprint is very high in developed countries.

3.2 Analysis of photochemical ozone production per square meter living space

In Figure 4, the photochemical ozone production is of 0.01 kg ethylene/m^2 in UK, France, Brazil and Belgium. This one, is two times higher in Cameroon and Nigerian, than the previous countries (UK, France, Belgium . . .). It is interesting to notice that the photochemical ozone production is about 4.5% (in the European Union), 2.8% (in South Africa), 42.8% (in USA and Australia), and 17.7%

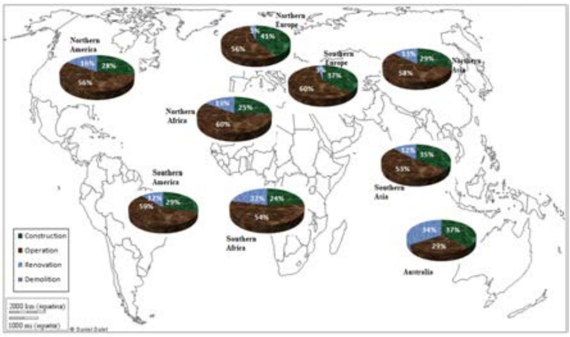

Figure 3. Distribution of Photochemical ozone production frequency of different phase of sustainable neighbourhood in several world regions

(in High-income countries); lower, than the world average. In addition, (POP), is 14.3% (in Japan and India),and 5.7% in Africa; higher than world average.

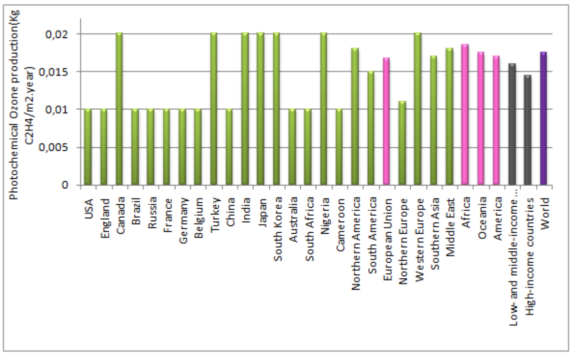

Figure 4. Assessment of photochemical ozone production per square meter coming from a sustainable neighbourhood distributed in some countries, regions and continents in the world

3.3 Photovoltaic effect on the photochemical ozone production

As shown in Figure 5, Photovoltaic panel has a significant effect on the photochemical ozone production, indeed, it allows to reduce up to 8.6% of this one. It is interesting to notice that photovoltaic impact on the photochemical ozone production, vary according to climate types. For example, in temperate zone, photochemical ozone production decrease up to 9.70% (from 9.07 kgC_2H_4/dwelling to 8.18 kgC_2H_4/dwelling); in tropical climate, photochemical ozone, decrease up to 7.67% (between 12.31 kgC_2H_4/dwelling and 11.37 kgC_2H_4/dwelling). However, it has been noticed that in some coastal countries such as Madagascar island, Italy, Egypt, the implementation of photovoltaic in a sustainable neighbourhood accelerated the photochemical ozone production.

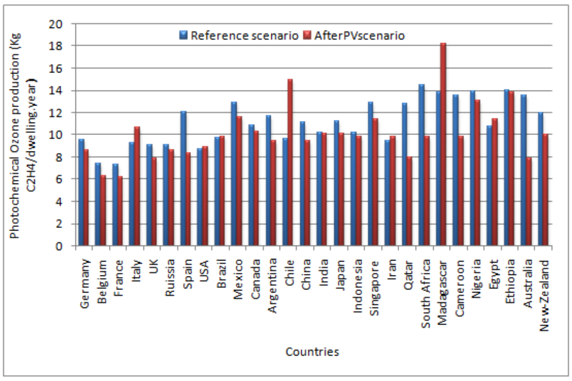

Figure 5. Comparative diagram of the photochemical ozone production impact of the "Initial" and "Photovoltaic" Scenarios (Functional Unit: dwelling)

3.4 Environmental components and costs

Figure 6 shows the frequency of the different environmental components in the generation of the photochemical ozone production in 29 representative countries located in the five continents of the world (Europe, America, Africa, Asia, and Oceanic). The total photochemical ozone production concentration coming from each component is 40.3% (from building material), 36.4% (from electricity), the 3.9% (from water), 3.5% (transportation), 2.4% (heating building), and 3.4% (from waste). These results show that the main source of photochemical ozone production is "building material" followed of "electricity production". In China, USA, India, Indonesia and Spain, the electricity is the first source generating the photochemical ozone production. Despite that, it has been noticed that, the contribution of building material is still very significant.

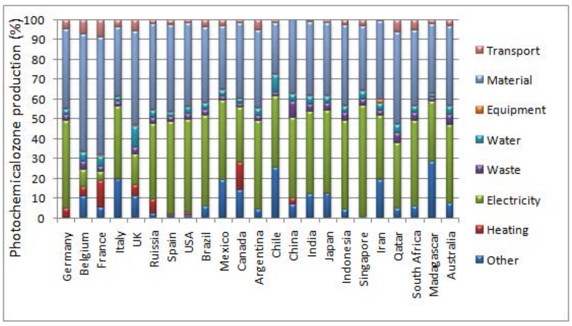

Figure 6. Frequency (%) of the different environmental components in the generation of the photochemical ozone production, for some countries located in the five continents of the world

All these different components are automatically given by the simulation tool[14]. Photochemical ozone is very dangerous, indeed, it decreases the photosynthesis activity in plants, thus limiting their growth. This leads to yield losses in agricultural and forestry crops. This one reinforces the greenhouse effect, contributes to the deterioration of paints, plastics, rubber and nylon.

An average of 13.5% photochemical ozone production comes from heating in France and Canada. In the Figure 7, it is seen that the global photochemical ozone production over 50 years is 0.013 €/m^2. In China, such as in USA, the photochemical ozone production cost is 30.7% lower than mean world. In Europe, such as in America countries, the photochemical ozone production cost is 15.4% higher than mean world. In Africa, the Photochemical ozone production cost is expected to be 0.17 €/m^2 over 50 years of life cycle of neighbourhood. Some relevant data are showed in Figure 7.

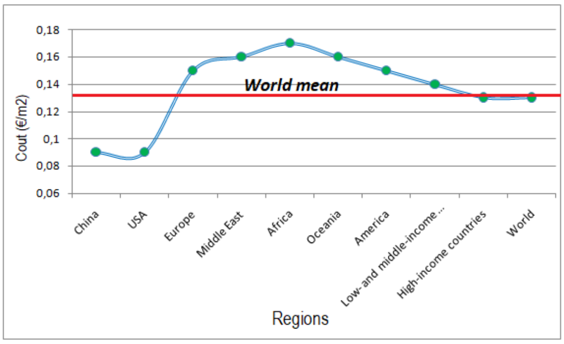

Figure 7. Photochemical ozone production over 50 years per square meter

Globally, photochemical ozone productioncostis 7.7% higher in Middle income countries than High-income countries. This result is not surprising, indeed, this last decade, the photochemical ozone production concentration has considerably increased in the countries having Low and Middle incomes.

4 Discussion

In this research, it has been found that the photochemical ozone production is 31% during the construction of neighbourhood, 57% (operational phase), and 11.9%(retrofit phase). Only, the 0.1% of photochemical ozone is produced during the demolition of the neighbourhood. The operational phase is the most important of four phases of neighbourhood's life cycles. In other studies applied in other neighbourhood's types, similar results were found[30–32]. This result is similar for the majority of environmental impacts, excepted the impact from waste, which the production rate is more important in the demolition phase of building.

The photochemical ozone concentrations measured far from the precursor sources are higher than those measured near the emitting sources themselves[33]. For example, suburban and rural areas are more affected than urban areas by peak ozone concentrations[34]. Globally, in functional unit: square meter, the photochemical ozone production is 14.3% higher in Low income than High income countries. This one is 10.8% higher in Africa countries than European Union countries. In addition, the photochemical ozone production is 2 times higher in Canada than the USA, then 2 times higher in Turkey than France, 2 times lower in Brazil and Germany than India and Japan. This huge difference may be due to weather conditions favouring the emergence of high concentrations of ozone such as high air temperature, low air humidity, long sunshine, high irradiation, and a low synoptic wind speed. These previous results seem to be more connected with sustainable neighbourhoods. An extension can be assessed with old neighbourhoods. The effect of Photovoltaic (PV),on Ozone is positive, because, solar energy is the main source of PV. This study shows that the 8.6% of ozone's damage can be reduce by using PV in the neighbourhood scale.

Overall, PV effect depend on kind of environmental impact. For example some studies showed that PV allow to mitigate up to 10% of energy consumption in the residential buildings in temperate climate, but increases the waste quantity[35]. Other ones showed that the PV, according to the climate can generate a negative effect on the biodiversity[36]. The strong photochemical ozone production has an impact on human health. Indeed, it causes irritation of the respiratory tract and eyes, decreased physical performance and deterioration of lung function[36]. The electricity production is one of the main components of the photochemical ozone production at the neighbourhood scale. Globally, in Europe, the photochemical ozone cost is 7.1% higher than Low income countries.

In Africa, this one is 6.3% higher than Middle Eastern. The fight against the destruction of the ozone layer is a concern of all nations. According to IPCC[?], the total contribution to the greenhouse effect is 60% of H_2O; 26% of CO_2; 8% of O_3 and 6% of ($CH_4 + N_2O$), these data may be of interest to the researchers to protect the ozone layer (O_3), because its destruction causes significant damage.

5 Conclusion

This research evaluated the photochemical ozone production in a neighbourhood initially located in Belgium. The same neighbourhood has been built in 149 other countries by respecting some parameters own at each country, such as the use of different materials, the heating/cooling systems, the energy mix, the buildings insulation thicknesses, mobility, the climate related to the temperatures. The detailed study of this environmental impact is very important, indeed, ozone is involved in the greenhouse effect. It is the third greenhouse gas in terms of global warming potential after CO_2 and CH_4. The buildings classified after the industries and transports have a great influence on the photochemical ozone production. During 100 years of the neighbourhood's life cycle, it has been found that the majority of photochemical ozone production (57%) is emitted during the exploitation phase. In the sustainable neighbourhoods, the photochemical ozone production concentration is 14.3% higher in Low income countries than High income countries. The implementation of PV shows a positive effect on the protection of photochemical ozone production. Today, the electricity and building material represent the main component of photochemical ozone. This study analyses the photochemical ozone production in many countries. The applied methodology is easily reproducible to other kind of neighbourhoods. The next step in the research will suggest, analysis and compare some scenarios, allowing to reduce the photochemical ozone rate at neighbourhood scale.

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