Life cycle assessment of a nearly zero-energy neighborhood in Belgium

Modeste Kameni Nematchoua[1,2*] , Sigrid Reiter[2]

[1]*Beneficiary of an AXA Research Fund postdoctoral grant, Research Leaders Fellowships, AXA SA 25 avenue Matignon75008 Paris, France.*

[2]**Management & Analysis (LEMA), Allée de la Découverte9, Quartier Polytech 1, BE-4000 Liège, Belgium.**

Email : [1,2*]mkameni@uliege.be , [2]sigrid.reiter@uliege.be

Abstract— ***Life Cycle Analysis (LCA) is the most appropriate method to quantify scientifically the environmental and health impacts of buildings. The purpose of this research is to determine, at the neighborhood scale, the most important sources of buildings' environmental impacts, based on twelve different environmental impacts including the health impact. This paper compares the impacts on the environment generated by an existing energy efficient neighbourhood, where all the buildings should be passive, and its transformation into a zero-energy district thanks to the addition of numerous photovoltaic panels on the roofs of the buildings. For that, we used the combination of three simulation tools — ALCYONE, COMFIE-PLEIADES and nova-EQUER for studying the Life Cycle Assessment (LCA) of buildings and networks (roads, parking, etc). An eco-neighbourhood, located near the University of Liege in Belgium, has been selected as the case study. The buildings heating modelled by the dynamic thermal simulation has an average heating load of 15.4 kWh/m².year.Photovoltaic panels on all the roofs of the buildings allow achieving a nearly zero-energy neighbourhood and can mitigate up to 25% of greenhouse gas emissions of the passive neighborhood and reduce 5% of its health impacts. However, the photovoltaic panels have a mixed environmental record for other indicators, with a majority of the environmental impacts being improved compared to the passive neighborhood, but four of the twelve environmental impacts studied being increased.We also notice the strong predominance of the occupation phase on the life-cycle environmental impacts of this nearly zero-energy neighborhood. The use phase concentrates more than 70% of the greenhouse gas production and of the cumulative total energy demand of the neighborhood calculated during 80 years. Moreover, the results show a very strong participation of the mobility component and the household waste management component, in the LCA, at the neighbourhood level. The cumulative energy demand from inhabitants' mobility and waste management during the use phase was 60% of the total cumulative energy demand of the neighbourhood, over its entire life cycle. The results show also that an improved mobility management allows reducing all the environmental impacts of the neighborhood and may reduce its health impacts up to 32%.***

Key-words : Life cycle assessment, urban scale, zero-energy neighborhood, health impact, environmental impacts.

I. INTRODUCTION

The building sector is one of the sectors that consume the most natural resources, especially fossil fuels. It induces enormous environmental impacts [1]. The strong environmental impact of the residence building sector has been well understood by the European authorities. For this, several new regulations came into force, aimed for reducing energy consumption of new buildings. These regulations are more and more demanding. However, they only target one scale, that of the building, which concerns only one indicator, the energy consumption and only one stage of the life cycle, the occupation stage[2].Beyond the building scale, the zero-carbon city concepts , city without CO2, or post-carbon city are emerging around the world. Cities are concentrating more and more population, they now welcome 50% of humanity. According to Colombert et al. [3], Cities are becoming aware of the need to preserve biodiversity and green spaces.

In the literature, it is stated that the transport sector is responsible for 31% of overall final energy consumption, and the industry sector for 27%. However, the biggest consumer in many countries is the building sector. It is recommended that in order to reach the energy efficiency targets, wished by the European Commission, all energy consuming sectors must evolve and take ambitious measures[4-5] .

The life cycle assessment (LCA), allows achieve different types of comparative studies to be conducted. Indeed, this method also makes it possible to quantify the environmental impact on the complete life cycle of a product or only on one stage of the cycle without necessarily making a comparison. Thus, it is a tool that can serve as a decision aid but also allows to target the phases of the life cycle of a product that would need to be reworked with an eye to the environment. Many sustainable building certification schemes are based on LCAs of building materials [6].

Such an approach allows choices to be made that reflect a long-term vision and push each stakeholder to assume their environmental responsibilities .

Guinea et al. [7] explained that one of the first LCA researches on the analysis of aluminum cans was carried out by the Midwest Research Institute for The Coca Cola Company. In addition, Buyle et al. [8] explained that the first LCA was performed in the 1970s. In the early 1980s, life-cycle analysis widened its interest to the field of construction. Different studies used different methods, approaches and terminologies.

In one study, Bribiánet al.[9] showed that the environmental impacts can be significantly reduced by applying the new methods of eco-conception.in addition, Ramesh et al.[10] found that a redundant use of passive characteristics in a habitat cannot be profitable.Vilches et al.[11] showed that in the new researches regarding LCA, the energy demand and greenhouse gas are two elements always studied.

Lundin et al. [12] showed a new method allowing to compare the environmental burdens of sanitation systems and different technical solutions by means of their Life Cycle Analysis. Johanna Berlin [13] identified those activities which contributed to the environmental impact the cheese during its life cycle. Milk production was observed as having the biggest environmental impact as well as the production of plastic wrapping. Jian et al. [14] showed that urban life cycle assessment is an effective way for environmental impact assessment of development projects. Peters [15] explained in detail the algorithms which reduced computing time and memory usage for solving LCA systems as well as conducting Monte Carlo analyses.

This research determines, at the neighborhood scale, the most important sources of buildings' environmental impacts, based on twelve different environmental impacts including the health impact. This paper compares the impacts on the environment generated by an existing energy efficient neighbourhood, where all the buildings should be passive, and its transformation into a zero-energy district thanks to the addition of numerous photovoltaic panels on the roofs of the buildings. The next section showed the main objective and research methodology and the last section presented some results and then, an analysis and discussion.

II. Main objective and research methodology

The main aim of this research is to evaluate three environmental impacts such as energy demand, greenhouse gas and health damage of a nearly zero-energy neighborhood. In addition, this research will seek to quantify the impact of photovoltaic panels on the environmental balance sheet of a sustainable neighborhood.Even if the general influence of the use of renewable energy sources are known, we wished to quantify precisely their environmental impacts on an eco-neighborhood and compare them.

The research methodology is divided into four steps : (a) data gathering and investigation on the characteristics of the chosen case study, (b) site modeling and LCA of the eco-neighborhood; (c) LCA results analysis for the reference neighborhood; (d) Comparison between a passive neighborhood and near zero-energy neighborhood.

In this work, we used a combination of three software: ALCYONE, COMFIE-PLEIADES and nova-EQUER.All these tools are regularly used by numerous international researchers (for example [23]).ALCYONE is a graphical input tool. It allows the description of the geometry of the buildings, to represent its solar masks and to define the composition of the walls. COMFIE-PLEIADES allows the dynamic thermal simulation of the buildings. From the geometry created via ALCYONE and imported in COMFIE-PLEIADES and information specified concerning the materials, the occupation scenarios and the meteorological data, this software evaluates the energy consumptions of the buildings. It is possible to disaggregate the results by thermal zone or by period of time. NovaEQUER is the environmental quality assessment tool. The LCA is based on COMFIE-PLEIADES results and additional data, such as the energy mix, the mobility of users, the constitution of outdoor spaces and networks for example. The software allows performing the LCA of a building or a district and presents the 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.

The environmental data, which we use for the LCA modelling, 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 [16]: (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 the version 2.2 (2012) of the ECOINVENT database. The development of this database follows processes that have been certified several times as 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 is recognized for the transparency of their methods [17].

In this research, we evaluate three (03) environmental impacts of an eco-district over its life cycle :the greenhouse effect(via the *Global Warming Potential,*GWP); Cumulative Energy Demand; Damage to health(via the Disability Adjusted Life Year, DALYs).

III. The case study

Liege is a city located in Belgium, in Europe. The Liege city is characterized by a temperate climate, which is favorable for outdoor activities. In this study, the Sart-Tilman eco-district in Liege was selected as a modelling site. Indeed, this site is one of the privileged places of the country where the concept of sustainable design were applied. The site is strongly served by public transport linking it to the center of Liege, this because of the proximity of the University of Liege. Figure 1 shows the studied eco-district.

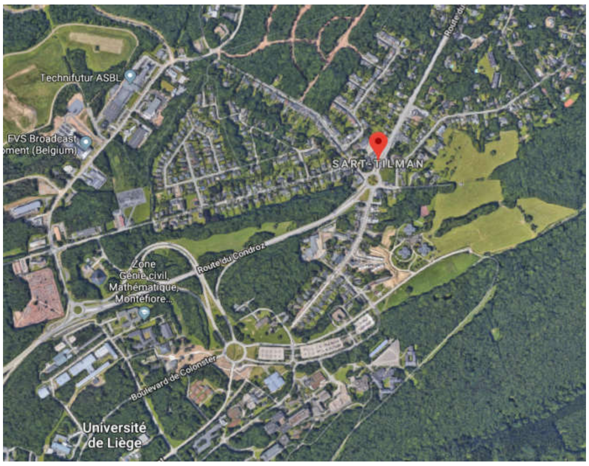

Figure 1: The case-study: an eco-neighborhood located near the University of Liege in Belgium.

This neighborhood offers different types of residential buildings: apartment buildings and semi-detached single family houses. 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 all, we count 40 small apartments, 45 larger apartments, 11 single-family duplex houses and 6 complementary functions (shops and service buildings). Private parking spaces are planned near the buildings. The accommodations on the ground floor have all a private garden.

Nearly all the buildings of this eco-neighborhood were designed with respect to energy consumption imposed by the passive standard. Moreover, this district meets almost all the criteria of the sustainable neighborhood assessment method published by the University of Liege [18-19] and other sustainable assessment tools. The site has a density of 40 dwellings / hectare. Outdoor spaces are landscaped with more than 30% "green" or permeable surfaces and there is a separate water management for rainwater and wastewater. Valves and water recovery tanks are also implemented.

In this research, only the neighborhood residential part was studied. The neighborhood environmental impacts are calculated on the basis of three functional units. The gross results corresponded to the functional unit "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 for around 220 people, studied on a life cycle of 80 years and located in Liege in Belgium. These results were then transformed to answer two additional functional units, which are more convenient for comparison with other studies : the area (per m²) and the population (per inhabitant).

In the implementation process of this modeling, we defined the thermal zones and their scenarios of occupancy, in order to carry out our dynamic thermal simulation. Looking at the study scale, only three types of thermal zones were created for each dwelling. We separated the apartments into two zones: a day zone and a night zone. In addition to that, we have created an area corresponding to the halls. The statistical analysis of the meteorological data showed that in the day zone, the heating set point temperature was 16°C between 22:00 hours and 07:00 hours and 19°C during the day, whereas, in the night zone, the temperature was about 18°C between 22:00 hours and 07:00 hours and 16°C during the day. We assumed the area that was occupied during the day and unoccupied at night and conversely for the night area. We judged a temperature of 18°C was sufficient for the rooms, in case of sleep. The dissipated power inside the building was mainly due to the use of electrical equipment generating heat. Their values were increased during the daytime, when the occupants' requirement of electrical appliances was assumed to be greater. The analysis of the data obtained showed that between 7:00 a.m. and 10:00 a.m. and between 6:00 p.m. and 9:00 p.m., it was around 5.7 W / m². The data analysis allowed us to set the occupancy of our apartments at 0.033 inhabitants / m², which approximated to one occupant per 30 m².

IV. Results

As showed on figure2, it is saw that the concentration of Greenhouse gas over 80 years varied from 52.4tC02 to 21925.1tCo2 at the "Basic neighborhood"; but, between 52.4 and 16359.7tCo2 at " neighborhood with photovoltaic panel ".

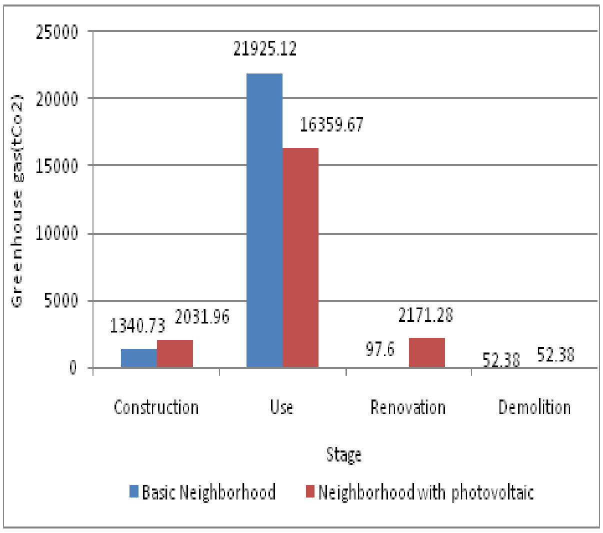

Figure2. Comparison of greenhouse gas emission in the basic neighborhood and neighborhood with photovoltaic panel.

The operational phase broadcasted 93.6% of greenhouse gas over this period, while only 5.7% is broadcasted during the construction of this neighborhood. Overall, the installation of photovoltaic panels in the initial neighborhood leads to the reduction of greenhouse gas emissions by 12%. This high CO2 concentration generated during the neighborhood operational phase has a significant impact on global warming of the earth. This is mainly due to the daily mobility of the human (displacement by bus, bus, train etc.),fossil energies use , heating, public space management etc.

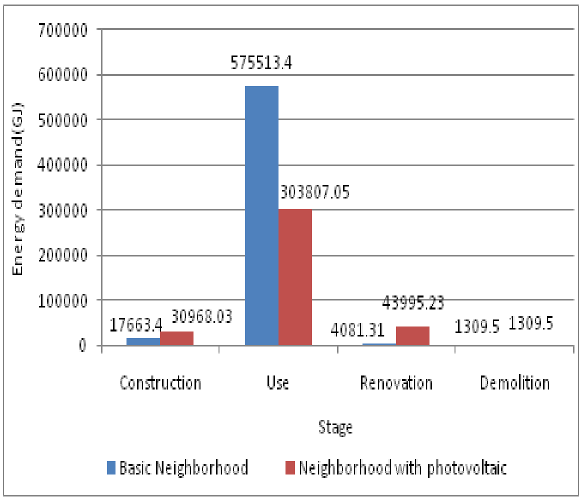

Figure3. Comparison of energy demand in the basic neighborhood and neighborhood with photovoltaic panel.

On the figure3, it is seen that over 80 year , energy demand is expected for varying from 1309.5 GJ to 575513.4 GJ in the "Basic neighborhood", and between 1309.5GJ and 303807.05GJ, in the same neighborhood, but with the installation of photovoltaic panels. The 96.2% of total energy demand is used during the neighborhood operational phase. It is important to notice that 36.5% of total energy demand is saved after installing of photovoltaic panel . This technique facilitates the autonomous of neighborhood in energy. The energy consumed is 33; 141; and 439 times higher during the neighborhood operational phase than construction phase; the operational phase than renovation; and the operational phase than neighborhood demolition phase, respectively. The data analysis shows that 39.12kgCo2 is emitted into the atmosphere per GJ of energy produced .

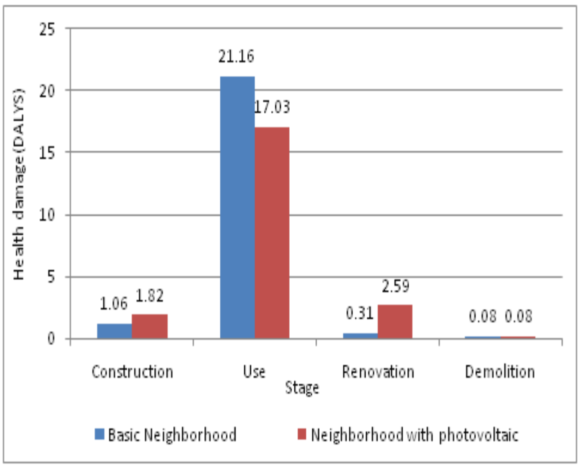

Figure4. Health damage in the basic neighborhood and neighborhood with photovoltaic panel.

Figure4 shows the health damage in near zero energy neighborhood. The heath damage is 93.6%, 4.7%, and 1.3%, for neighborhood operational, construction, and renovation phases, respectively. The health damage is reducing from 4.9% in the neighborhood with the green neighborhood.

V.Discussions

The results of this research shows that the greenhouse gas emission, as well as energy demand and health damage are different in both neighborhoods. They are more significant in the basic neighborhood. Besides, after installing of Photovoltaic panels in basic neighborhood, it is noticed a decrease of 12% of greenhouse gas, 36.5% of energy demand and 4.9% of health damage. Globally, the installation of photovoltaic panels has a mixed record. We see that the manufacture of such panels is not neutral for the environmental impacts. Despite like that, they allow to have an ecology neighborhood.

According to several experts and researches[20-24] the implementation of renewable energy systems plays an important role in mitigating environmental impacts. Using photovoltaic panel systems is the best strategy for limiting the generation of radioactive waste and the cumulative demand for energy. However, their manufacture has a negative impact on LCA in terms of damage to biodiversity and waste produced. Thus, considering the possibility of their large-scale implementation, researches aiming to improve their manufacturing and recycling processes from the environmental point of view are urgently needed. The 40.1% , 14.8%, and 9.7% of greenhouse effect is broadcasted by transportation, heating and electricity production. These results showed that the mobility of population has a significant effect on greenhouse gas emission. These results are almost similar at those published in several IEA reports[25-26].

VI.Conclusion

This research has analyzed the impacts of renewable energy, such as photovoltaic panels on greenhouse gas emission, energy demand and health damage in a near zero energy neighborhood. It's noticed that the environmental impacts are mitigated in sustainable neighborhood. The mobility management should be treated as a priority, given their considerable influence on the LCA of an already energy efficient neighborhood. It is really important to install photovoltaic panels on the residence buildings to reduce the cumulative demand for energy and the greenhouse gas , while increasing research to reduce their environmental impacts during the renovation and construction phases. But also to reduce to 4.8% the health damage.

This research was focalized under analysis of three impacts, however, many other parameters remain to be studied in order to provide designers with complete lines of conduct, such as acidification, odor, waste water etc.

Other LCA studies should be carried out in several other neighborhoods located in several countries with different climate in order to better compare the results and adapting a global resolution .

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