IAPE '19, Oxford, United Kingdom
ISBN: 978-1-912532-05-6

Life cycle assessment of an eco-neighborhood: influence of a sustainable urban mobility and photovoltaic panels

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ABSTRACT
During this decade, the human exploitation on the environment is being to completely change the nature of the ecosystem. According to the experts, Life Cycle Analysis (LCA) is the most appropriate method to quantify the different environmental impacts of human activities.The main purpose of this research is to quantify, at the neighborhood scale, twelve environmental impacts. Moreover, this research proposes to study two sustainable strategies to reduce these impacts on the environment: a sustainable urban mobility and the addition of photovoltaic panels on the buildings' roofs. We will thus seek to quantify the impact of mobility management and local energy production on the environmental balance sheet of a sustainable neighborhood.For that, we used the combination of three simulation tools — ALCYONE, COMFIE-PLEIADES and novaEQUER for studying the Life Cycle Assessment (LCA) of a case study. An eco-neighborhood, located in Belgium, has been selected as the modeling site. The results show that a sustainable mobility management in cities allows reducing from 4% to 50% of each of the twelve environmental impacts calculated for a neighborhood over its entire life cycle. The photovoltaic panels can mitigate up to 25% of greenhouse gas emissions, but this scenario generates an increase up to 18% for the damage to biodiversity and 21% for waste production.

Keywords
Life cycle assessment, neighborhood, urban mobility, renewable energy.

1. INTRODUCTION
More than 50% of the world's population lives in cities [1]. This number is constantly growing, especially in developing countries. The building sector is one of the sectors that consumes the most natural resources, especially fossil fuels. It induces enormous environmental impacts. In industrialized countries, the construction sector is responsible for 42% of final energy consumption [2], 35% of greenhouse gas emissions [3], and 50% of all-material extractions [4]. In addition, urban sprawl is causing ever greater land use. Between 1980 and 2000, European built space increased by 20% [5]. According to Allacker et al [6], buildings are responsible for different types of soil consumption: a so-called primary consumption, that is to say their physical footprint, but also a secondary consumption, due to extraction, production, transportation and end-of-life treatment of construction products. This type of impact is very little, if at all, considered in most studies, including life cycle analysis studies of the built environment [7]. However, researchers, politicians and companies have been working for several decades to significantly reduce the energy consumptions and, to a lesser extent, the environmental impacts of buildings [8]. For this, regulatorytools and European standards were put in place.

Targets are set at European level to address environmental issues. The "2020 Package", a set of binding legislative acts, aims to reduce greenhouse gas emissions by 20% (compared to 1990 emissions), reducing primary energy consumption by 20% and reaching 20% of renewable energy use of overall European consumption. These goals, defined in 2007, are to be achieved by 2020 as part of smart and sustainable growth [9].

In Europe and so also in Belgium where is located our case study, the regulation on the energy performance of buildings (EPB) sets the mandatory energy requirements [10]. According to Anderson et al. [11], various methods make it possible to draw up the environmental assessment of a construction. Some methods use statistical models, others simulations. At the building level, the Life Cycle Assessment (LCA) method is a clearly validated scientific method and is even standardized at the European level. It is currently the best scientific approach for conducting an environmental assessment at the building and neighborhood levels[12]. It allows a quantitative study of buildings and neighborhoods over their entire life cycle. Most scientific studies on the subject use this method, which has been used more and more at the building level since the last 25 years. However, its use at the urban or neighborhood level is recent [13]. Some interesting studies on LCA of buildings are showed in [14-18].

Some recent studies aimed at studying LCA at the neighborhood level in the literature,often focusing on a single environmental impact (such as energy use). This research assesses at the scale of the neighborhood the twelve main elements that impact the environment and deepen the study of the influence of inhabitants' mobility and the potential addition of photovoltaic panels, as

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DOI: http://dx.doi.org/10.17501.......................................

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sustainable strategiesto mitigate the different impacts of this eco-neighborhood.

This work consists of six main sections: the first section is the introduction, the second presents the detailed methodology, the third section presents the case study, the fourth section presents the evolution scenarios; the fifth presents the results and discussion, which analyzes the influence of urban mobility and photovoltaic panels on the various studied environmental impacts, while the last section presents the conclusion and references.

2. MAIN OBJECTIVE AND RESEARCH METHODOLOGY

The main purpose of this research is to quantify twelve environmental impacts of an eco-neighborhood. In addition, this research will seek to quantify the impact of mobility and photovoltaic panels on the environmental balance sheet of a sustainable neighborhood.Even if the general influence of a sustainable mobility and 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 modelling and LCA of the eco-neighborhood; (c) LCA results analysis for the reference neighborhood and development of scenarios to improve them; (d) LCA modelling of the evolution scenarios for environmental improvement and analysis of their results.

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 [19]: (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).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 [20].

In this research, we evaluate twelve (12) environmental impacts of an eco-district over its life cycle :the greenhouse effect(viathe*Global Warming Potential*,GWP) ; acidification(via the Potential of Acidification, PA); Cumulative Energy Demand; the water used; Waste produced; the depletion of abiotic resources (via the Abiotic Depletion Potential, ADP); eutrophication (via the Potential of Eutrophication , PE) ; the production of photochemical ozone (via the Ozone Depletion Potential, ODP); damage to biodiversity; Radioactive waste; Damage to health(via the Disability Adjusted Life Year, DALYs); Odours(via the Odour Threshold Value, OTV).

3. 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 Liège. Figure 1 shows the studied eco-district.

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

This neighbourhood 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 appartments, 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 neighborhoodassessment method published by the University of Liège [21] 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

DOI: http://dx.doi.org/10.17501.......................................

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.

4. THE SCENARIOS FOR A SUSTAINABLE STRATEGY

Or basic scenario, takes into account the real eco-neighborhood with commuting habits equivalent to the mean distance travelled and the usual means of transport in this region (Wallonia, in Belgium). This hypothesis considers a significant use of the car for daily commutes. We will compare this scenario with a second one where the site is considered urban, perfectly integrated with the public transport networks and at a short distance from the shops of primary needs and employment places and a modal choice preference toward sustainable transport modes. Let’s summarize the mobility assumptions: (1) Initial scenario: (i) 80% of the occupants make a home-to-work journey daily, with the distance from home to work of 20km carried out daily by private car, (ii) the distance between home and shops of 5km is carried out weekly by car. (2) "Urban Site" scenario: (i) suppose that the 100% of the occupants make a journey daily; (ii) assume that the commuting distance of 2.5 km is performed daily by bus and suppose the 300m home-shopping distance is done weekly by bike or on foot.

In the initial scenario, all the electricity used comes from the Belgian electricity grid and the production impacts are taken into account. In a “Photovoltaic” scenario, we have a photovoltaic system on all the roofs of the site and we consider a panel area equivalent to two thirds of the roof area for each building. It should be noted that the buildings only use electricity to light and to power household appliances. Indeed, the climatic conditions in Belgium do not require cooling in residential buildings. The selected installation consists of mono-crystalline photovoltaic solar panels. The sensors are placed using a support on the roof terrace. They are oriented south and inclined 35 °, which is the optimal inclination in Belgium.

5.RESULTS AND DISCUSSIONS

5.1. Analysis of mobility impacts

As shown in Figure 2, it is now clear that mobility has a huge impact on the neighborhood's environmental record. Adopting the sustainable urban mobility scenario, this is seen that, all the environmental impact indicators are reduced from 4% to 50% and that 7 out of 12 indicators are reduced by more than 20%.

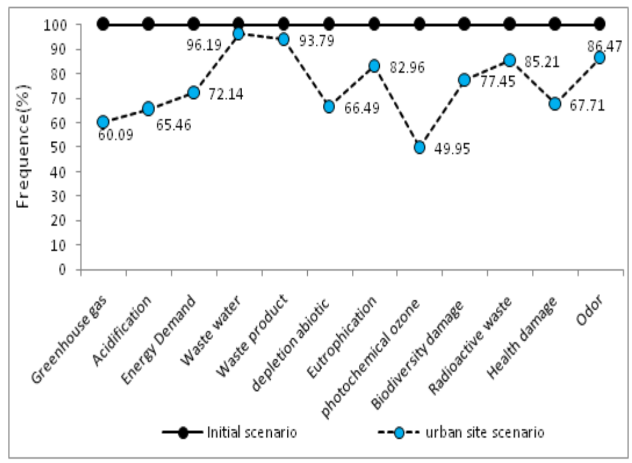

Figure 2. Comparison of environmental impacts of the neighborhood with different mobility scenarios(Functional Unit: Entire neighborhood).

It is important to note that photochemical ozone production is reduced by more than 50% over the entire new neighborhood's life cycle. In fact, the combustion of fuels is the main source of nitrogen oxide production, which transforms into ozone under the effect of sunlight. In the proposed scenario, relating to the urban site and a sustainable modal choice, 54% of the photochemical ozone production of the use phase is avoided by reducing the use of the car. Indeed, 95% of the ozone production due to transport during the operational phase is avoided in this scenario. Note that the second photochemical ozone station is waste management.

Regarding the greenhouse effect, the observation is identical, we observe a 40% decrease in emissions over the entire life cycle of the neighborhood, this thanks to a 93% decrease in emissions from transport during the use phase. Acidification is also strongly impacted by the elimination of the use of the car. We observe a 35% decrease in this impact indicator over the entire life cycle of the neighborhood. It is the same for the depletion of abiotic resources and the damage to health that sees their score reduced by 34% and 32% respectively. Indeed, much less fuel and fossil resources are consumed and the pollution responsible for many health problems is also greatly reduced.

Decreasing the use of the car can make huge energy savings. Public transport uses the energy contained in fuels in a more

DOI: http://dx.doi.org/10.17501.......................................

efficient and rational way. Thus, the cumulative energy demand is reduced by 28%.Finally, we observe a 23% decrease in damage to biodiversity, 17% of eutrophication, 15% of radioactive waste, 13% of odors, 6% of waste products and 4% of waste water.

So, it is obvious that mobility and the use of personal vehicles to carry out daily commuting distances have a huge impact on the neighborhood's environmental record. Climate impact indicators are the most affected. It is possible to reduce them by 40 to 54%. The cumulative demand for energy, acidification, depletion of biotic resources and damage to health over the entire neighborhood’s life cycle can be reduced by a third thanks to a sustainable mobility.

5.2. Impacts of a local renewable energy production

At the level of the dynamic thermal simulation, consumption and electricity production are calculated. As shown in Figure 3, for all buildings, production exceeds consumption over the whole year except for the months of December and January where the installation covers respectively 45% and 75% of the consumption. The dwellings consume on average 12kWh / m² of electricity per year. These results are in line with the Belgian averages for dwellings that do not heat up with electricity. The dwellings have an heating load on average of 15 kWh / m² (Passive standard) and no cooling loads. Solar panels produce an average of 26kWh / m² over the year. Thus, apart from the months of January and December, no electricity will be drawn from the Belgian network.

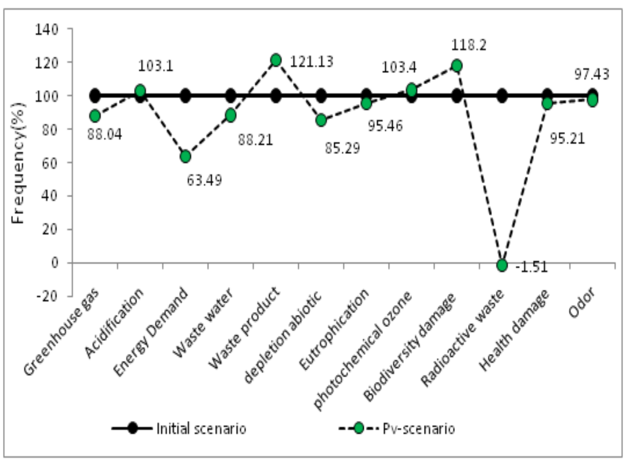

Figure2. Comparative Diagram of the Environmental Impacts of the "Initial" and "Photovoltaic" Scenarios (Functional Unit: Entire neighborhood).

The most affected impact due to the “Photovoltaic” scenario is the production of radioactive waste. Over the entire life cycle, the production of radioactive waste is reduced by 102%. Indeed, even if this production of waste increases during the construction phase and renovationbecause of the impact of the manufacture of panels, the use phase makes up for this decrease. This is because energy production is higher than energy consumption. As a result, not only is the construction and maintenance of the system offset, but the production of radioactive waste from the use phase is also eliminated. And moreover, it allows other buildings to benefit from the clean energy produced. Thus, our neighborhood reduces the production of radioactive waste from additional buildings, which gives a negative score for this indicator.

The second most impacted indicator is the cumulative demand for energy. The total energy needed by the neighborhood to operate over its entire life cycle is reduced by 37%. Once again, the construction and renovation phases are negatively impacted. However, the occupation phase saw its demand decrease by 47%. The depletion of abiotic resources and the greenhouse effect also decrease by 14% and 12% respectively over the entire life cycle. The evolution of the indicators follows once again the same pattern, ie a significant increase in the construction and renovation phases but a greater reduction in the use phase.

Conversely, some indicators see their score increased. This is the case of the production of waste. The renovation phase saw its waste production increase by 742%. In fact, the 4400m² of panel area must be replaced three times over the neighborhood's life cycle and in addition include their initial installation. The 15% decrease in waste production during the use phase does not fill this increase. As a result, the district's total waste production over its entire life cycle is up 21%.Finally, the damage done to biodiversity is also increasing in this scenario. It is again the manufacture and the replacement of the panels which is in question. Thus over the cycle, damage to biodiversity increases by 18%.

To conclude, the installation of photovoltaic panels has a mixed record. We note that the manufacture of such panels is not neutral for the environmental impacts. If in some areas (radioactive waste generation, abiotic resource depletion, greenhouse effect or cumulative energy demand) the savings made during the use phase far outweigh the impacts of manufacturing, this is not the case for others (production of waste, damage to biodiversity).

5.3. Comparison of the two sustainable strategies

A comparison of the results of the two sustainable strategies tested is summarized in Table 1.

Table1. Variations of the environmental indicators studied on the initial scenario and the two additional sustainable strategies tested (Functional unit: occupant).

	PE	Radio active waste	GWP	OTV - Odour	Waste	Energy	Biodiversity. damage	PA	ADP	Water	Health damage - DALYs	ODP
Initial neigh-bourhood (%)	100	100	100	100	100	100	100	100	100	100	100	100
Sust urban mobility (%)	82.9	85.2	60.1	86.5	93.8	72.1	77.4	65.5	66.5	96.2	67.7	49.9
Photo-voltaic panels(%)	95.9	-1.5	88.0	97.43	121.1	63.5	118.2	103.1	86.3	88.2	95.2	103.4

The design strategies assessed can thus be classified according to their influence on the neighborhood's environmental balance sheet:

1- Sustainable urban mobility: 282% cumulative decrease on all environmental indicators and all the environmental impacts are reduced.

2- Photovoltaic panels: 138%cumulative decrease on all environmental indicators. Nevertheless, four environmental indicators on twelve are increased.

Between the two studied strategies, the management of mobility is the most impacting and beneficial for the environment. This is the parameter that can reduce the most impacts in terms of greenhouse effect, odors, damage to biodiversity and health,

DOI: http://dx.doi.org/10.17501.......................................

acidification, depletion of abiotic resources, production of waste and photochemical ozone. Reducing widely the distance traveled daily combined with the use of green transport modes or public transports,makes it possible to limit the greenhouse effect four times more than to generate all the energy consumption of this eco-district thanks to photovoltaic panels. Thus, mobility management must be one of the issues to be addressed as a matter of priority in any urban reflection. Designing a neighborhood that is sustainable and environmentally friendly while being located far from shops, services and employment places is nonsense.

The implementation of renewable energy systems also 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.

6.Conclusion

While the majority of LCA work at the building and neighborhood level is focused on a very limited number of environmental indicators and often only one parameter, we have demonstrated the interest to study twelve indicators and compare their impacts on an eco-neighborhood and two additional sustainable strategies. This wide range of studied parameters allowed us to make several interesting observations. First, there is a need to broaden the environmental thinking at the urban scale. The predominance of the impacts due to mobility in the overall environmental assessment of the district attests to this. We have shown that mobility management has to be treated as a priority, given their considerable influence on the LCA of an already energy efficient neighborhood.It is found that eliminating the use of personal cars for the benefit of public transport or bicycling or walking, makes it possible to limit the greenhouse effect four times more than to generate all the energy consumption of this passive district thanks to photovoltaic panels. To mitigate the different environmental impacts, it is important to raise awareness among the population to commonly borrow the modes of public transport (bus, train ...) and the active modes of transport (bikes, walking, …) and to reduce their travel distances daily. It is also important to install photovoltaic panels on the buildings in Belgium to reduce the cumulative demand for energy and the radioactive waste, while increasing research to reduce their environmental impacts during the construction and renovation phases.

However, many other parameters remain to be studied in order to provide designers with complete lines of conduct. And other LCA studies should apply also on old and poorly efficient neighborhoods in orderto verify if the mobility conclusion remains valid for older districts. Finally, this work remains open and will be completed with an in-depth study on the effect of outdoor climate variation and energy mix on the environmental impacts of photovoltaic panels in other countries.

7.References

[1] Nations Unies. (2013). *Population, Development and the Environment*.

[2] International Energy Agency. (2011) *World Energy Outlook 2011*.

[3]Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L. (2007). *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

[4] Comité européen de normalisation. (2011). EN 15978. *Contribution des ouvrages de construction au développement durable - Évaluation de la performance environnementale des bâtiments - Méthode de calcul*. Bruxelles, Belgique.

[5] European Environment Agency. (2006*). Urban sprawl in Europe, the ignored challenge.* Copenhagen.

[6] Allacker. K., & Sala, S. (2014). Land use impact assessment in the construction sector: an analysis of LCIA models and case study application. *Life Cycle Assess. , 19,* 1799–809. doi:10.1007/s11367-014-0781-7.

[7] Trigaux, D., Oosterbosch, B., De Troyer, F., & Allacker, K. (2017). A design tool to assess the heating energy demand and the associated financial and environmental impact in neighbourhoods. *Energy and Buildings, 152,* 516–523. https://doi.org/10.1016/j.enbuild.2017.07.057

[8]Buyle, M., Braet, J., & Audenaert, A. (2013). Life cycle assessment in the construction sector : a review. *Renewable and Sustainable Energy Re-views, 26,* 379-388. doi : 10.1016/j.rser.2013.05.011.

[9] European Commission - Joint Research Centre - Institute for Environment and Sustainability. (2014). *ILCD handbook: general guide to life cycle assessment–detailed guidance*. Luxembourg: Publications Office of the European Union.

[10]European Parliament. (2003). Directive 2002/91/EC of the European Parliament and of the Council on the energy performance of buildings. *Communities, L(1)*, 65–71.

[11] Anderson, J.E., Wulfhorst, G., & Lang, W. (2015). Energy analysis of the built environment - A review and outlook. *Renew. Sustain Energy Rev., 44,* 149-1581.

[12]Reiter, S. (2010). Life cycle assessment of buildings - a review. In Arcelor-Mittal International Network in Steel Construction, Sustainable Workshop and Third Plenary Meeting. Bruxelles.

[13]Lotteau, M., Loubet, P., Pousse, M., Dufrasnes, E., & Sonnemann, G. (2015a). Critical review of life cycle assessment (LCA) for the built environment at the neighborhood scale. *Building and Environment*, *93*, 165–178. https://doi.org/10.1016/j.buildenv.2015.06.029

[14]Greening, L.-A., Greene, D.-L., & Difiglio, C. (2000). Energy efficiency and consumption—the rebound effect—a survey.*Energy Policy, 28*(6–7), 389–401.

[15] Erlandsson, M.,& Levin, P. (2005).Environmental assessment of rebuilding and possible performance improvements effect on a national scale.*Building and Environment, 40*(11), 1459–71.

[16] Peuportier, B., Popovici, E., &Troccmé, M. (2006). Analyse du cycle de vie à l'échelle du quartier, bilanet perspectives du projet ADEQUA. *Build. Environ.2013.03.017.*

[17] Reap, J., Roman, F., Duncan, S., & Bras, B. (2008). A survey of unresolved problems in life cycle assessment: Part 1: goal and scope and inventory analysis. *The International Journal of Life*

Cycle Assessment, *13*(4), 290–300. https://doi.org/10.1007/s11367-008-0008-x

[18] Rossi, B., Marique, A.-F., Glaumann, M., & Reiter, S. (2012). Life-cycle assessment of residential buildings in three different European locations, basic tool. *Building and Environment*, *51*, 395–401. https://doi.org/10.1016/j.buildenv.2011.11.017

[19] Riera Perez, M.G., & Rey, E. (2013). A multi-criteria approach to compare urban renewal scenarios for an existing neighborhood. Case study in Lausanne (Switzerland).Build. Environ. 65, 58- 70.

[20]ecoinvent LCI database. https://simapro. com/databases/ ecoinvent/?gclid= CjwKCA jwsdfZBRAkEiwAh2z65sg-fOlOpNksILo.Web site consulted in 2017.

[21] Jacques teller, Anne-françoise Marique, Véronique Loiseau, Florence Godard et Caroline Delbar, 2014. Référentiel Quartiers Durables, SPW- DGO4, Namur : 65 p.

[22] Rossi, B., Marique, A.-F., & Reiter, S. (2012). Life-cycle assessment of residential buildings in three different European locations, case study. *Building and Environment*, *51*, 402–407. https://doi.org/10.1016/j.buildenv.2011.11.002

DOI: http://dx.doi.org/10.17501.......................................