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, regulatory tools 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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sustainable strategies to 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, 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 [20].

In this research, we evaluate twelve (12) environmental impacts
of an eco-district over its life cycle: the greenhouse effect (via the
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
Lievre 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.](image)

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 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 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
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-neighbourhood 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 and the usual means of transport in this region (Wallonia, in Belgium). This hypothesis considers a significant use of the car and the usual means of transport in this region (Wallonia, 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).

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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](image-url)
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.

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, i.e. 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.

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,
acification, 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. Firstly, 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. If 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 order to 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

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