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LCA APPLICABILITY AT DISTRICT SCALE DEMONSTRATED THROUGHOUT A CASE STUDY: SHORTCOMINGS AND PERSPECTIVES FOR FUTURE IMPROVEMENTS

A. Mailhac[1, 2], G. Herfray[1], N. Schiopu[1, 2]*, N. Kotelnikova-Weiler[1, 3], A. Poulhes[1, 3], S. Mainguy[1, 4], J. Grimaud[1, 5], J. Serre[1, 6] G. Sibiude[1, 2], A. Lebert[1, 2], B. Peuportier[1, 7], C. Valean[1, 8]

[1] Efficacity - R&D Institute Energy Efficiency for a Sustainable City, Champs-sur-Marne, France

[2] University Paris-East, Scientific and Technical Centre for Buildings (CSTB), Saint Martin d'Hères, France

[3] Mobility, Urban planning, Transport Laboratory (LVMT), University Paris-East, Champs-sur-Marne, France

[4] Arcadis, Villeurbanne, France

[5] Veolia / 2EI - Eco Environnement Ingénierie, Paris, France

[6] Veolia Research and Innovation, Paris, France

[7] Center for Energy efficiency of Systems MINES ParisTech, Paris, France

[8] TPF Ingénierie, Bourg-la-Reine, France

* Corresponding author; e-mail: nicoleta.schiopu@cstb.fr

Abstract

To meet the current challenges of sustainable development, the environmental assessment of urban projects is essential to developing substantial arguments regarding their performances. To do so, the Life Cycle Assessment (LCA) starts to be applied to large systems such as neighbourhoods. The advantages of this methodology (e.g. evaluating pollution transfers, considering a wide range of local or global impacts, etc.) make it a good candidate for an efficient performance assessment. Nevertheless, districts are highly complex systems, their scope includes various sectors such as construction, transport, energy, water and waste management. Existing tools have to be adapted in order to simulate all these sectors in a systemic way. To achieve such an ambitious goal, the first step is to harmonize the analytic simulation of district components.

The aim of this work is to identify key elements that may improve the systemic simulation of districts and thus ensure a better assessment of their environmental performances. The work is based on the study of a four-hectare project located in the Paris region. Simulations of project's associated mobility, buildings and district energy consumptions and waste and water management have been combined to provide global environmental evaluation based on the LCA methodology. This study shows the relevance of adopting multi-domain simulations in order to evaluate relative contributions of the system's different components. However, to enhance the coherence of holistic evaluation, further work is needed to harmonize methodological choices such as allocation criteria and definition of functional units. Also this study underlines the need to use consistent and harmonized assumptions (e.g. for usage scenarios) and to work at different scales for network-based activities (e.g. mobility) in order to take global and local interactions into account. To overcome these challenges potential solutions are put forward and their feasibility and perspectives are presented in the context of urban planning projects.

Keywords:

Systemic approach; LCA; multi-domain evaluation; mobility; building; energy; waste and water management

1 INTRODUCTION

Environmental performances assessment of urban projects is essential to meet the current challenges of urban sustainable development.

In recent years, LCA has been applied to large and complex systems such as district [1]–[3], urban facilities [4], [5] and territory [6]. However, prevalent challenges remain for LCA application at district scale [3]. This work aims to identify key elements that may improve and ease the systemic simulation of districts and thus ensure a better assessment of their environmental performances.

Firstly, we will introduce our approach to urban system modelling and simulation. We will then present its application through a case study and finally discuss the limits and perspectives of district systemic simulation.

2 URBAN SYSTEM SIMULATION

2.1 District model

Districts are complex systems, to describe them we use a hybrid model (figure 1) based on district object-oriented description [7] and building contributors-oriented model [8].

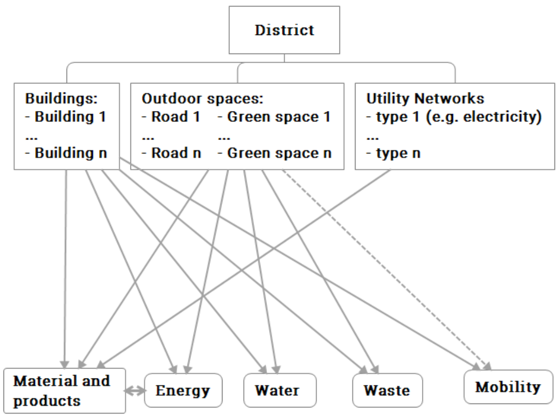

Fig. 1: District modelling.

We distinguish a) **3 types of objects:**

- **Buildings:** all use types and morphologies of buildings can be considered here
- **Outdoor spaces** of any kind: public space, green space, road network
- **Utility networks:** network for water furniture, sewage, electricity, gas, telecom and urban heating network

And b) **5 types of contributors:**

- **Material and Products** necessary for construction, rehabilitation and disposal of buildings, outdoor spaces and utility networks
- **Energy** necessary in the use phase of buildings (e.g. heating) and outdoor spaces (e.g. street lighting)
- **Water** (tap water, rainwater and wastewater) flow in the use phase of buildings and outdoor spaces
- **Waste** generated in the use phase of buildings and outdoor spaces
- **Mobility** of people living or working in the buildings

This model is structured to emphasize the interactions between district components: between buildings (e.g. shadowing), between buildings and mobility (e.g. influence of urban density on public transportation viability), between buildings and waste production…

In the remaining part of this section, we will present how each contributor is modelled and assessed.

2.2 Material and energy simulation

In buildings, energy consumptions related to heating, air conditioning, ventilation and lighting are closely linked to the buildings' material energy performances and buildings form. Thus, we jointly evaluate material and energy contributors through buildings dynamic energy simulation combined with LCA (see figure 2).

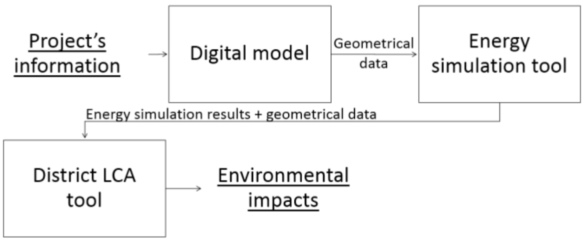

Fig. 2: Toolchain for simulation of energy and material contributors.

Firstly, a digital model of the urban project is created from available information (construction program, master plan...). Then, data is transmitted to the energy simulation tool: DIMOSIM [9] and COMFIE [10] have been used. And finally geometrical data, energy simulation results and data about outdoor spaces and utility networks (geometry, types) are compiled in the LCA tools which evaluate project environmental impacts: novaEQUER (www.izuba.fr) and ELODIE (www.elodie-cstb.fr).

For environmental assessment many Life Cycle Impact Assessment (LCIA) methods can be used leading therefore to different indicators [11].

2.3 Waste management simulation

Figure 3 presents the toolchain used to simulate the waste management system. Waste generated in the use phase in the district by residential, commercial and municipal activities is an input to the waste model. The system's function is to treat 1*kg* of waste generated by the district. Different treatment options (traditional or innovative) can be simulated.

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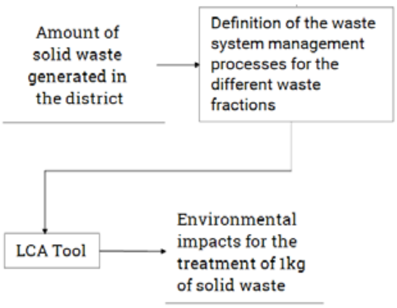

Fig. 3: Toolchain for waste LCA.

The waste system management is modelled from available information on the district regarding waste quantities, and existing processes in the territory. Sinoe database (www.sinoe.org/) was used to define the system. Data regarding inputs (materials, energy) and outputs (emissions of substances) for each waste process were project specific or generic (from EcoInvent database, www.ecoinvent.org/).

As stated before, different impact methodologies can be used. The case study presented here relies on the Impact 2002+ [12] methodology.

2.4 Water management simulation

The approach is similar to waste management. The functional unit is the production of $1m^3$ of drinking water, and the treatment of $1m^3$ of wastewater during the use phase of the district. An urban water life cycle is presented in figure 4.

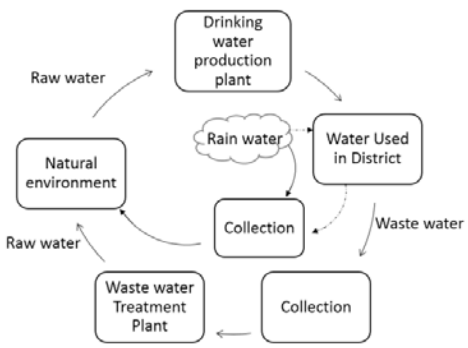

Fig. 4: Urban water life cycle.

The toolchain used for water management system LCA is presented in figure 5.

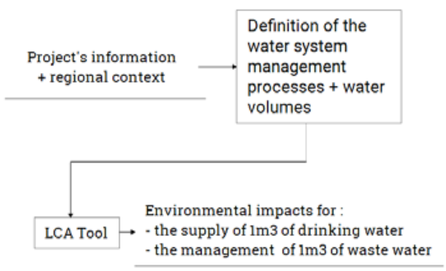

Fig. 5: Toolchain for water LCA.

Firstly, volumes of drinking water and associated wastewater generated in the district and the processes are defined thanks to the available information about the project and its territory. Secondly, the life cycle inventory of every type of water production or treatment process is carried out using either specific available data or generic EcoInvent data. Finally, impacts are assessed, for the work presented here we used the Impact 2002+ methodology, but other methodologies can be used [11].

2.5 Mobility simulation

Mobility associated with an urban project closely depends on its location at the regional level, both in terms of spatial organization of activities and configuration of transportation networks. Mobility simulation was therefore performed using a regional transportation model, MODUS, adapted for this study. It is based on the four-step formalism which is illustrated in figure 6.

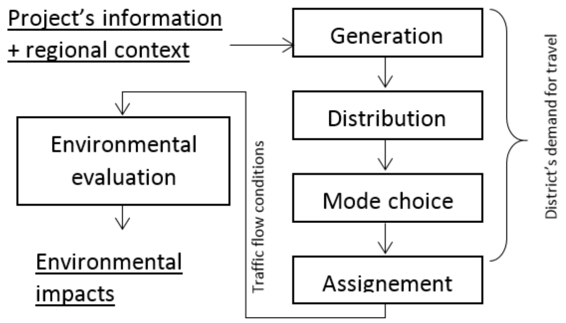

Fig. 6: Mobility simulation chain.

It is a classical transport model usually applied at the regional level for the peak-hour simulation. “Generation” allows the simulation of total in and out flows for a project given in terms of its program. “Distribution” allows for origin and destination matching at the regional level. “Mode choice” splits mobility demand among available transportation modes. “Assignment” corresponds to the route choice and determines congestion levels, mean speed and travel times. An additional step was added to the model to estimate energy consumption and pollutant emissions concerning individual trips associated with the project.

Adjustments were brought to the model to deal with mobility at the project's level (spatial refinement) and to estimate fuel consumption and pollutant emissions over a one-year period (scaling down for the off peak-hour periods and scaling up for the week and year ranges).

The environmental impact of mobility during the use phase was thus determined for energy, greenhouse gas and pollutant emissions indicators.

3 APPLICATION TO A CASE STUDY

The presented models have been applied to a case study of a 4 ha project including 25 buildings of different types (residential, offices…) located in the suburb of Paris (see figure 7).

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Fig. 7: Project location in the Region of Paris.

While the project is in its early phase, the project managers' aim is to design and build a district following high environmental standards. To provide them with information about the project's performances, we ran simulations of the project's associated mobility, buildings and district energy consumptions and waste and water management on the entire life cycle of the district, as presented above. The main hypotheses, results and analyses of these studies are presented below.

3.1 Material and energy simulation results

In line with the project managers' objectives regarding sustainable development, we explored 4 construction scenarios:

(i) Low energy buildings (LEB) [reference]
(ii) Passive buildings (PB)
(iii) LEB and 8000m² of photovoltaic (PV) panels to produce local electricity (LEB+PV)
(iv) PB and 8000m² of PV panels (PB+PV)

To offer a comparison of these scenarios we used the toolchain presented in section 2.2. Main simulation hypotheses are summarized in table 1.

Occupation rate for each building type (occupants/m² floor area)	Collective housing =0,032 ; Office Building=0,083 ; Commerce= 0,138
Energy type for heating and hot water production	Natural gas
Length of time considered for the analysis (LCA)	100 years

Table 1: Main simulation hypotheses.

As indicated in section 2.2, many environmental aspects can be considered. In figure 9 we have presented as an example, simulation results for this specific case study regarding 7 environmental aspects.

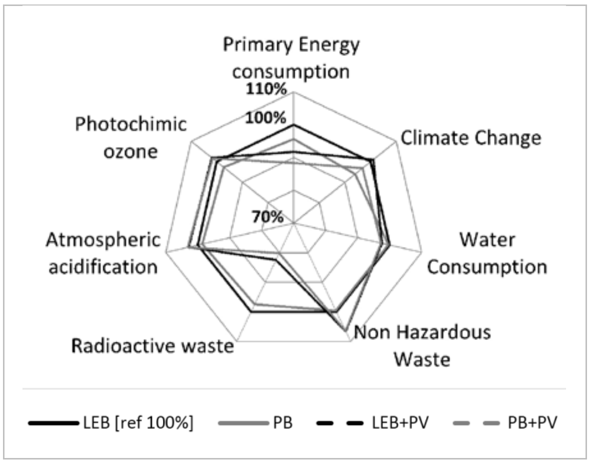

Fig. 9: Buildings LCA results.

As expected, no variant is optimal on all indicators. Nevertheless, if the project managers' main objective is to focus on the reduction of radioactive waste production or energy consumption, the results show that the 4th scenario (PB+PV) presents lower impacts than other studied options. At the same time, regarding climate change more progress could be achieved with 2nd (PB) option.

To help the interpretation further analysis could be provided through normalization of LCA results. Normalization makes it possible to translate impact scores for every impact indicator into relative contributions of the district to a reference situation [13].

3.2 Waste management simulation results

Two waste management scenarios were explored:

(i) Collection and treatment within the territory's existing waste management system (including an industrial composting platform) [reference]
(ii) Implementation of a local collective composting facility for organic waste

The different fractions of Municipal Solid Waste (MSW) and waste from activities are collected (1407 t/yr. in total) and sent to the following processes, similarly to the existing processes in the territory: incineration, landfill, composting, sort-in, drop-off centre. With exception to the drop-off centre and sorting centre modules that were created according to the data available in the SIETREM [14] activity report, data from EcoInvent database was used. The LCA allocation method by system expansion is chosen, for secondary materials (i.e. paper, glass, wood, steel, compost etc.), leading to avoided burdens, or "credits". Impact 2002+ as chosen as the Impact Assessment method.

For this case study, results show that both scenarios have approximately the same impacts. Because an industrial composting platform is already in operation on the territory, environmental avoided burdens obtained with the implementation of a local collective composting

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facility are not very significant. Therefore, in this case, investment in this kind of facility is not recommended.

3.3 Water management simulation

Table 2 presents explored scenarios for drinking water production and wastewater management.

	Reference scenario	Alternative
Drinking water production	Drinking water production from Annet sur Marne plant	Collection and reuse of rainwater for watering the gardens
WW treatment	Treatment in the existing WWTP (Saint Thibault des Vignes)	Treatment in a micro-WWTP (OrganicaTM)[14]

Table 2: Water management scenarios.

In the reference scenario, 352 m^3/day are produced in the drinking water production plant to meet the district's needs. After its use 90% is sent to the WWTP, the last 10% being consumed or evaporated in the district. In the alternative scenario, the potential rainwater volume that can be collected in specific equipment implemented on the roofs of buildings is estimated to be 23 m^3/day (then, only 329 m^3/day of drinking water is produced).

Concerning drinking water production, results show that the reuse of rainwater for watering gardens is significantly beneficial if the rainwater tanks are reused or recycled in their end-of-life phase. Concerning wastewater treatment, both scenarios generate different impacts but neither appears to be the best solution. As described in section 3.1, further analysis could be provided through normalization of LCA results.

3.4 Mobility simulation

The project site is currently well connected to Paris with an existing RER line and is easily accessible by car, benefiting from a close highway. It is also located at one of the Grand Paris Express development sites related to the extension of the transit network. Several new metro lines will connect at the existing RER station, increasing its accessibility.

Land use at the project's level	Population 0.032hab/m² and split between active (72%) and non-active (28%); Jobs 0.041/m² for offices and 0.024/m² for retail
Land use at the regional level	IAU projections for 2030 at the Paris Regional level
Transportation network	Road – unchanged between 2010 and 2030; Transit – Grand Paris Express project, 2030

Table 3: Main mobility simulation hypotheses.

The main simulation hypothesis, summarized in table 3, pertain to land use (local and regional) and the transportation network. Although the ontology differs between building and transport simulations concerning the buildings' occupation rate, we attempted to harmonize hypotheses related to buildings' occupation scenarios.

Simulations were performed during E. Vanhille's master's degree project [15]. Figure 10 shows results in terms of modal split (daily distance per mode associated with the project) and CO_2 emissions.

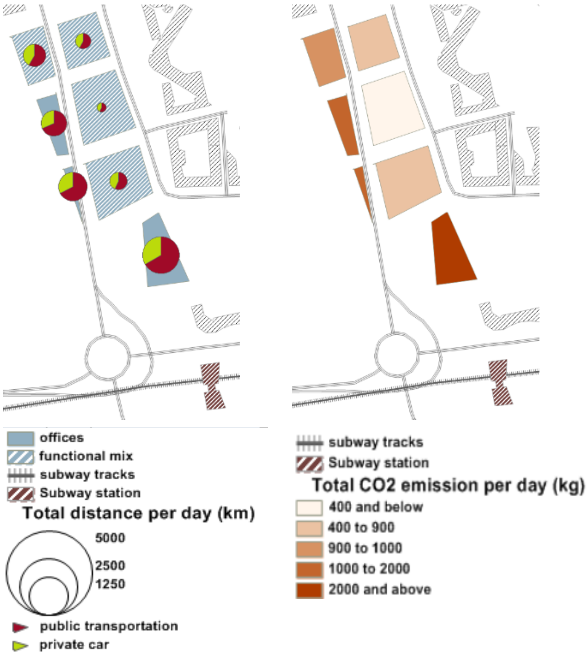

Fig. 10: Mobility simulation results: modal split and daily CO_2 emissions.

The main results can be summarised as follows:

- spatial refinement of the model allows to obtain results at the building's level;
- results are sensitive to the project's program: offices vs. mixed-use buildings;
- and to the local context: modal split and therefore CO_2 emissions vary with distance to the main RER station;
- and also to the regional context: modelling at the regional level allows to take into account transit ridership (the higher it is the lower per-passenger impacts are), road congestion (reduced speed therefore increased emissions) and fleet composition.

4 DISCUSSION

In order to bring substantial and objective arguments regarding their performances, the environmental assessment of districts should rely on systemic simulation combined with LCA of its main components (see figure 1). Models and tools presented here, already make it possible to simulate and evaluate individual or group of contributors of a district with a good precision level. However, these detailed simulations performed by field experts are partitioned and it is not yet possible to perform a systemic simulation of the district. Based on the observations emerging from the case study results, we

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identified two major steps needed to achieve district systemic simulation:

- Harmonizing simulation hypotheses
- Harmonizing methodological choices

4.1 Harmonizing simulation hypotheses

The different studies presented in section 3 reveal some inconsistencies in hypotheses between simulations:

(i) Foreground data harmonization

The occupation rates of buildings vary between simulations resulting from different practices between energy and transport simulation. To overcome this issue, we recommend creating a master model of usage scenarios concerning mobility, water, waste, energy and occupation in buildings.

(ii) Background data harmonization

For instance, simulations of water and energy both use weather data, focusing on rainwater in the first case and on thermal aspects (e.g. temperature…) in the second. In this case the use of consistent weather data is recommended to enhance the consistency of the study.

To harmonize simulation hypotheses, we recommend using a shared data dictionary containing all data that can be mutualized.

4.2 Harmonizing methodological choices

Methodological harmonization aims to enhance interoperability of sectorial simulations in order to provide a comprehensive picture of a project performances. This work raised 3 main methodological harmonization issues:

(i) The local and global environmental impact simulations

For example, in this work the mobility simulation was not combined with LCA. Indeed, focus was on greenhouse gases and some other emitted pollutants and their integration in the LCA is essential in further work. For this study, first adjustments were brought to the mobility model to deal with mobility at the project's level (spatial refinement) and to estimate fuel consumption and pollutant emissions over a one year period (scaling down for the off peak-hour periods and scaling up for the week- and year- ranges). Work is in progress in order to use these mobility simulation outputs in an LCA based simulation.

(ii) LCIA method to be used

LCIA methods normally assign a factor to each elementary flow in an inventory table to provide LCA results through impact categories. Based on methodological debates, different LCIA methods and thus different impact categories can be implemented.

(iii) The methods for environmental impact allocation in the case of multifunctional systems

Two examples of multifunctional systems possibly encountered in districts are:

- A building's main function is to host human activities (residential, business or commercial) but buildings can also generate energy sent to the electric network.
- Waste treatment processes are often multifunctional as energy or secondary raw materials can be generated.

This consideration raises two questions: How should the environmental impacts of these processes be allocated to the different products (or functions) involved? Which processes belong to the product system studied and which do not? Different views disagree on the way to model multifunctional systems, we can mention cut-off and substitution approaches [16], [17].

Today, no final decision has been taken regarding these methodological choices. Further research and discussion of these questions are necessary to harmonize methodological choices.

5 CONCLUSION

The work and simulations conducted here bring substantial arguments regarding the performances of the project under study. The main simulation findings are listed below:

Concerning energy and material contributors in buildings, simulation results bring a lot of information. To help their interpretation further analysis could be provided through the normalization of LCA results.

Regarding drinking water management: simulation results show that harvesting rain water rather than using drinking water for watering gardens is environmentally beneficial if rainwater tanks are reused or recycled at their end-of-life.

Regarding waste management, simulation results demonstrate, in this particular case, that investing in local composting systems is not relevant from an environmental point of view.

Finally, the environmental impact of mobility during the use phase was thus determined for energy, greenhouse gas and pollutant emissions indicators.

Based on observations emerging from the case study, we present prevailing issues that should be addressed in priority in order to improve systemic simulation and environmental evaluation of districts:

(i) Harmonize simulation hypotheses, pertaining to the project (e.g. occupancy scenarios) or to background data needed in simulations (e.g. weather data)

(ii) Harmonize methodological choices to be able to combine simulation results in order to measure the relative contribution of each district contributor (energy, water, waste…) to the total impacts of the district

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In addition to these priorities, further enhancements could also improve assessment of district performances, we especially identify:

- Articulate LCA with local impact studies for instance concerning sanitary impacts related to air pollution from vehicles and buildings, local studies on air pollution transfer are essential
- Evaluate economic and social indicators to perform district global assessments
- Question the representation and associated interpretation of results. To answer this problem, the use of 3D digital model is worth considering

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