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LCA APPLIED TO THE RESTORATION OF A BUILDING IN BAYONNE

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ABSTRACT

Under a partnership agreement between the City of Bayonne and the Business line "Energy France" of GDF SUEZ, the Research & Innovation Department of GDF SUEZ (DRI/CRIGEN), has assessed in 2009 the relevance of different solutions for the renovation of a building in the city of Bayonne, from an environmental point of view.

For an ambitious project, the life cycle assessment (LCA) methodology has been chosen to realize this evaluation in order to take into account the whole life cycle of the restoration of the building (restoration, using and end of life phase).

The building, located in the city center if Bayonne, has a high heritage value. Thus, the different solutions vary essentially according to the energy systems for heating and domestic hot water (DHW). Then, 5 majors scenarii have been evaluated through 5 environmental impact indicators.

This study highlights the main contributors of the different impacts and the main way of improvements for the sponsor. This paper presents more precisely the context of the study, the system description with the main hypotheses and limits and the results of the study.

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2. CONTEXT

The optimization of environmental impacts of buildings is currently a major issue. The building is the sector which consumes the most energy before transport and industry in urban areas. Evolutions of thermal standards led to decrease more and more these energy consumptions, until building passive houses. Improvements concerning construction materials have also been realized. The launch of a French standards for environmental and health declaration of construction products has generated a higher awareness of manufacturers about their environmental impacts and the life cycle approach.

Figure 1 : Localization of the building

Life Cycle Assessment (LCA) is today accepted as the best methodology to evaluate environmental impacts of buildings. Indeed, thanks to this methodology, all the steps of the building life can be integrated: construction, utilization, maintenance and disposal.

Under a partnership agreement between the City of Bayonne and the Business line “Energy France” of GDF SUEZ, the Research & Innovation Department of GDF SUEZ (DRI/CRIGEN), has assessed in 2009 the relevance of different solutions for the renovation of a building in the city of Bayonne in France, from an environmental point of view. Life Cycle Assessment was used, in order to avoid pollution transfer, either from a given stage of the life cycle to another, or from a given environmental impact to another.

This study was also used as a pilot for the development by the DRI / CRIGEN of a methodology combining LCA and Material Flow Analysis (MFA). This has enabled us to design a software to simplify the modeling of buildings and districts, in order to include environmental assessment in the decision making process of local authorities principally.

The concerned building in Bayonne, with high heritage value, includes 9 apartments spread over 5 floors, and a shop on the ground floor. Ambitious targets were set in terms of energy consumption because the requirements were based on the goals of the “Grenelle de l’Environnement” (French initiative bringing together government and civil society representatives with the aim of defining a roadmap for ecology and sustainable development). The target was between 80 and 110 kWh/m²/year of primary energy consumption. It was difficult to achieve, especially because of constraints from Conservation Plan set by the city and the progress of the project when the LCA study was launched. Those conditions have limited the numbers of available comparisons, because several criteria had already been fixed.

Thus, 5 majors scenarii differ primarily in terms of energy systems (see table 1). In order to reach those targets, innovative energy solutions were tested like micro-CHP (Combined Heat and Power) or natural gas heat pump, in combination with of thermal solar energy or photovoltaic.

Various partners were associated to the project :

- ADEME (French environment and energy management agency) which financed the thermal studies;
- MEDDTL (French ministry of ecology, sustainable development, transport and housing) which financed the modeling of thermal comportment of old housing;

In accordance with ISO 14040 and 14044 and in order to ensure the credibility of the study, a peer review of this LCA has been realized, which showed the relevance and compliance of the study with the standards.

3. SCOPE OF THE STUDY

3.1. Functional unit

The scenarii definition has been realized jointly by :

- the thermal research department working for the city of Bayonne,
- the architect,
- the city of Bayonne,
- the business line "Energy France" of GDF SUEZ,
- thermal experts of the research center of GDF SUEZ.

Thus 5 scenarii have been defined. For three of them, an additional parameter has been evaluated (presence or not of photovoltaic panels and of solar thermal system). The definition of scenarii is presented in the table 1 below. All the environmental impacts of the scenarii have been compared with the environmental impacts of the buildings before restoring, in order to evaluate the improvement of environmental performances.

The reference used to compare scenarii (called "functional unit") is "the operation of 1 square meter of net floor area of a naked building during one year for the 5 scenarii with a common need for heating and domestic hot water (DHW)".
(It has to be noticed that the need for heating and DHW are not identical for the case before renovating than for the cases after renovating).

	Scenarii definition	Primary energy consumption (kWh/m²/year)
Scenario 0	(before restoring) domestic standard natural gas boilers – natural ventilation	262
Scenario 1a	collective natural gas condensing boilers for heating + collective solar water tank with extra domestic heating (CSWTEDH) + photovoltaic panels (PV)	87
Scenario 1b	scenario 1a without photovoltaic panels	94
Scenario 2a	collective condensing natural gas boiler used for heating and domestic hot water + collective solar water heater (CSWH) + PV	71
Scenario 2b	scenario 2a without photovoltaic	78
Scenario 3	micro- CHP (combined heat and power)	44
Scenario 4a	Natural gas heat pump + low-temperature natural gas boiler	75
Scenario 4b	scenario 4a + CSWH	72
Scenario 5	(All electric) electric heating + CSWTEDH + PV	128

Table 1 : Scenarii definition

3.2. System description

The three main phases of the life cycle of the restoring of the building have been integrated, as presented in the figure below.

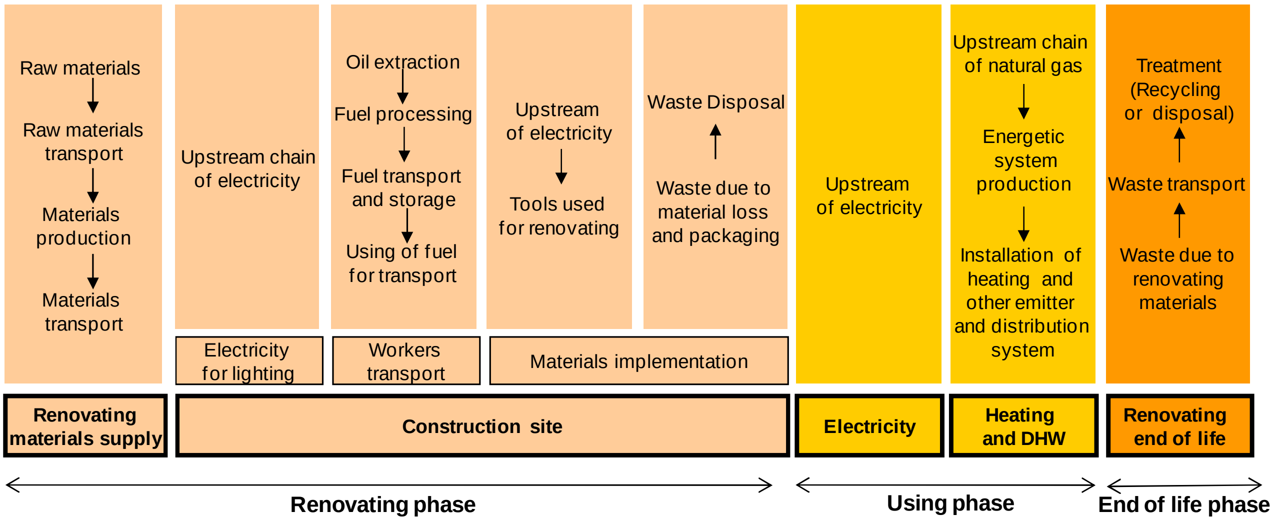

Figure 2 : System description

Additional information concerning the system description are described below :

The renovating phase:

- A number of elements of the existing building were kept and only the materials provided during the restoration were taken into account in this LCA.
- For the construction site, a lifetime of 30 years was considered in order to divide the impact of this phase in time per 30 and bring them to 1 year. Demolition waste were not included in this phase, in fact, it was considered that they were attributable to the first system (corresponding to the life of the building before the renovation).

The using phase:

- The data for energy consumption for heating and DHW were calculated using one calculation method of the French thermal regulation applicable to existing buildings (called Th-C-E ex). This calculation has been realized by the department of thermal engineering working for the city and experts from GDF SUEZ - CRIGEN. This method calculates the energy consumption of a building according to the needs. This conventional method does not take into account the behavior of inhabitants. Thus, all specific electricity needs are not taken into account (for example electricity for household appliance). Consumption due to the office systems and use of appliances were added, while consumption due to lighting, ventilation and auxiliary heating were already integrated.
- The consumption of electricity for electrical appliances (without regulatory use) were estimated at 60 kWh of primary energy / m² of net floor area / year. This consumption were common to all scenarii, assuming that there are common equipment between the scenarii. This may be a limit to the scenario before renovation for which it would be possible to consider a higher consumption due to the use of older appliances. Note that the consumed electricity does not only come from the national grid because some scenarii include their own means of electricity generation (PV or micro-CHP).

  The upstream chain of electricity production varies according to the electricity mix considered. The French average electric mix was chosen and detailed according to three main uses :

  - The base uses occur all year long, e.g. electrical appliance, domestic hot water
  - The heating use corresponds to an increase of need in winter
  - The lighting use is a specific use and occurs mainly during the evening and more in winter.

The choice of the electric mix is a sensitive parameter of the study. A sensitive analysis has been realized in order to compare the results obtained using the marginal electric mix. Indeed, the marginal mix has a CO_2 emissions factor around 5 time higher than the average mix.

The end of life phase :

- It was considered that there would be no heavy renovation of the building until the end of its life. Thus, renewal of materials is directly related to their life duration. This phase is the same for all scenarii.

The processes and stages excluded of the life cycle are:

- Transport and behavior of residents (meals, equipment, leisures ...) during the use phase of the building.
- The infrastructure outside the building: Relay Plug, TV connections, internet or telephone connection, energy and materials for the district (road lighting, irrigation).
- Water consumption.
- Natural gas and electricity meters and electrical panels in the buildings.
- Maintenance work on the various energy systems.

3.3. Sources of inventory data

- The data of the architectural firm for all consumptions of materials for the frame.
- The data of the thermal engineering department for the description of some of the energy systems and their energy consumptions.
- The internal data of GDF SUEZ for natural gas innovative solutions
- The database ECOINVENT, version 2.0
  Its completeness and transparency make this database an international reference among practitioners of LCA. Data from our study are from the version 2.0 published in 2008.
- The database INIES, developed in partnership with ADEME and CSTB, lists French EPD (Environmental Product Declaration) of building products provided by manufacturers or trade associations. These EPD, made according to a French standard have been sources of valuable information for buildings LCA.

3.4. Impacts assessment

The following impacts had been studied :

- Climate change
- Depletion of non renewable energy resources
- Air acidification
- Eutrophication
- Photochemical ozone formation
- Nuclear waste production

The choice of indicators was done according to their relevance to the objectives of the study, especially in terms of energy systems compared. Moreover, this choice included indicators with most credible assessment methodologies. Thus, the main objective of comparing different energy systems for the scenarii after restoration did not make relevant the indicator of abiotic resource depletion which would had very little variation between scenarii. This indicator would only have been relevant if the scenario before and after renovation scenarii had been compared which was not the main objective of the study. Three indicators were

also chosen : air pollution, climate change, inevitable today, and acidification of the air, regional phenomenon known by the city of Bayonne. Similarly, as an indicator of pollution of water, we felt more appropriate to use the water eutrophication, which is a regional phenomenon.
The table below summarizes the major compounds playing a role in these effects.

Impact	Unit	Methods	Most important substances followed
Climate change	kg CO2 eq.	GIEC 2007	CO_2, CH_4, N_2O
Depletion of non renewable energy resources	MJ (LHV)	CED	All non renewable energy consumption
Air Acidification	g SO2 eq.	CML 92	NO_X, SO_X
Water Eutrophication	g PO_4^{3-} eq.	CML 2000	Nitrous, phosphorous
Photochemical ozone formation	Kg C_2H_4 eq.	CML 2000	SO_2, CH_4, CO Formaldehyde and NMVOC (Hydrocarbons)
Nuclear wastes production	g	Direct from inventory	waste of low and intermediate level waste, high activity

Table 2 : Indicators followed

3.5. Limits

This study was modeled using numerous assumptions and it is important to be aware of their limits. Indeed, it relies mainly on generic data adapted to the information collected, but not always strictly conform to reality. In addition, this study occurred in the design phase of the project, so the results are theoretical and will probably be different from the completed project. This applies, in particular, to energy consumption during the using phase, calculated from a regulatory calculation software.

Furthermore, the collection of more data on the other steps could also increase accuracy and improve the overall level of relevance of the study. Thus, special attention should be paid to the end of life phase of life cycle whose modeling parameters are poorly controlled, whereas they can have a significant impact on results.

4. RESULTS

4.1. None of the solutions reduce all environmental impacts

In order to simplify the interpretation of the results, it has been chosen to present only 4 scenarii. The other scenarii obtain impacts closed to the scenario 2b and 3 presented below. So the conclusions are not influenced by this selection.

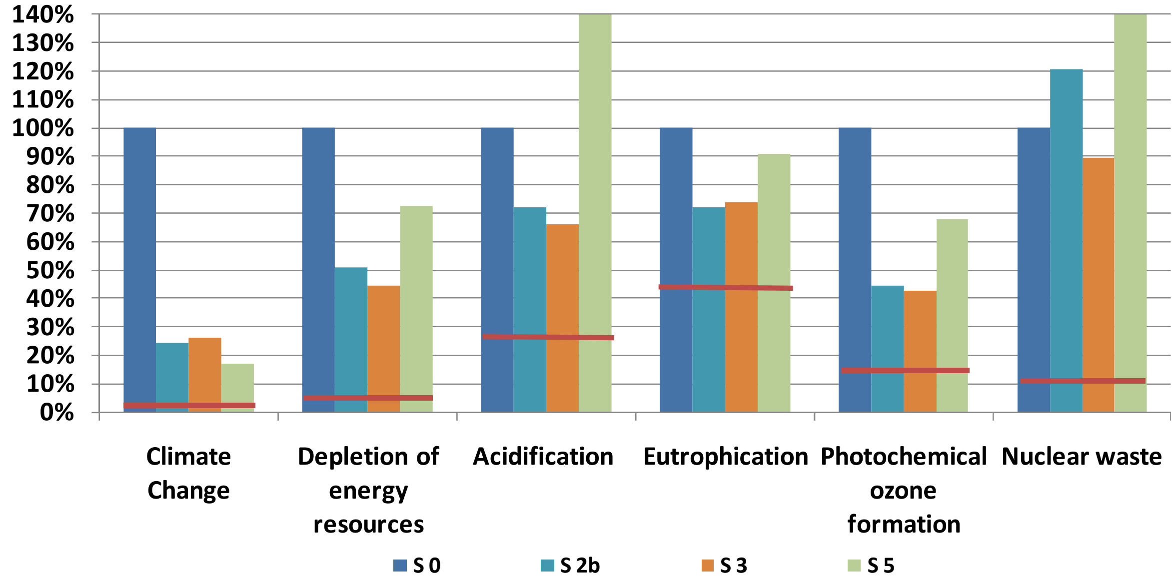

Figure 3 : Comparison of impacts of 4 scenarii throughout the lifecycle
(the red line specifies invariant across scenarii: renovating phase and end of life)

The improvements of the building restoration in terms of environmental benefits are uneven in function the impacts considered:

- The renovation of the building as a significant advantage on the impacts on climate change (reduction between 74 and 83% compared to the scenario before renovation), depletion of non renewable energy resources (reduction between 27% and 55%), eutrophication of water (reduction between 10% and 31% compared to the scenario before restoration), and the photochemical ozone creation (reducing the impact between 32% and 61%), but not necessarily for atmospheric acidification (increase of 39% for scenario 5 and 34% decrease for scenario 3). Thus, the consequences of the renovation are not positive for all indicators even if there are offset by energy saving linked to more efficient heat generating systems during the use phase. Note however that the renovation can provide more comfort to the inhabitants which is not evaluate by LCA.

The conclusion of the comparison of the different scenarii are:

- Scenario 5, all electric, generates a lower impact on climate change due to the use of seasonally average electric mix. On the other hand, it has a strong impact on air acidification and nuclear waste production. Electricity consumption has indeed a higher impact than natural gas consumption on these two indicators (impact generated by the production of electricity from nuclear, coal and oil). About the depletion of non renewable energy resources, eutrophication and photochemical ozone creation, this scenario is slightly better compared to scenario 0 (no restoration), but is less effective than other renovation scenarii.

- Scenario 3 obtains the lowest impact on the depletion of non renewable energy resources, air acidification and production of nuclear waste. These results demonstrate the environmental gains due to electricity generation from the micro-CHP, which avoids the use of electricity from the grid. In terms of climate change, it gets worse performance, because the use of natural gas emits more CO_2 than the French average electric mix.
- Scenarii 2b achieve good compromise for all environmental indicators, always having impact among the lowest. Thus, collective heating and DWH seems to be a good solutions to reach thermal regulations.

Environmental criteria cannot put forward a solution before the others, scenarii 2b and 3 getting in their entirety similar results and having different positions in function of the impact considered. But one conclusion is that this study shows that conventional technologies, like condensing boiler, present interesting advantages: an environmental impact among the lowest on all the impacts, a low investment compared to the other solutions and an easy maintenance with a good feedback on these products. Thus, it seems to be interesting to continue the development of innovating technologies.

4.2. Depending on impacts, potential improvements are linked to different stages

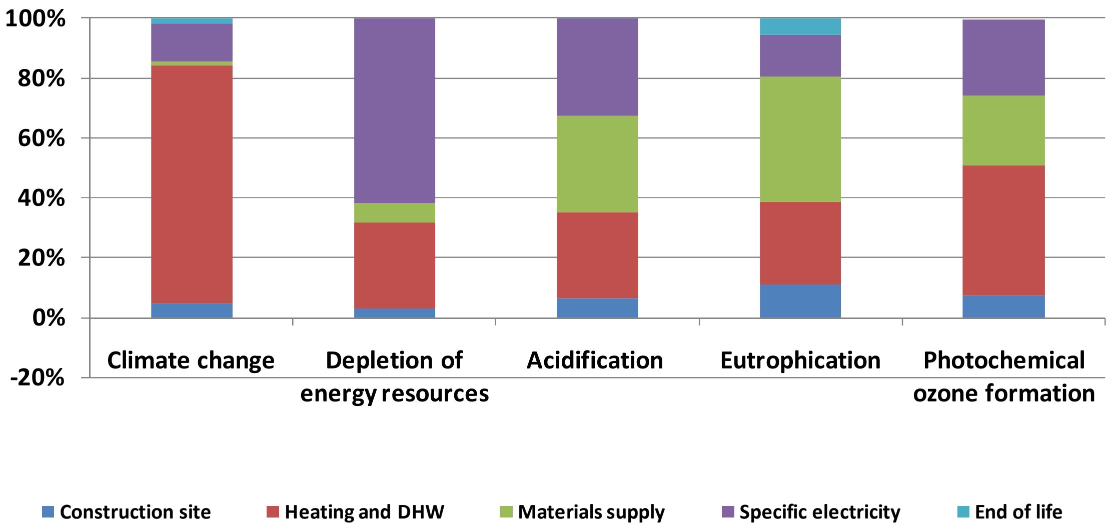

Figure 4 : contribution of the different stages of the life cycle to the impacts (scenario 2b)

The conclusions described above are linked to the contribution of the various phases of the whole life cycle according to the impacts (analysis according to the scenario 2b but the observed trends are applicable to other scenarii "after restoration" studied).

- The renovation phase has an variable impact, depending on the indicators monitored. The stage of supply of materials predominates in this phase, the impact on the depletion of energy resources accounts for 6% of the impact of total life cycle, whereas it is 42% for eutrophication of water, 32% for acidification air and 23% for the photochemical ozone creation. This impact is mainly due to the transport of materials from their manufacturing site to the site (between 70 and 80% of the impacts of the step supply of materials). However, the impact of this phase on climate change is very low (less than 1% of the whole life cycle), which is explained by the inclusion of CO_2 capture for the wood based products during their growth. This result enhances the benefits of choosing a major use of products to photosynthetic growth, such as wood, for the emission of greenhouse gas emissions. Conversely, the stage of construction, including electricity consumption for the construction and transportation of workers, is marginal for all scenarii, its impact rarely exceeding 10%, whatever the scenario.

- The use phase of the building is divided into two uses:
    - The use of heating and DHW is largely majority on climate change (80% of the whole life cycle), and has significant effect on the photochemical ozone creation (44%). The impact of this step represents 29% of the impact on the depletion of energy resources and over 29% on air acidification on the whole life cycle, then it impacts up to 27% for eutrophication. Energy consumption has indeed strong impacts on air pollution (climate change and atmospheric acidification) and depletion of resources, but little impact on water pollution. The limited impact on air acidification is due to the use of natural gas, low SO_X emitter.
    - The use of electricity is negligible on climate change and eutrophication of water (about 13 of the impact of the whole life cycle), and represents around one third of the total impact in terms of air acidification and photochemical ozone creation. On the other hand, this step is majority on the depletion of nonrenewable energy resources (62% of the total impact) because of the efficiency of power plants.
- The end phase of life is marginal on almost all indicators (less than 1%), but slightly higher on the water eutrophication (6% of the total impact). Note that this phase get sometimes negative results due to methodological choice to consider avoided when a material is reused on its energy value recovered at its end of life.
- The significant impacts of materials supply stages and end of life on air acidification and water eutrophication explain the lower interest of the renovation on these indicators.

  So the ranking of scenarii after restoration varies depending on the impacts considered.

It has to be noticed that the choice of electricity mix for the modeling of electricity consumption causes significant variations on the impacts of scenarii including electricity for heating and domestic hot water. Two mix are possible : a mix calculated on the basis of historical called average mix and a mix representing the marginal means that would be implemented if additional electricity would be needed. The average mix was used as a basis on this study. Taking into account the marginal mix modifies the ranking of scenarii including electricity for heating and domestic hot water generation, compared to scenarii using only natural gas : the impact on climate change and acidification is multiplied by 2.5 for scenario 5 compared to the basis case with the French average electricity mix.

4.3. Conclusions and ways of improvement for the project

The main way of optimization concerns the heating and DHW production, with the use of the best available technologies. However, on the other stages, simple decisions adapted to the roles of sponsors can improve the environmental performance of buildings. Thus, two examples of improvements, evaluated thanks to sensitivity analysis, can be put forward :

- The choice of the insulation of buildings (natural or mineral) is one of the only elements not constrained by respect for the historic character of the building. The use of wood wool saves in thermal inertia, provides benefits on the quality of indoor air and improves environmental performance, particularly on climate change.

- Depending on the supply distance of restoring materials, the results vary significantly (between -50% and +240% on the step of materials supply), particularly on the climate change indicator. This result supports the use of a local economy. In addition, a short supply distance can develop the activities of craftsmen and local industrial and thus boost the region.

Thus, given the current developments taking place in the construction sector (BBC label, home to positive energy ..), we can predict that the use phase will weight on less and less in the future the whole life cycle of the building. Thus, the share of other steps will increase and these parameters, which have little effect today, will become more significant.

To improve the accuracy of the LCA studies of building, it is necessary to continue work on the modeling of energy systems, in order to adapt more precisely different implementations, but also to compare different software thermal calculations, to see if there are significant variations. The proliferation of environmental studies in the building area will capitalize on information and improve the quality of the data transmitted by the various stakeholders and available in databases.

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