Sustainability assessment within the residential building sector based on LCA and MFA: the experience in a developed (Spain) and a developing country (Colombia)

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Abstract More than ever, the residential building sector is concerned with improving the social, economic and environmental indicators of sustainability. In order to overcome the increasing concern of today's resource depletion, environmental considerations and to address sustainability indicators, a practical life cycle method has been proposed to decision making integrating environmental and socio-economical aspects to analyse the impact of sustainability within the residential building sector using two practical life cycle methods. One method is the Material and Energy Analysis (MEA) which is suggested as an appropriate tool to provide a systematic picture of the direct and physical flows of the use of natural resources and the other is the environmental management tool of Life Cycle Assessment (LCA) as a complement to evaluate environmental impacts throughout the life cycle of the system.
Furthermore, the method provides sustainability information that facility an adequate decision making towards sustainable development at macro and micro levels. Sustainability assessment at macro level is determined by exogenous variables that can influence the development of a country. Meanwhile sustainable at the micro level is made within the limits of the whole building life cycle, starting from the construction, use (operation and maintenance) and finishing with

the end-of-life phase. To illustrate it, a case study has been carried out based on the application to two buildings, one located in Barcelona, Spain and one situated in Pamplona, Colombia. Then, the main objective of this thesis is to propose a practical life cycle method including environmental and socio-economical aspects to evaluate indicators that explicitly measure the residential building sector's impacts. This thesis has also provided initiatives for residential dwellings to reduce environmental impacts and assist stakeholders in improving customer patterns during the dwelling life cycle.
The findings of this thesis state that the appropriate combination of building materials, improvement in behaviours and patterns of cultural consumption, and the application of government codes would enhance decision-making in the residential building sector towards sustainability. The difference in consumption in Colombia and Spanish dwellings is not only due to the variation in results for bio-climatic differences but also because of the consumption habits in each country. The importance of consumption habits of citizens and the need to decouple socio-economic development from energy consumption are sought for achieving sustainability from a life cycle perspective. There is a crucial necessity to provide satisfaction to basic needs and comfort requirements of population with reasonable and sustainable energy consumption.

1 Introduction

Economical and socially, in 2001 the construction sector represented 10% of global Gross Domestic Product (GDP) with an annual output of USD 3.000 billion, of which 30% was in Europe, 23% in developing countries, 22% in the United States, 21% in Japan, and 4% in the rest of the developed word [1]. Furthermore, the European Commission (2006) stated that 11.8 million operatives are directly employed in the sector in Europe and that is Europe's largest industrial employer, accounting for 7% of total employment and 28% of industrial employment in the EU-15. About 910 billion euros were invested in construction in 2003, representing 10% of the GDP [2]. Environmentally, taking into account its entire lifespan, the built environment is responsible in each country for 25 to 40% of total energy use, 30 to 40% of solid waste generation and 30 to 40% of Global Greenhouse Gas (GHG) emissions [3].

Some initiatives for tackling adverse environmental impacts have been taken. To accomplish it, diverse technical and conceptual approaches must be applied. In particular, our interest has been on research on assessment tools based on Life

Cycle Thinking as a means to quantify the amount of natural resources consumed and identify the associated environmental impacts in order to provide sustainability indicators and create goals preventing adverse environmental impacts, consequently enhancing quality of life and allowing people to live in a healthy environment and improve socio-economic aspects.

This work is then concerned from a quantitative life cycle perspective to measure sustainability within the residential building sector based on the application of two tools.

One tool is the Material and Energy Analysis (MEA) which is suggested as an appropriate tool to provide a systematic picture of the direct and physical flows of the use of natural resources. The second tool is Life Cycle Assessment (LCA) as a complement tool to evaluate environmental impacts throughout the life cycle. Use of materials is characterized by MEA and its environmental performance is determined by LCA. The usefulness of MEA and LCA tools has been applied within the residential building sector in two countries: one in a developed country (Spain) and one in a developing country (not emerging Colombia). To our knowledge, this work is one of the first applying the mentioned tools to the sector in Colombia and the first that demonstrates the errors that would come up of just extrapolating European database for buildings (case study in Spain to Latin America, case study in Colombia).

2. METHODOLOGY

The application of analytical tools are sought to provide consistent environmental information that facilities an adequate decision making towards sustainable development. In this work, a method has been applied at macro and micro levels.

Sustainability assessment in a macro level is determined by exogenous variables that can influence the development of a country. Exogenous variables are classified in socio-economic sphere (i.e. GDP, natural growth, employment rate, etc.), and environmental sphere. We compute a composite indicator, through a limited number of factors, available information on the social, economic and environmental conditions in the residential building sector of a set of variables.

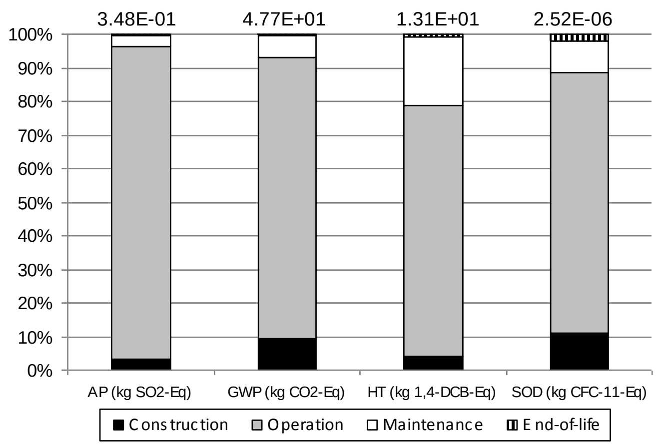
Sustainability assessment at the micro level is the boundary and the most relevant within this work which is the frontier between the environment and the whole process construction of a dwelling during the full building life cycle, starting from the construction, use (operation and maintenance) and finishing with the end-of-life phase. In each phase, the inputs (materials, energy and labour), and outputs (emissions and wastes) have been taken into account.

3. RESULTS

3.1 Sustainability assessment results for the application of the Mediterranean home.

Figure 1 shows how the life cycle environmental impact is distributed over four categories: acidification potential (AP), global warming potential (GWP), human toxicity (HT) and stratospheric ozone depletion (SOD). As can be seen in the figure 1, the time phase with the highest environmental impact is the operation phase; approximately 77-93% of the life cycle's total, except for the human toxicity impact, of which the operation accounts for approximately 75% and the maintenance and refurbishing activities contributed up to 20%. Regarding the environmental issue of SOD, there was a total emission of 2.52E-06 kg CFC-11-Eq m-2 y-1 during the 50 years occupation, of which about 11% was during the construction phase (external and internal walls represented 54%) and the use phase accounts for 87% and 2% was during the end-of-life due to the construction waste of stone with 97% (concrete 61%, brick 32%, and roof tile and ceramic tiles 7%) of the total stone waste.

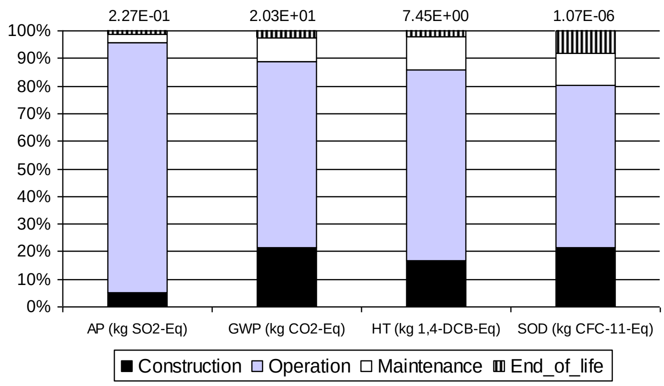
Figure 1: Environmental impacts distribution during the Mediterranean full building life cycle.



3.2 Sustainability assessment results for the application of the Colombian home.

The highest environmental impacts during the Colombian dwelling's life cycle took place during the use, while construction was about 9-31%, transportation and maintenance combined only account for less than 10% of the life cycle impacts. Figure 2 shows the environmental impact results presented for the dwelling life cycle studied.

Figure 2: Environmental impact results during the full building life cycle (Colombian home).



3.3 General results

Data availability: The process of obtaining data in Colombia was a laborious one due to the lack and widely dispersed of the data, therefore it was necessary to draw up estimates, while the development of data collection in a developed country (Spain) was straight forward process because of the national database available.

Macro level: Macro level has been evaluated calculating the composite indicators in both countries. It can be concluded that factor analysis has identified three factors from the list of nineteen variables of the Spanish case and seventeen variables of the Colombian case. In the main, the first factor for the Spanish and the second factor for the Colombian was represented by the specific statements written to reflect the evolution of the residential building sector in both countries. Energy and cement can be used as suitable proxies to capture the global development of the building sector and because are significant inputs for any construction especially for housing to get a real vision about the operation of the building sector.

Micro level: Sustainability impacts used in this research has been chosen to allow an easy public comprehension. Basically typical LCA indicators like GWP, AP, HT and SOD have been used to compare our results with others presented in common LCA indicators.

Building materials: the present work has shown that the combination of building materials can lead to reduced environmental impacts. There is a widespread desire to reduce CO2 emissions, therefore decisions need to be made with rigorous and appropriate environmental goals set out by the government. This work evaluated and analyzed adverse environmental impacts during the construction, use and end-of-life phases. LCA has been used in decision-making when applying the environmental management principle of “choose it right first” without compromising the quality of a construction project. Hence, this allowed us to see and evaluate environmental burdens based on combinations of different building materials. The adequate combination of energy supplies leads to reduced environmental impacts. The use of efficient energies such as natural gas clearly reduces the environmental impacts during the operation phase. Regarding electrical appliances, the most recent methodologies which incorporate information about environmental aspects, embodied energy and efficiency are necessary for minimizing environmental impacts. Decision-making regarding any environmental impact depends on global and local environmental quality goals and also on environmental threats identified in research and development by governments. Governments need to apply policies and construction codes that lead to improved quality of life for citizens because these same citizens want assurances that an investment in a dwelling will pay for itself over an acceptable time period. In other words, cost is an important issue for the market in facilitating the best economic and ecological value for society, customers and users.

Energy: the origin of the energy source used in each Country plays an important role to minimize adverse environmental impacts, as was demonstrated by the environmental impacts of its use in Colombia where 78% of the electricity came from hydroelectric plants whereas in Spain it is more mixed, 50% coming from fossil fuel combustion. Then, there is a widespread necessity to preserve the environment from the use of fossil fuels (oil and coal) and also to promote the use of renewable energies. Nevertheless, even electricity usage data was based on modelling, data was checked with electricity bills and results it can be concluded that it is not understand that in Colombia where electricity is generated from hydroelectric and there is a charge of € 0.086 cents per kilowatt-hour, when in Spain the cost is € 0.1125 cents per kilowatt-hour and in some Latin American regions such as Venezuela, Ecuador, Peru and Brazil the energy is cheaper than in Colombia and thus Colombia lose competitiveness of green markets.

Waste: In Spain, the waste management phase represents less than 1% of the environmental impact of the total full building life cycle. However, when building wastes are not recycled the amount of waste generated at the building site is higher than urban waste generated by other means. Therefore, architects, contractors, designers and engineers should be proactive and consider sustainability criteria that help decision making at the planning and design stage that allows decisions to be made at the draft stage on the choice of materials and constructive solutions according to techniques during the construction phase. In the incineration scenario attention should mainly focus on plastic and insulation materials because they emit toxic compounds. Paper and cardboard are materials that provide power and thermal energy recovery due to their high calorific value. Recycling plastic and cardboard is important because it reduces the amount of raw materials that have to be sourced. Meanwhile, in Colombia there is a urgent need to foster techniques such as recycling, reusing and recovering materials for optimum waste disposal. [4], [5].

4. Conclusions

Life Cycle Thinking can be applied to the whole construction process, thus making it possible to improve the sustainability of buildings. For example, a proper design and choice of building materials during the construction phase can improve the energy efficiency during the use phase and the final distribution of buildings' consumption for heating and cooling. Also applying strategies during the operation phase, such as making changes in consumption patterns, would improve consumption for illumination and household equipment in terms of energy and environmental considerations.

Future research will analyze whether the practical LCT guidelines used in the construction industry for single buildings in Spain, strong depending on climate conditions, can be applied in tropical areas. Social and economic indicators the two other parts of sustainability will be considered more in detail because of their major and particular role in developing countries. This is expect to use an optimization model (based on a friendly environment software) that considers variables like thickness of walls, type of window, type of insulation material etc, in order to optimize a model to the correct conditions determined by variables like temperature, direction and wind speed.

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