LIFE CYCLE ASSESSMENT OF AN OFFICE BUILDING IN GREECE

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EXTENDED ABSTRACT

As concern over the environmental impacts of construction grows, life cycle assessment is used as a means to quantify natural resources consumption, and emissions of global greenhouse gases. This work presents the environmental performance of an office building built in Athens, Greece. Assessing the environmental impact of a complex system, such as an office building, requires an understanding of the environmental impacts of all of its parts. The building was selected because it is close to the average size of new buildings built in Greece and uses standard construction materials and techniques.

The modelling of the system has been done with the help of the GaBi Software. The modelling of the building life cycle included the construction phase and the use phase of the building. The demolition and disposal phase was not included due to lack of comprehensible data.

The construction of the building was further divided to its components-levels that are, the 3rd basement, the 2nd basement, the 1st basement, the ground floor, the 1st floor, the 2nd floor, the 3rd floor and the rooftop. The materials that were used for the construction of the building included concrete, steel, bricks, masonry mortar, insulation materials, aluminium, glass, marble, gypsum fibre board, paint, PVC, epoxy resin, roof slabs, ceramic tiles, light weight concrete, metals and wood. The use phase of the building includes the energy consumption for heating, cooling and lighting purposes. The life span of the building is taken to be 80 years. The modelling of the use phase has been done with the use of bibliographic data based on the Greek climatic conditions. The best scenario for a building in Greece has been used for the energy consumption modelling.

The environmental impact assessment study has shown that the distribution of energy consumption and environmental impacts are concentrated in the use and renovation phase of the office building. The results showed that the use phase environmental impacts accounted for more than 92% of the total inventoried environmental burdens. Global warming potential (GWP) is the environmental impact with the larger contribution to the total environmental score of the life cycle. GWP contributes 78,77% to the total environmental score. The environmental impact of the use phase is attributed to the energy consumption that is related with fossil fuel use in energy production processes. Energy is used for the heating, cooling and lighting of the building during its life cycle.

Key words: Life Cycle Assessment, Sustainable Construction, Office Building

1. INTRODUCTION

The use of life cycle assessment as a means to quantify natural resources consumption, and emissions of global greenhouse gases is being mandatory due to the environmental problems. Historically, focus has been on understanding energy use during the operational period of the home (use phase). To understand overall environmental impacts of the building, all life cycle stages should be inventoried (material production, manufacturing, use, retirement). Assessing the environmental impact of a complex system, such as an office building, requires an understanding of the environmental impacts of all of its parts. As the production sequence is followed upstream, the material and energy input requires more effort to quantify. Life Cycle Assessment (LCA) [1] is a method, which quantifies the environmental impacts associated with the delivery of a particular service or product. The definition of SETAC for LCA is: *'LCA is a systematic way of evaluating the environmental impact of products or activities by following a 'cradle to grave' approach. This approach implies the identification and quantification of emissions and material consumption which affects the environment at all stages of the entire product of life cycle'.* Thus the analysis includes all processes connected to the delivery of this service or product, from the extraction of raw materials to the disposal of wastes. This network of processes forms the life cycle of the product or service. Using this method ensures that all processes, which contribute to the environmental impacts of the delivery of a particular service or product are included in the final result [2,3].

2. THE OFFICE BUILDING LIFE CYCLE

This work has taken into consideration the production cycle of the materials including the construction phase of the building and the investigation of the impacts regarding the use phase of the building. Material and energy consumption, emissions to the environment and disposal problems are also recorded. It has included all the material and components in the building from "cradle-to-grave". "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product, the use phase of the product (mainly energy consumption) that is very much dependent on the design of the building. It ends at the point when all materials are returned to the earth (end of life management). Based on the LCA study material, reduction opportunities, energy savings, recyclability, reusability and end of life management options will be determined. The functional unit of this study is one (1) office building.

The life cycle system of the office building comprises of the following stages:

- **Raw material extraction:** The building consists of various components, which are made of a large variety of materials and substances. This phase includes both the production of raw material and the use of these raw materials to produce other materials and substances. The environmental aspects and impacts from this phase arise from the mining operations, refining of ores, and manufacturing of materials and substances.
- **Components manufacture:** This phase covers the manufacturing of the components used in the office building, such as concrete, paint, bricks, gypsum fibre boards, aluminium windows etc. The components manufacture is characterised by several environmental aspects main among them being energy consumption and use of materials with hazardous properties. The role of component manufacturers is crucial to reduce the environmental impacts from this phase.
- **Components transportation:** Components are delivered to the construction site by road transport. The environmental impacts in this phase mainly arise from the energy consumption of the carriers.
- **Construction of the office building:** The main process is components placement. The main environmental aspect from this phase is the energy consumption

and solid waste production of construction processes.

- **Use and Maintenance stage:** The use phase encompasses all activities related to the use of the building over its life of 80 years. These activities include all energy consumed within the building, including heating, cooling and lighting.
- **Demolition - Final Disposal/Recycle/Waste Management stage:** It begins after the building has served its intended purpose and includes the demolition process and the solid waste management system (recycling and final disposal of inert materials). The recycling, incineration, or other end-of-life management processes have not been included in this study.

The life cycle inventory (LCI) analysis component is a technical, data-based process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes and other releases for the entire life cycle of the office building. Once the inventory has been performed and is deemed as accurate as possible within the defined scope and boundaries of the system, the results can be used directly to identify areas of greater or lesser environmental burden. This will lead to support a subsequent life-cycle impact analysis and as part of a preliminary improvement analysis.

The data used for the purpose of this study was mainly raw data provided by the construction company EDRASIS C. PSALLIDAS S.A. This data included the mass of materials or construction components required for the construction of the office building. Data from the GaBi software construction materials database were also used. They consist of life cycle data of generic construction materials and components. Literature data was used wherever it was necessary [4-11]. During data collection, flows that are very small in the total mass of the product may have been disregarded. This rule does not apply where the flow, although below the cut-off level, cause significant environmental burdens, for example where the flow is classed as hazardous. Modelling of the system has been done with the help of the GaBi Software.

3. IMPACT ASSESSMENT OF THE OFFICE BUILDING

The impact assessment step analyzes and evaluates the magnitude and significance of the potential environmental impacts of the life cycle of the office building. The results of the inventory analysis are translated into contributions to relevant impact categories. Impact assessment consists of the classification, characterisation, normalisation and evaluation step. The **classification** step assigns data identified in the inventory stage to various impact categories such as abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, photochemical oxidant formation, and radioactive radiation. The **characterisation** step aims at quantifying and aggregating the potential effects, normalized to the functional unit of the product system studied. In this step the environmental interventions are quantified in terms of a common unit for that category, allowing aggregation into a single score: the indicator result. Equivalence factors are used for the different environmental effects. **Normalization** is defined as an optional element relating all impact scores of a functional unit to the impact scores of a reference situation. The **evaluation** step is the process where the impact scores of the different impact categories are compared and weighted for the comparison of the alternative products/processes. The relative importance of the impact scores is brought into perspective by normalization. In this way, impact scores are related to the total magnitude of the given impact category from all sources in a given area/period. The factors that are used in this study were developed by the Institute of Environmental Sciences of the Leiden University (Tables 1 and 2) [3].

Table 1: CML2001 Normalization factors (Europe)

Quantity	Unit	Weights
Abiotic Depletion (ADP)	kg Sb-Equiv.	4,94E-11
Acidification Potential (AP)	kg SO2-Equiv.	2,68E-11
Eutrophication Potential (EP)	kg Phosphate-Equiv.	5,88E-11
Global Warming Potential (GWP 100 years)	kg CO2-Equiv.	1,55E-13
Ozone Layer Depletion Potential (ODP)	kg R11-Equiv.	8,83E-09
Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	8,90E-11
Radioactive Radiation (RAD)	DALY	1,51E-05

Table 2: CML2001 Evaluation factors (Southern Europe)

Quantity	Unit	Weights
Abiotic Depletion (ADP)	kg Sb-Equiv.	1,5
Acidification Potential (AP)	kg SO2-Equiv.	1
Eutrophication Potential (EP)	kg Phosphate-Equiv.	7
Global Warming Potential (GWP 100 years)	kg CO2-Equiv.	10
Ozone Layer Depletion Potential (ODP)	kg R11-Equiv.	2
Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	3
Radioactive Radiation (RAD)	DALY	0,5

The results of the environmental impact study performed on the construction and use phase of the building is shown in Figure 1. Not surprisingly, the use and repairing stage is significantly high for the environmental impacts of the office building life cycle. The use phase contributes by 91,94% to the total of the life cycle. The construction phase contributes by 8,06% to the total environmental score. The global warming potential is the environmental impact with the largest contribution to the overall score. GWP contributes by 83,53% to the construction phase and by 78,35% to the use phase of the building. The contribution of GWP to the total environmental score is 78,8% (Figures 2 and 3).

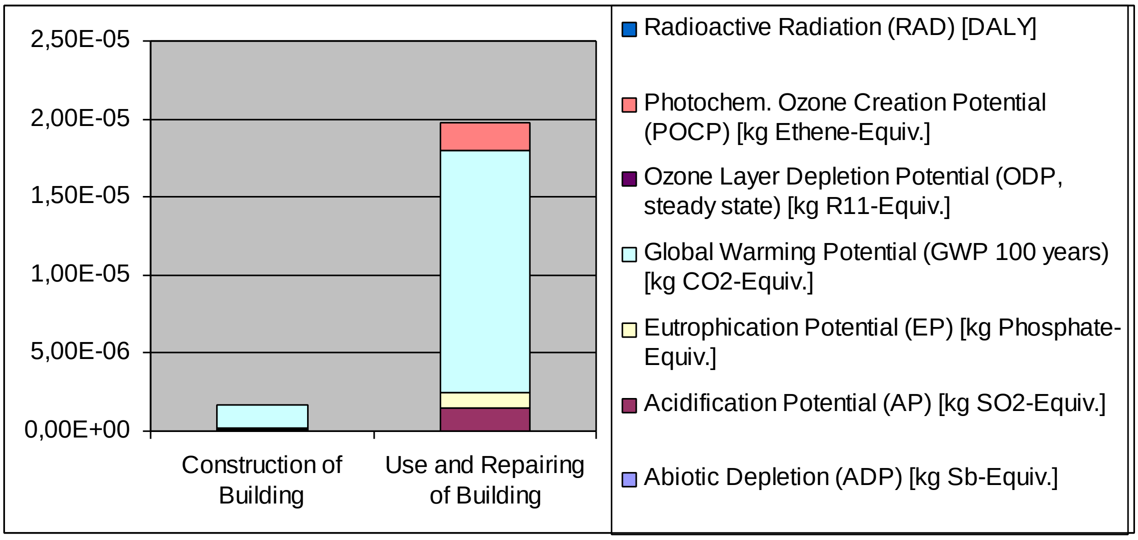

Figure 1: Total impact of the construction and use phase of the office building.

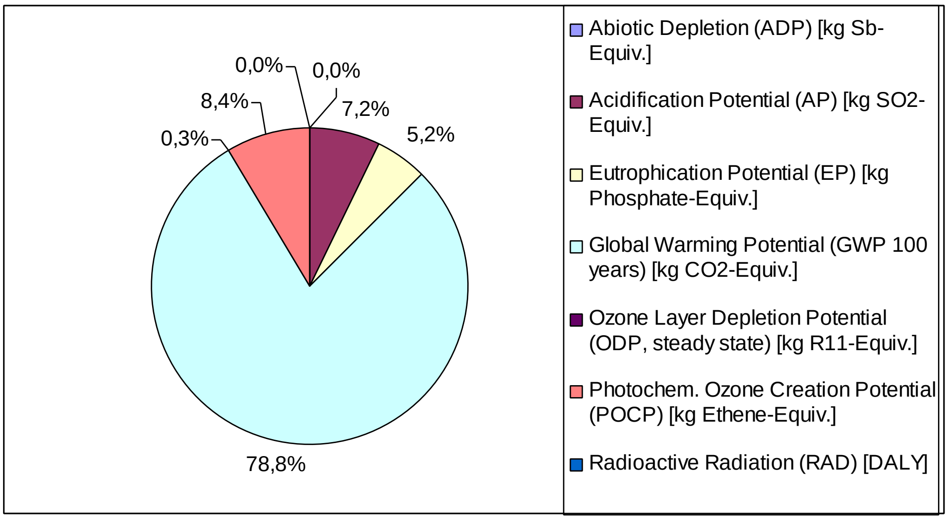

Figure 2: Percentage contribution of each impact category to the total impact of the office building.

Photochemical ozone creation (POC) contributes by 8,4% to the total environmental score. POC contributes by 4,77% to the environmental impact of the construction phase of the building. At the same time, it contributes 8,76% to the overall impact of the use phase due to impacts of energy production and consumption processes. The acidification potential contributes by 7,24% to the total life cycle (production and use phase). Acidification contributes by 3,81% to the environmental impact of the construction phase of the building. At the same time it contributes 7,54% to the overall impact of the use phase. The eutrophication potential contributes by 5,25% to the total life cycle (production and use phase). Eutrophication contributes by 7,27% to the environmental impact of the construction phase of the building. It also contributes 5,07% to the overall impact of the use phase. The ozone layer depletion potential contributes by only 0.27% to the total impact. Radioactive radiation is also contributing by only 0.03% due to energy consumption for material production that is done in European countries where nuclear energy is part of the total electricity production. The use phase is the larger contributor to most of the impacts of the building life cycle (Figure 1). Its contribution is at least 89% to the GWP, the acidification potential, the eutrophication potential and the ozone depletion potential. Abiotic depletion and radioactive radiation are mainly caused by the construction phase due to emissions regarding the material production stages.

The amount of material consumption is the main reason for the distribution of the environmental impact of each level of the office building construction phase. The groundfloor appears to be the level with the largest environmental impact during its construction phase (Figure 4) since it consumes the largest part of material. The three basements are the next largest contributors while the office floors have a little less contribution. The construction of the rooftop is the smallest contributor since it uses the smallest amount of materials. The global warming potential (Figure 5) is the environmental impact that corresponds to the largest portion (at least 82%) of the total impact of the construction phase of each level. The eutrophication potential corresponds to at least 6,5% to the impact of the construction of each level, the photochemical ozone creation potential around 4-4,5%, the acidification potential varies between 3,25-4,21% and the ozone layer depletion effect average contribution is 0,08%.

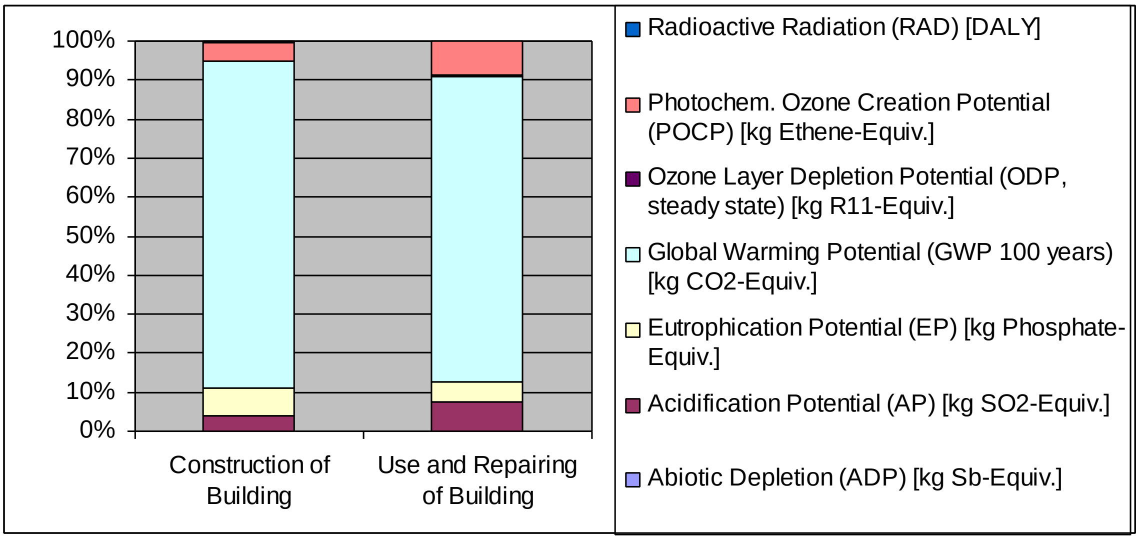

Figure 3: Percentage contribution of each impact category to the total impact of the construction and use phase of the office building.

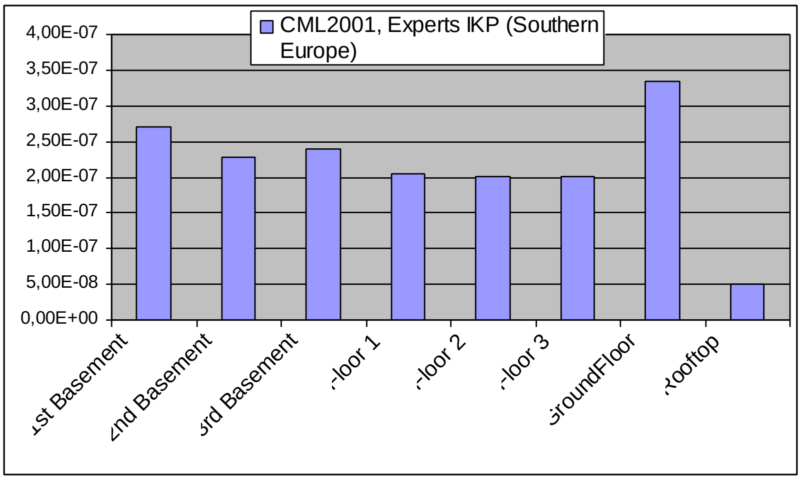

Figure 4: Total impact of each construction component of the office building.

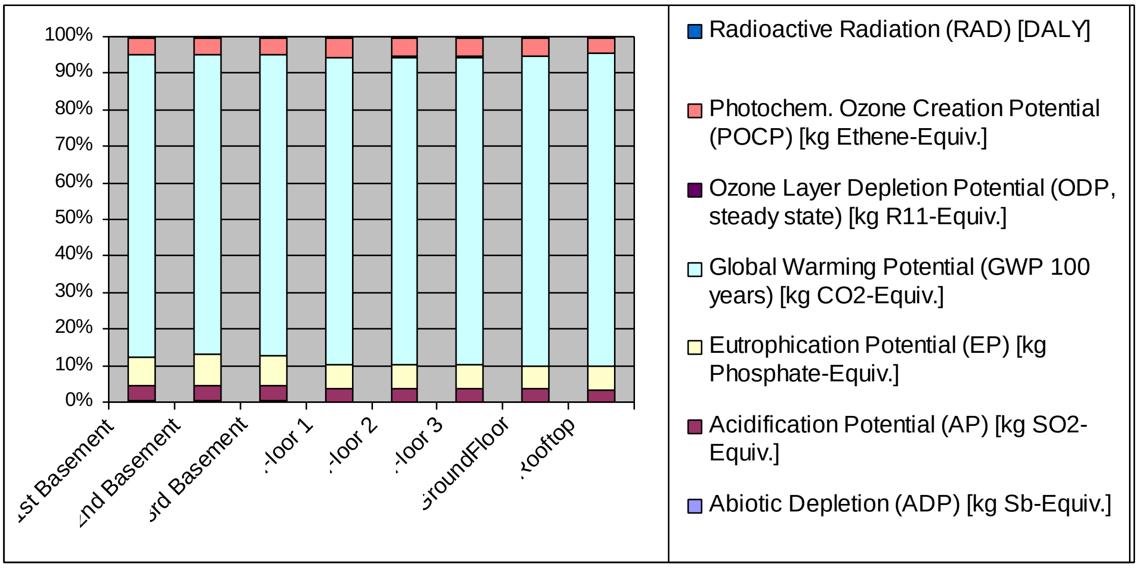

Figure 5: Percentage contribution of each impact category to the total impact of the construction components of the office building.

The environmental impact of the materials used for the construction of the 2nd floor level is presented in Figure 6. Concrete production and placement is the largest contributor to the construction stage of each level of the office building. Steel is the material with the second largest contribution. Both materials are produced by energy intensive processes where air emissions are related with fossil fuel consumption. Epoxy resin that is used for the industrial floor placed in the three basements is also contributing significantly to the overall impact of the construction phase.

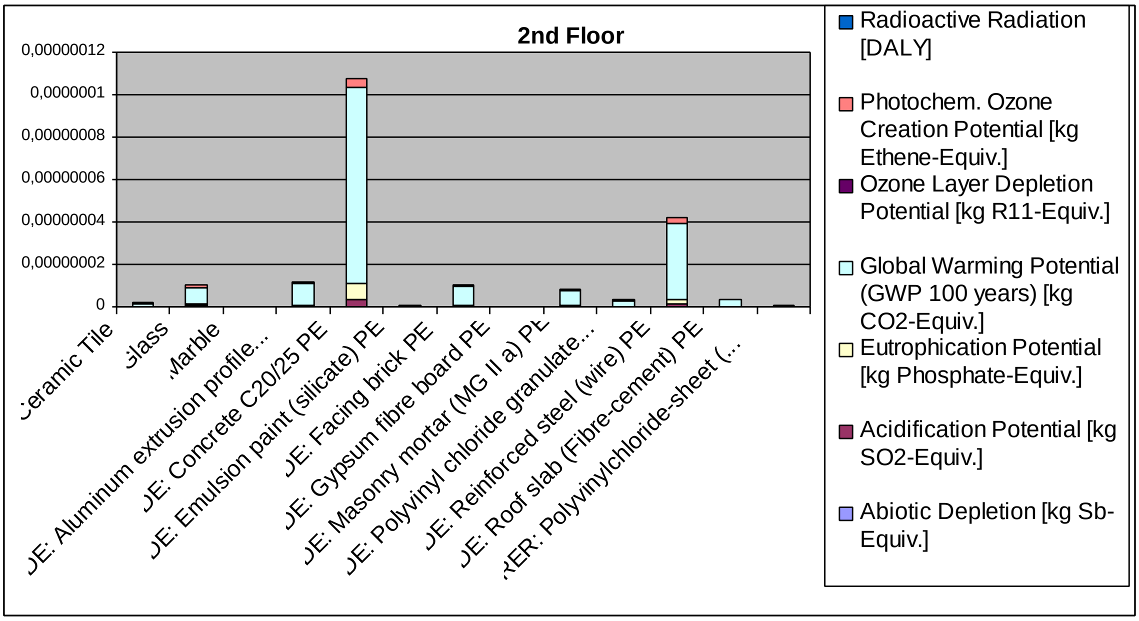

Figure 6: Contribution of each construction material - component to the total environmental impact of the construction phase of the 2nd floor of the building.

4. CONCLUSIONS

Life cycle distribution of energy consumption and environmental impacts are concentrated in the use and renovation phase of the office building. The results showed that the use phase environmental impacts accounted for more than 92% of the total inventoried environmental burdens. Global warming potential is the environmental impact with the larger contribution to the total environmental score of the life cycle. GWP contributes 78,77% to the total environmental score. The environmental impact of the use phase is attributed to the energy consumption that is related with fossil fuel use in energy production processes. Energy is used for the heating, cooling and lighting of the building during its life cycle.

The optimization of operations phase performance should be the primary emphasis for designing to minimise life cycle environmental impacts. For example, design improvements related to the building energy losses can significantly reduce cumulative burdens even at the expense of greater material production and construction burdens. The use of renewable energy sources would also improve significantly the environmental profile of the life cycle (Figure 7). Consequently, material selection can become a more critical factor as non-renewable resources become more scarce. However, this is still the exception rather than the rule, and for the time being the differential balance of burdens between the use phase and the construction phase shows that focus should be put onto the improvement of the use phase. The initial design can minimise many environmental impacts and can influence opportunities for future improvements. While designers cannot control what happens after a building is completed (i.e. how it is renovated, or operated) the initial design of a building will determine in large part the baseline from which the building will begin its operational life. Future improvements of the study should include a more detailed modelling of energy consumption during the use phase of the life cycle. Detailed calculation of energy consumption would reveal improvement opportunities to the design of the building. The energy consumption practices of the building users could also offer solutions for minimization of the energy consumption during the 80 year, use phase.

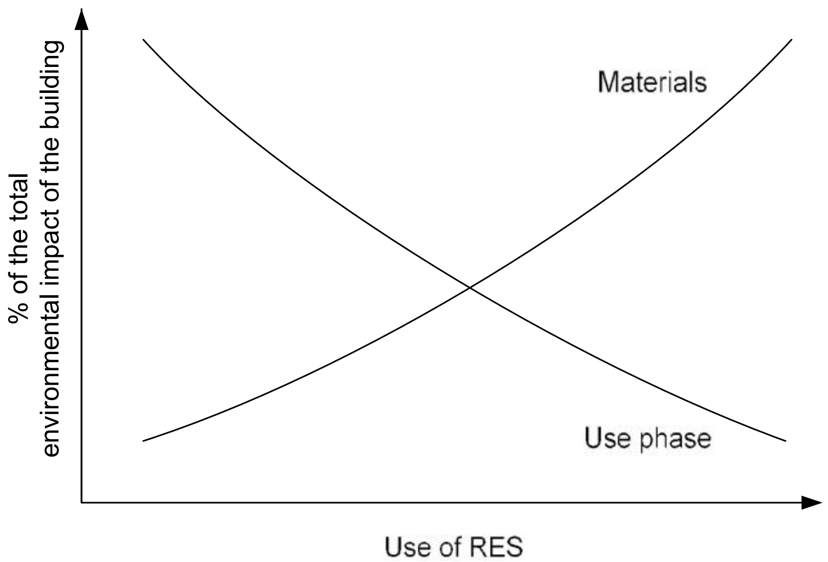

Figure 7: Impact of RES usage in the total environmental impact of the building

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