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Analysis of Low Carbon Efficient Building Materials

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Abstract

Better construction and use of buildings in the India would influence 42% of final energy consumption, about 35% of our greenhouse gas emissions and more than 50% of all extracted materials. It could also help to save up to 30% of water consumption. This research outlines and draws conclusions about different aspects of the material efficiency of buildings and assesses the significance of different building materials on the material efficiency. The research uses an extensive literature study and a case-study in order to assess should the depletion of materials be ignored in the environmental or sustainability assessment of buildings, are the related effects on land use, energy use and/or harmful emissions significant, should related indicators (such as GHGs) be used to indicate the material efficiency of buildings, and what is the significance of scarce materials, compared to the use of other building materials. This research suggests that the material efficiency should focus on the significant global impacts of material efficiency; not on the individual factors of it. At present global warming and greenhouse gas emissions are among the biggest global problems on which material efficiency has a direct impact on. Therefore, this paper suggests that greenhouse gas emissions could be used as an indicator for material efficiency in building. Depletion of abiotic resources is a much disputed impact category in life cycle assessment (LCA). The reason is that the problem can be defined in different ways. Furthermore, within a specified problem definition, many choices can still be made regarding which parameters to include in the characterization model and which data to use. This article gives an overview of the problem definition and the choices that have been made when defining the abiotic depletion potentials (ADPs) for a characterization model for abiotic resource depletion in LCA. Updates of the ADPs since 2002 are also briefly discussed. Finally, some possible new developments of the impact category of abiotic resource depletion are suggested, such as redefining the depletion problem as a dilution problem. This means taking the reserves in the environment and the economy into account in the reserve parameter and using leakage from the economy, instead of extraction rate, as a dilution parameter Therefore, this paper suggests that greenhouse gas emissions could be used as an indicator for material efficiency in building.

Keywords: Material efficiency; resource efficiency; energy efficiency; building; construction; land-use; life-cycle; case-study; greenhouse gas; abiotic resource depletion.

Introduction

Resource efficiency means efficient use of energy, natural resources, and materials, in order to create products and services with lesser resources and environmental impacts. It is based on life cycle thinking and comprises of energy efficiency and material efficiency. Whereas the energy efficiency considers sparing use of energy, and ratio of energy use and production, material efficiency is about sparing use of natural material resources, effective management of side streams, reduction of waste, and recycling. Natural resources underpin the functioning of the European and global economies and the quality of life. These resources include raw materials, such as fuels, minerals and metals, as well as food, soil, water, air, biomass, and ecosystems. A roadmap to a resource-efficient highlights the buildings sector as one of the three key sectors for improvements. Better construction and use of buildings in India would influence 42% of final energy consumption, about 35% of our greenhouse gas emissions and more than 50% of all extracted materials. It could also help to save up to 30% of water consumption. The importance of material efficiency and the need to improve it can be studied from several perspectives. Limited availability or scarcity of materials may lead to threats to the economy, and the production processes of materials can have significant environmental impacts. The extraction of raw materials and the production of materials may also be energy and/or labor intensive and very costly, and the extraction of materials may lead to land use changes and related impacts. This article presents an overview of the different aspects of resource and material efficiency in

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building construction. The paper also presents the results of a case study and analyses the significance of building materials in terms of material scarcity.

Natural resources can be divided into renewable and non-renewable resources. Non-renewable resources are those that can only be harvested once. These are often referred to as stocks (e.g., iron ore) or resources that form extremely slowly (e.g., crude oil). Azapagic divides the minerals industry into energy minerals (e.g. coal, oil), metallic minerals (e.g., iron, copper and zinc),construction minerals (e.g., natural stone, aggregates, sand, gravel, gypsum), and industrial minerals(e.g., borates, calcium carbonates, kaolin, plastic clays, talc). A reserve is defined as that part of the reserve base that could be economically extracted or produced at the time of determination (in accordance with the terminology used by the Ministry of urban Development of India). The reserves of the most common building materials (aggregates, clay, lime and stone, gypsum, and quartz) are either large or very large. However, buildings also consume materials whose reserves are more limited, for example, coal, oil, and metallic minerals. The usability of resources depends specifically on the economy and the available technology. Resources that have previously been uneconomical to extract may become usable because of rising values and improved extraction technologies. Political situations and the effects of extraction on the landscape and environment may also affect the usability of resources. Scarcity always has a time dimension: it can be interpreted as a change in availability over time. Steen claims that many life cycle impact assessment (LCIA) approaches mix scarcity with issues such as difficulty of extraction. This can be viewed as double counting, as the effects thereof, such as high energy demand, are accounted for in other categories. Metals in use can also be seen as a global inventory of available metals. Virgin metal is added when necessary to this inventory. Future backup technologies will probably require significantly less energy and other resources than the extraction of virgin metal. Meadows identify that the increasing cost of resources is becoming a major problem for societies. As resources become scarcer, this may influence the quality of life in some parts of society. This, in turn, may have negative impacts on human health as a specific area of protection. It may therefore be important not to separate the environmental and economic aspects. Yellyshetty argue that resource depletion needs to be considered in LCAs from the perspective of time, environmental and economic aspects of mineral extraction, and future consequences of decreased availability of mineral resources for a region. Steen highlights three issues that should be considered when drawing conclusions about the inclusion of resource depletion in LCAs:

LCA is a technique to assess the potential environmental impacts associated with a product or service throughout its life cycle using the following process: Goal and scope definition: defining suitable goal and scope for the LCA study.

1-The time perspective when evaluating impacts on abiotic resources.

2-The separation of environmental and economic aspects.

3-The consequences of decreased availability should form part of the LCI or the LCIA. The socio-economic value of mineral extraction can be significant in some regions, and changes in the extraction industry can have important social consequences. When the MCI is multiplied by future resource demand, the future costs to society can be determined.

Resource efficiency can be defined with a number of indicators. Each indicator has a specific definition, which contains only certain aspects of the issue. Resource efficiency may be defined, for example, in terms of land area that an economy requires, human impacts on natural processes, impacts on land use, amount of material use or related environmental impacts, ratio of GDP to material use, or national monetary input-output tables expanded with environmental information. When moving from the level of economies to the level of technologies or products, other life-cycle related indicators are more common. The indicators are typically not correlated, so a wide range of environmental indicators are needed.

For example, life cycle assessment (LCA) methodology assesses the harmful impacts of buildings in terms of global warming, ozone depletion, acidification of soil and water, eutrophication, photochemical ozone creation, and depletion of abiotic resources(elements and fossil fuels). The impacts from resource use, often referred to as, resource depletion, is a prominent impact category in LCA. LCA methodology addresses abiotic, or non-living, resources in terms of their availability for present and future generations. The depletion of such resources can be studied from the perspective of amounts of deposits, extraction rates, future ore extractions, or energy consumption.

The use of natural raw materials in building can be decreased by using lightweight structures, minimizing loss, improving durability and service life, using secondary materials and improving appropriate flexibility. Improved space efficiency also contributes to better material efficiency when assessing it in terms of functional units (a building that fulfils the required performance).The following equation shows how these different aspects of material efficiency relate to the wider concept of resource efficiency. Equation (1) defines the total impacts associated with the production and processing of a specific material as

$$I = D \times M \times Y \times E \quad \ldots\ldots (1)$$

Where,

I= Impact due to the Demand

D= Demand for Products Containing materials

M= Mass of material per Product

Y= Yield ratio of supplied material *versus* material in the final product

E=Average emissions per unit of material

The demand for new buildings is influenced by their durability, service life and flexibility. The use of lightweight structures impacts the average mass per product, and the yield ratio is affected by material losses during processes. Finally, the use of secondary materials impacts—in addition to the use of natural material resources—the average emissions, as reuse and recycling are typically significantly less energy intensive than primary production.

The building sector is the single largest contributor to global greenhouse gas emissions. On the other hand, it also has a substantial emission saving potential. Material efficiency extends to all the underlying factors of resource efficiency, making it a significant contributor to resulting impacts from materials. Considering these viewpoints, material efficiency has a significant role in reducing the global GHG emissions from buildings. The greenhouse gas emissions from buildings are related to the embodied energy of building materials and the emissions from operational energy use and the role of materials is becoming increasingly important. The research and policies have focused only on the operational energy use until recently. This can be explained by the fact that, the role of embodied energy has been relatively low, at some 10%–20% but development towards more energy efficient buildings increases the importance of materials. In low-energy buildings the role of materials can be as high as 50% and ultimately, at zero-energy-level, all the energy-consumption, and related greenhouse gas emissions come from the embodied energy of building materials. Due to this development, the embodied energy and related emissions cannot be omitted in life cycle assessments.

In addition to initial material consumption, the buildings also need materials for their lifetime renovations. The energy consumption of interior renovations over the lifetime of a building can account for some 20% to 30% of the initial embodied energy. The need of this recurrent embodied energy can be almost halved, with the use of materials with longer service life. When looking at the issue from the level of residential areas, also transport needs to be considered. Significant greenhouse gas savings can be achieved in all, embodied, operational and transport energy needs when planning residential areas. From sector-level, the most important factors affecting the greenhouse gas emissions are housing size, style and location. Another viewpoint to the issue is the temporal perspective of emissions from building. The initial GHG emissions emitted over a short period of time in the construction phase may compromise the greenhouse gas mitigation goals in short and medium term. Therefore, the greenhouse gas emission targets cannot be achieved with energy-efficient new buildings alone.

Objective

- To Study the depletion of raw materials and its long-term socio-economic impacts.
- To Study the Land use change due to the extraction of raw materials and its environmental impacts, and impacts on the landscape and future recreational use.
- To analyze use of energy in production processes of materials and depletion of non-renewable energy.
- To Study harmful emissions from production processes of materials and their local and/or global environmental impacts.

To Study the outline and draw conclusions about different aspects of the material efficiency of buildings

Material

Material efficiency is a way to reduce the demand of abiotic building materials. Whereas the importance of material scarcity is growing in general, the issue is not as clear for building materials. Common building materials, such as metals and ceramics, are derived from ores. Some of the minerals are approaching their production peaks and some have already passed their peak. There is also a continuous decrease in ore grade at which some materials are being mined. The inevitability of peaking of oil is generally acknowledged, although, it is still under debate, whether or not the peak has already passed Oil is needed, for example, for production of polymer-based building materials. The building industry uses large amounts of materials, equating to approximately 50% of Indian resource extraction, but the most common building materials are also common in nature. Aggregates, for example, are the key component of many building elements but are generally not a scarce resource. However, due to their heavy and bulky nature, aggregates need to be sourced close to their markets. Viable sources may be constrained at regional and local level, for example in rapidly growing developing countries, if their viable local supply is not strategically planned. Relating to these problems, approaches which account for local resources have been proposed in literature.

The buildings also require metallic minerals for the production of, for example, concrete reinforcements and structural steel in the building frames, roofs, façades, windows and doors of the building envelope and pipes, ducts and wirings of building systems. Despite of dependence on the import of metallic minerals in some countries these resources are not considered scarce, as their global availability is good. However, mining of these minerals may become critical in terms of social impacts that mining activities cause locally on land and ecosystems.

When buildings become more energy efficient and building systems more advanced and complex, the demand for scarcer resources may increase. Some of the components of advanced, energy-efficient building systems, such as wind turbine magnets, high-capacity batteries, energy-efficient lighting and photovoltaic cells require rare earths and critical natural resources in their production. However, the exact selection and weighting of factors, which make a raw material critical or scarce, are still open research questions. Raw materials may be considered critical, for instance, if they have national significance for economies and their current or future supply is at risk. Other sources of criticality may rise from specific ecological, social, or political considerations.

Methodology

The case-study aims to add to the existing knowledge by showing the importance of different building materials, in terms of their abiotic resource depletion potential (ADP). It also studies the importance of building materials, in relation to operational energy use and the role of advanced building systems. Finally, the case-study offers new information on the current calculation method for ADP, together with its limitations. These issues were selected as the focus of the case-study, based on the gaps in the existing literature. This section presents the case-study building, and explains the calculation method and main data sources used in the study. This case-study assesses the resource depletion of a case-building, by using impact categories of ADP elements and ADP fossil, recommended by current standardization and guidelines. The following subsections go through the calculation method, principles of the used life cycle assessment method, material quantities used in the assessment, calculation of energy consumption and, especially, calculation of ADP elements and ADP fossil.

Calculation Method

This research used life cycle assessment to determine the ADP of a case building. The calculation was carried out by using the bill of quantities (BOQ) of a real world building and assigning each of the materials with a specific characterization factor for their ADP (elements). For ADP fossil, the energy consumption associated with the materials of BOQ was completed with lifetime energy consumption information.

LCA is a technique to assess the potential environmental impacts associated with a product or service throughout its life cycle using the following process: Goal and scope definition: defining suitable goal and scope for the LCA study. Inventory analysis: compiling an inventory of relevant inputs and outputs of a production system. Impact assessment: evaluating the potential environmental impacts associated with the selected inputs and outputs. Interpretation: interpreting the results. LCA considers the potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The most important tool of the LCT approach is Life Cycle Assessment (LCA). Proper environmental evaluation is a crucial issue that should always be taken into consideration in order to insure sustainable development in practice.

Impact Factor

S.No	Environmental Issues	Impact factor
	Abiotic depletion	0.01
	Global warming	2.4
	Human toxicity	1.1
	Fresh water aquatic ecotoxicity	0.2
	Marine aquatic ecotoxicity	0.2
	Terrestrial ecotoxicity	0.4
	Photochemical oxidation	0.8
	Acidification	1.3
	Eutrophication	1

Surprisingly – so far abiotic depletion is treated as the least important environmental impact indicator in the whole LCA analysis.

Results & Discussion

The following subsections present the calculation results of the case-study, along with the references for the used data sources. The ADP elements and ADP fossil for the case building are shown in the first two subsections, followed by results for soil stabilization. After this, the impacts of advanced building systems are assessed, followed by the impacts of transports and construction work. The last result section shows the results for ADP from operational energy use and compares it to the material-related ADP results.

ADP Elements of Building Materials

This section shows the results for ADP Elements of building materials for the case building. The following table (Table 1) shows that the total need of building materials over a 50-year life cycle for the case building is 4960 t. The total material need includes the initial material needs for construction of the building (89%), recurrent material needs for replacements and refurbishments (6%), and material losses (5%). The table also shows that the production of the building materials for the case-building requires a total of 7320 t of abiotic inputs. According to the results, the building-level abiotic depletion potential, over the lifetime of the building, is 1.05 kg of Antimony equivalents, In addition to these results, the following Table 1 also includes the ADP characterization factors used in the calculations for each of the main materials. It also shows the noteworthy information on abiotic inputs, which lack an ADP characterization factor, and are therefore not included in the calculation results.

Table 1
The total need of building materials over a 50-year life cycle for case building

Material	**Total mass of Material**	**Abiotic material Input Materials per ton**	**Total Abiotic material Input**	**Abiotic material inputs with no ADPCF (%)**	**ADPAG of abiotic Input (t sbeq/t**	**Total ADP of materials (kg Sbeq)**
Aluminium	29	4.8	142	87.2	$3.22 \times 10-6$	0.46
Concrete	3549	1.4	5016	99.9	$8.28 \times 10-9$	0.04
Copper	4	6	26	99.2	$1.90 \times 10-5$	0.49
Fossil materials	90	2.8	256	99.9	$7.40 \times 10-10$	0
Gravel	629	1.9	1202	100	……	0
Other minerals	337	0.8	254	100	$2.83 \times 10-10$	0
Steel	83	3.5	291	91.6	$1.86 \times 10-7$	0.05
Wood	42	0.1	5	99.7	$4.79 \times 10-9$	0
Wood boards	200	0.6	129	99.7	$4.84 \times 10-9$	0
Total	4963		7319	99.3		1.05

ADP Fossil of Building Materials

This section shows the results for ADP Fossil of building materials for the case-building. The total material needs presented in the following table (Table 2) match those presented in the previous section. According to the results, the ADP Fossil of the case-building is 15,900 GJ of fossil energy inputs.

Table 2

Material	Total mass of Materials(t)	Fossil energy inputs per material ton (GJ/t)	Total ADP of Materials(GJ)
Aluminium	29	4.8	1088
Concrete	3549	1.4	2720
Copper	4	6	75
Fossil materials	90	2.8	7696
Gravel	629	1.9	38
Other minerals	337	0.8	1259
Steel	83	3.5	1297
Wood	42	0.1	27
Wood boards	200	0.6	1728
Total	4963		15928

ADP of Soil Stabilization

This section studies the effect of soil stabilization on the ADP elements and ADP fossil. The total material need for stabilization is 1420 t, including material losses (5%). The following Table 3 shows that the ADP elements value of soil stabilization is 530 g, or 0.17 g/m2, and that the ADP Fossil is 3500 GJ.

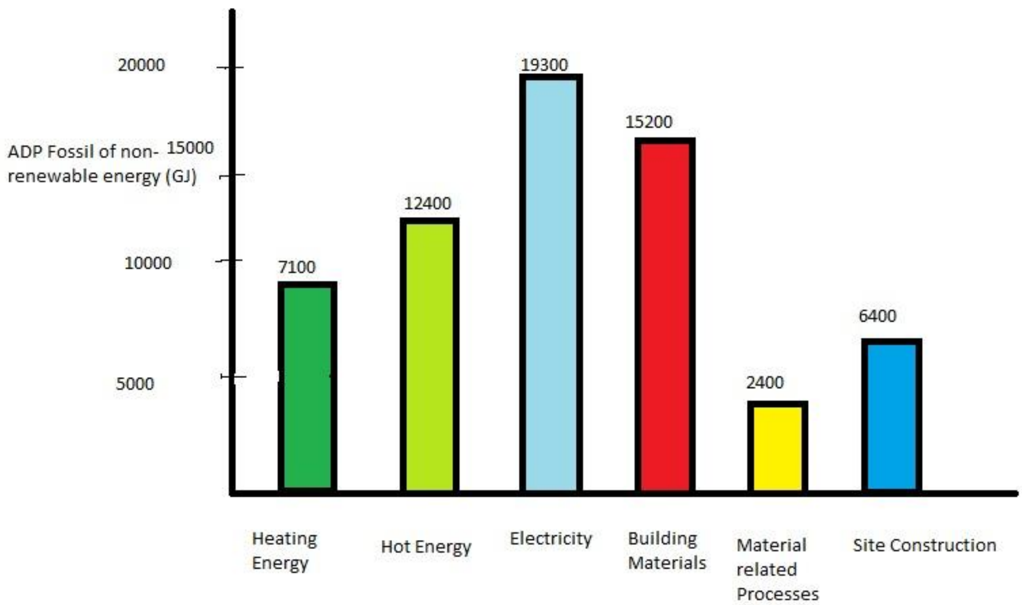
Table 3

Material	Total mass of materials (t)	Fossil energy input per material ton(GJ)	Toatal ADP Fossil of materials (GJ)	Abiotic Material input per matrial ton (t)	Total abiotic material input (t)	Abiotic material input with no ADP(%)	ADP avg of abiotic input	Total ADP of materials
CEMII	709	3.6	2558	1.7	1199	99.6	0.00045	0.53
Cao	709	5.4	3820	3.2	2303	100	…..	….
Total	1420	9	6380	5	3500	99.8	…..	0.53

Summary

- The APD Fossil due to operational energy totals 38,700 GJ and material-related ADP Fossil is in total 17,600 GJ or 24,000 GJ depending on the stabilization needs. Therefore, the total lifetime ADP Fossil varies from 18.5 to 20.5 GJ/m2. The result shows that the role of material-related non-renewable energy consumption for the case-building is at the level of 30% to 40% of lifetime total energy consumption.
- The case-study of this research aimed to fill in the gaps in the current knowledge, as identified in the literature review. It looked into the depletion of natural raw materials, through an assessment of lifetime abiotic depletion potential (ADP) of a residential multi-storey case-building with concrete structures.
- For both ADP elements and ADP fossil, as defined in current guidelines. It should be highlighted that due to the case-study approach, the generalization of the results should be done with caution, especially considering the building type and location.
- The material quantities were extracted from the building information model (BIM) of a real world building, so the data accuracy for initial material consumption can be considered high.
- The material losses, on the other hand, were estimated to be at the level of 5% of total material consumption. Commonly used values in literature vary from 0% to 10%. Also, the lifetime material needs for replacements and refurbishments were assessed through simple estimates on service lives of different building components.
- An analysis on the impacts of estimation errors show that a change of 25% in these factors would increase/decrease the material amounts by some 10% for the case-building.
- The case-study used the Asian reference life cycle database, to derive the abiotic material inputs and energy requirements for each of the main materials of the building.

The LCIs of the database are compiled mainly by process analysis. It can be argued that this method is associated with under estimation of the impacts, as the number of processes and the order of upstream processes are limited, and sufficient boundaries may be difficult to cover due to the complexity of upstream processes



Conclusion

- The construction sector is an important part of the Indian economy with the contribution of 10% in the GDP and is registering an annual growth of 9%. Clay fired bricks are the backbone of this sector.
- The Indian brick industry is the second largest producer of bricks in the world after China. India is estimated to produce more than 14000 crores of bricks annually, mainly by adopting age-old manual traditional processes.
- The brick sector consumes more than 24 million tonnes of coals annual along with huge quantity of biomass fuels. The per annum CO2 emissions from Indian brick industry are estimated to be 42 million tonnes.
- Due to large scale construction activities in major towns and cities, a number of brick plants have been set up on the outskirts of these cities. These clusters are the source of local air pollution affecting local population, agriculture and vegetation.
- For the production of clay bricks, top soil to the extent of 350 million tonnes is used every year, which is a reason for concern. Since this brick sector is labour intensive, it limits its capacity to produce any other type of bricks. With the introduction of NREGA scheme in various states, these labour intensive industries are facing the shortage of manpower.
- The brick industry has started exploring other options like introduction of partial/full-scale mechanization in this sector.
- Studying the market in the developed countries, it has been observed that they have completely switched over from solid brick to other resource efficient products like perforated bricks and hollow bricks.
- These products consume less fuel (coal, biomass etc.) and raw material (fertile top soil) for their production and have better insulation properties during its usage.

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