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Sustainability impacts of building products: An assessment methodology for developing countries

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Abstract

This article investigates sustainability impacts of building products during production stage in developing countries. An analysis of literature is undertaken in order to establish current building product assessment methodologies and their relevance to developing country contexts. The review finds that many of these methodologies have limited applicability to developing countries and, therefore, an alternative methodology, termed the Sustainable Building Material Index (SBMI), is proposed. The SBMI methodology draws on both a life-cycle assessment approach and an expanded definition of sustainability, which includes social and economic aspects as well as environmental impacts, to develop a sustainability impact index of building products. The article describes and critically evaluates the SBMI and makes recommendations for further research. It appears that the SBMI has potential as methodology for establishing, and presenting, sustainability impacts of building products in developing countries. It is innovative as it provides a way of capturing simple socio-economic sustainability aspects related to building products that do not include other building product assessment methodologies. This aspect makes it particularly relevant to developing countries where there is a strong interest in using construction and related industries to create beneficial social and economic impacts such as job creation and training.

Keywords: sustainability, building materials, methodology, sustainable building material index (SBMI)

Abstrak

Hierdie artikel ondersoek die volhoubaarheidsimpak van bou-produkte tydens die produksie-fase in ontwikkelende lande. 'n Literatuurstudie is gedoen ten einde huidige bou-produk assesseringsmetodes te bepaal en vas te stel wat hul relevansie binne die konteks van ontwikkelende land is. Die oorsig het bevind dat baie van hierdie metodes beperkte toepaslikheid binne ontwikkelende lande het en dus word 'n alternatiewe metode, die Volhoubare Boumateriaal Indeks (SBMI), voorgestel. Die SBMI-metode maak gebruik van beide 'n lewensiklus assesseringsbenadering asook 'n uitgebreide definisie van volhoubaarheid wat maatskaplike en ekonomiese aspekte asook omgewingsimpakte insluit, om sodoende 'n volhoubaarheidsimpak indeks van bou-produkte te ontwikkel.

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Die artikel beskryf en evalueer krities die SBMI en maak aanbevelings vir verdere navorsing. Die SBMI kom voor as 'n potensieële metode vir die stigting en aanbieding van volhoubaarheidsimpakte vir bou-produkte in ontwikkelende lande. Dit is innoverend, want dit bied 'n manier om eenvoudige sosio-ekonomiese volhoubaarheidsaspekte wat verband hou met bou-produkte wat nie in ander bou-produk assesseringsmetodologieë ingesluit is nie, vas te vang. Hierdie aspek is veral relevant vir ontwikkelende lande waar daar 'n sterk belangstelling is in die gebruik van die konstruksie en verwante bedrywe om voordelige sosiale en ekonomiese impak soos werkskepping en opleiding te skep.

1. Introduction

The assessment of materials in terms of sustainability is still in its infancy and is not well understood (Ding, 2008: 451-464). Current methodologies tend to focus on environmental issues and rely on life-cycle assessment or similar processes (Jönsson, 2000: 223-238). However, these systems tend not to address social or economic aspects and, therefore, cannot be said to assess sustainability (Cole, 2005: 455-467; Cooper, 1999: 321-331; Liu, Li & Yao, 2010: 1482-1490; Zuo & Zhao, 2014: 271-281). In developing countries, the lack of social and economic sustainability criteria and assessment is a significant shortcoming, as there is a strong interest in using construction and related industries to create social and economic impacts such as job creation and training (Gibberd, 2014: 49-61).

This article draws on a definition of sustainability, which includes social, economic and environmental aspects, and applies it to building products. The definition is analysed to develop environmental, social and economic criteria that can be used to assess the sustainability impacts of building-product manufacture. This is combined with concepts from a life-cycle assessment (LCA) approach in order to develop an index that can be used to compare building products. This index is referred to as the Sustainable Building Materials Index (SBMI). The article describes and critically reviews the SBMI and develops recommendations for further research.

2. Sustainability impacts of building materials

The building-product industry has very substantial environmental impacts. Conventional building processes mean that buildings require a vast quantity and variety of materials. In Spain, for instance, it is estimated that every habitable square meter of a conventional building requires a total of 2.3 tonnes of more than 100 types of materials (Zabalza Bribián, Valero Capilla & Aranda Usón, 2011: 1133-1140).

Approximately 50% of all materials extracted from the earth's crust are manufactured into construction materials and products.

Consequently, these materials also account for 50% of the waste stream (Koroneos & Dompros, 2007: 2114-2123). In Europe, minerals extracted for building materials amount to 4.8 tonnes per inhabitant per year, 64 times the average weight of a person (Zabalza Bribián *et al.*, 2009: 1133-1140).

The production of materials is also energy intensive and produces significant carbon emissions. For instance, the embodied energy of materials is estimated to account for between 15% and 60% of a building's life-cycle energy consumption (Huberman & Pearlmutter, 2008: 837-848; Liu *et al.*, 2010: 1482-1490). Carbon emissions from one industry, the cement industry, are estimated to produce 5% of global carbon emissions (Pulselli, Simoncini, Ridolfi & Bastianoni, 2008: 647-656). The very significant impacts of building materials and products indicate that it is important to understand how this can be assessed in terms of sustainability.

3. Defining sustainability

The World Conservation Union, the United Nations Environment Programme and the World Wide Fund for Nature define sustainable development as "... improving the quality of human life while living within the carrying capacity of supporting eco-systems (International Union for Conservation of Nature, 1991: 1-223).

This provides clear objectives, namely 'improving quality of human life' and 'living within carrying capacity of supporting eco-systems'. The World Wildlife Fund (WWF) quantifies these objectives to define sustainability as a state within which societies have an Ecological Footprint (EF) of less than 1.8 global hectares per person and a Human Development Index (HDI) value of above 0.8 (WWF, 2006: 1-44).

An EF is an estimate of the amount of biologically productive land and sea required to provide the resources a human population consumes, and absorb the corresponding waste. These estimates are based on consumption of resources and production of waste and emissions in the following areas:

- Food, measured in type and amount of food consumed.
- Shelter, measured in size, utilisation and energy consumption.
- Mobility, measured in type of transport used and distances travelled.
- Goods, measured in type and quantity consumed.
- Services, measured in type and quantity consumed
- Waste, measured in type and quantity produced.

The area of biologically productive land and sea for each of these areas is calculated in global hectares (gha) and then added together to provide an overall EF (Wackernagel & Yount, 2000: 21-42). This measure relates impacts to the earth's carrying capacity of 1.8 global hectares (gha) per person.

The HDI was developed by the United Nations to measure 'quality of life' and as an alternative to economic indicators for establishing development progress (UNDP, 2007: 1-224). The measure is based on:

- A long healthy life, measured by life expectancy at birth.
- Knowledge, measured by the adult literacy rate and combined primary, secondary, and tertiary gross enrolment ratio.
- A decent standard of living, as measured by the GDP per capita in purchasing power parity (PPP) in terms of US dollars.

The HDI is based on widely available data and provides an internationally acceptable definition of quality of life.

This article focuses on building-product manufacture impacts related to EF and HDI performance. While this is complex, an understanding of these fields can be developed by analysing the subcomponents of the EF and HDI and applying these to a building-product manufacturing site. This process can be informed by an understanding of life-cycle assessment processes that aim to establish the environmental impacts of products.

3.1 Life-cycle assessment (LCA)

A growing awareness of the environmental impacts of materials has led to a wide variety of claims in manufacturers' literature (Cole, 2005: 455-467). These aim to appeal to the architect and the client wishing to achieve a green building. However claims can be selective and highlight only positive aspects, while obscuring areas of poor performance. There is, therefore, a need for standardised, rigorous and objective assessment methods. This gap is being addressed by a range of systems, including Eco-Quantm, Athena, Envest 2, BeCost and BEES, that aim to understand and assess the environmental impacts of building materials.

Eco-Quantum is an Australian life-cycle assessment method based on ISO 14040. It assesses environmental impacts and greenhouse gas emissions of products over their entire total life cycle. Athena is an American life-cycle assessment tool for building and building assemblies. The process also complies with ISO 14040. Envest 2 was developed by the British Research Establishment to assess and present

environmental and life-cycle costs of different material and building assembly options. Twelve criteria, ranging from climate change to toxicity, are used to measure environmental impacts, and these are agglomerated into a single Ecopoint score. BeCost was developed by VTT Technical Research Centre in Finland. The tool can be used to assess and present environmental impact data and maintenance costs. BEES (Building for Environmental and Economic Sustainability) was developed by the National Institute of Standards and Technology in the USA. It measures the environmental performance of building products using a life-cycle approach aligned with ISO 14040. All of these assessment methodologies are based on life-cycle assessment approaches (Rincón, Castell, Pérez, Solé, Boer & Cabeza, 2013: 44-552; Hertwich, Pease & Koshland, 1997: 13-29; Peris Mora, 2007: 1329-1334; Esin, 2007: 3860-3871; Malmqvist, Glaumann, Scarpellini, Zabalza, Aranda, Llera & Díaz, 2011: 900-1907; Ekvall, 2005: 351-1358; Zabalza Bribián *et al.*, 2009: 2510-2520).

A number of benefits are associated with life-cycle assessment approaches. The methodology provides a structured process whereby often complex data sets can be acquired, assimilated and analysed in order to provide a picture of the impacts of product or building throughout its life cycle. It can be used to identify areas with significantly negative impacts and evaluate options for improving this. In addition, the results of life-cycle assessments support environmental labelling of buildings and can contribute to the setting of environmental targets for buildings and the building sector as a whole (Zabalza Bribián *et al.*, 2009: 2510-2520).

Life-cycle assessment approaches can support significant reduction in environmental impacts associated with building materials. For instance, González & García Navarro (2006: 902-909) show that 30% reductions in carbon emissions can be achieved through the careful selection of materials. Morel, Mesbah, Oggero & Walker (2001: 1119-1126) also show that the use of local materials can reduce the energy used in building materials by up to 215% and the energy used in transportation of materials by 453%. Life-cycle assessments of building materials can also identify the benefits of different production processes and the value of recycling waste materials. Demir & Orhan (2003: 1451-1455), for instance, demonstrate that 30% of the consumption of raw materials and production of waste, by mass, can be reduced in clay-brick manufacture by recycling fired waste bricks in production.

However, life-cycle assessments may also be regarded as overly complex and costly. Acquisition of data may be a problem, as

manufacturers do not readily share this with customers and LCA tool developers. The proliferation of systems and the differing results achieved with different systems also mean that there are concerns about the lack of a standard interface and potentially arbitrary results. Finally, there are also reservations about the accuracy of the results, in some instances (Zabalza Bribián *et al.*, 2009: 2510-2520). This may be the reason for the slow adoption of LCA approaches within building-certification processes, green-building rating systems and in-building regulations. Difficulties related to acquisition of data, cost, and technical capacity to undertake life-cycle assessments are likely to be even more acute in developing countries.

3.2 Developing country contexts

A review of the literature indicates that product life-cycle assessment is rarely applied to contexts in developing countries. This may be due to the lack of required data and the perception that the processes are overly complex and expensive (Malmqvist *et al.*, 2011: 1900-1907).

It may also be a result of the environmental focus of life-cycle assessment systems. While environmental issues are important, social and economic impacts are also of significant interest to developing countries. In these contexts, construction and related industries are often regarded as a means of creating beneficial social and economic impacts such as jobs and training. In South Africa, this is reflected in standards developed to promote preferential procurement of local products and materials, such as South African Technical Standard (SATS) 1286 (SABS, 2013: 1-5). SATS 1286 provides a protocol for measuring the local content of materials and products, in order to support the local industries. It enables local content requirements to be specified in tender documents and to be monitored during construction. Standards are also being developed to ensure that construction processes result in improved levels of education. Examples of this are the training targets set within the Standard for Developing Skills through Construction Works Contracts (cidb, 2012: 1-5). This standard sets out specific training requirements related to the construction value of projects and applies to both the professional teams and the construction workers.

In addition, it could be argued that environmental life-cycle assessment processes, by not measuring social and economic impacts, cannot claim to measure the broader concept of sustainability which includes social and economic aspects (Ortiz, Castells, & Sonnemann, 2009: 8-39). There is, therefore, a need to develop a simple methodology that is able to measure the social, economic and environmental sustainability

impacts of building products for contexts in developing countries. It is envisaged that assessments using this methodology, or the 'indication of the sustainability impact', of a building product will make a valuable contribution to understanding how sustainability principles can be integrated into building products (Ding, 2005: 3-16).

4. Research methodology

An index of sustainability impacts related to the manufacture of a building product can be developed by drawing on the definition of sustainability provided earlier in this article, and combining this with aspects of a life-cycle approach. This can be used to synthesise a 'hybrid' methodology, termed the Sustainable Building Material Index (SBMI). The steps in developing this index are as follows.

- Establish a specification for the SBMI based on contexts in developing countries.
- Define sustainability indicators by applying an appropriate definition of sustainability to a building-product manufacturing system and develop an assessment framework.
- Apply the concept of a functional unit to the assessment framework, in order to standardise calculation methods and allow comparisons between different products.
- Define performance tables that enable results to be classified in a scale of 0 to 5 and develop an appropriate report.

This study focuses on building-product manufacture, as this is within the sphere of influence of the building-product industry rather than a full life-cycle assessment approach which includes many aspects such as building operation and demolition that are not directly under their control.

4.1 Specifications for a sustainable building material index

In the context of a developing country, environmental, social and economic data related to building materials are not readily available. There are no detailed environmental databases for materials such as those used for life-cycle assessment in Europe and the US. Similarly, detailed industry-specific social and economic statistics are not readily available to support analysis. This means that data used for sustainability assessments of building materials must be sourced directly from building-material manufacturers.

A lack of available data makes undertaking detailed calculations to ascertain direct EF and HDI impacts of building materials complex

and time consuming (Malmqvist *et al.*, 2011: 1900-1907). In this context, it is proposed that proxy indicators, or equivalent factors, be used to make the process of sustainability assessment practical (Hertwich *et al.*, 1997: 13-29). As the capacity of small manufacturers to collect data may be limited, it is suggested that a restricted set of key sustainability indicators be developed. In addition, it is proposed that these be restricted to data that is readily available and easily collected by building manufacturers.

Therefore, the assessment methodology should:

- Use readily available data.
- Measure social and economic impacts related to sustainability as well as environmental impacts;
- Be simple enough to be carried out by small building-product manufacturers, and
- Provide reports that will enable materials and products to be assessed and compared in terms of their sustainability impacts.

4.2 The building manufacturing industry as a system

The first step in developing appropriate sustainability indicators is to describe the building-manufacturing industry as a system, with inputs, outputs, as well as social and economic impacts, as illustrated in Figure 1.

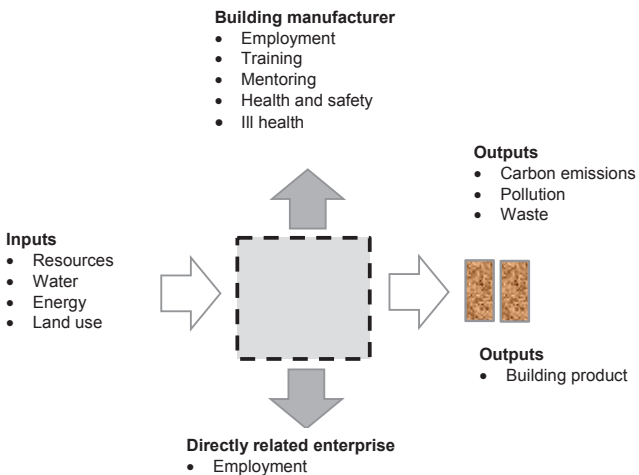


Figure 1: A building-product manufacturing system

Source: Author, 2014

Tables 1 and 2 describe in more detail indicators identified by means of this process. Table 1 describes ecological indicators and aims to provide a proxy for EF impact of building materials. Table 2 describes human development and aims to provide a proxy for HDI impact of building materials.

Table 1: Ecological indicators

<i>Ecological indicator</i>	<i>Units</i>	<i>Description</i>
Resource consumption	(kg/year)	This measures the quantity of material consumed to produce the building product.
Carbon emissions	(CO ₂ equiv/year)	This measures the quantity of carbon dioxide emitted to produce the building product.
Water consumption	(kl/year)	This measures the quantity of water consumed to produce the building product.
Land use	(ha/year)	This measures the quantity of land area used to produce the building product.
Waste	(kg equiv/year)	This measures the quantity of waste generated to produce the building product.
Pollution	(kg equiv/year)	This measures the quantity of waste generated to produce the building product.

Source: Author, 2014

Table 2: Human development indicators

<i>Human development indicator</i>	<i>Units</i>	<i>Description</i>
Employment	(FTE employment years/year)	This measures the employment required to produce the building product.
Employment in related enterprises	(FTE enterprise years/year)	This is a measure of employment in related enterprises, such as catering, transport and security industries, required to produce the building product.
Formal training	(Formal training hours/year)	This is a measure of education and training of employees during the production of the building product.
Formal mentoring	(Formal mentoring hours/year)	This is a measure of education and is the extent of mentoring of employees during the production of the building product.
Health and safety	(Incidents/year)	This is a measure of health and is the extent of health and safety incidents experienced to produce the building product.
Ill health per year	(Absenteeism days/year)	This is a measure of health and is the extent of absenteeism experienced to produce the building product.

Source: Author, 2014

Tracking these indicators on a manufacturing site can be used both to support improved understanding of the sustainability impacts associated with a building product and to establish a measure of the impact per building product. This is calculated by dividing annual ecological or human development impacts associated with a manufacturing process by the number of products produced within the same time period, as indicated in Figure 2.

$$\text{Ecological impact per product} = \frac{\text{Annual ecological impacts per year}}{\text{Number of building products produced per year}}$$

Figure 2: Ecological impact per product
Source: Author, 2014

Human development impacts per product are established in the same way, and can be calculated by substituting ecological impact with human development impact in the equation in Figure 2. This calculation, while useful for measuring sustainability performance of manufacturing processes, does not support comparisons between different materials. This requires further standardisation, and the application of the concept of a functional unit.

4.3 Functional unit

The functional unit concept was developed within the life-cycle assessment methodology in order to support environmental impact comparisons between products. ISO 14044 defines the functional unit as the “quantified performance of a product system for use as a reference unit” (ISO, 2006: 1-46).

In the building industry, this can be applied by defining products in terms of quantities of ‘final useful constructed elements’ such as ‘an area of compliant wall assembly’. ‘Compliant’, in this context, means that the wall assembly meets required local performance standards related to thermal resistance, structure, as well as fire and water resistance (such as those found in national building regulations). Thus, environmental and human development impacts can be ascertained, and then compared, for the same functional unit, such as a square metre of compliant wall area. In this way, the use of a functional unit supports comparisons of different materials and products (Kellenberger & Althaus, 2009: 818-825).

Therefore, if the impacts of clay bricks are to be compared with those concrete blocks, wall assemblies of both materials that achieve

the same, or similar, performance (such as thermal resistance, fire resistance, structural integrity, and so on) need to be modelled. From each of these wall assemblies, quantities of materials (bricks and blocks) can then be calculated. Once these quantities have been calculated, they can be multiplied by the respective human development and ecological impacts of the unit of building product, as calculated in the equation in Figure 2. This process provides a full set of ecological and human development impacts per functional unit of the different products enabling the two to be compared on a like-for-like basis.

Including performance in the concept of the functional unit is valuable, as it encourages innovation and improvement not only in the manufacturing process, but also in the design of complete buildings. For instance, if an innovative design was able to attain 'compliant' performance with fewer bricks, a lower ecological impact per functional unit could be achieved. This concept can be applied to all functional products and materials used in buildings, including components such as water taps and roof sheeting. An example of its application to a building envelope is shown in Figure 3.

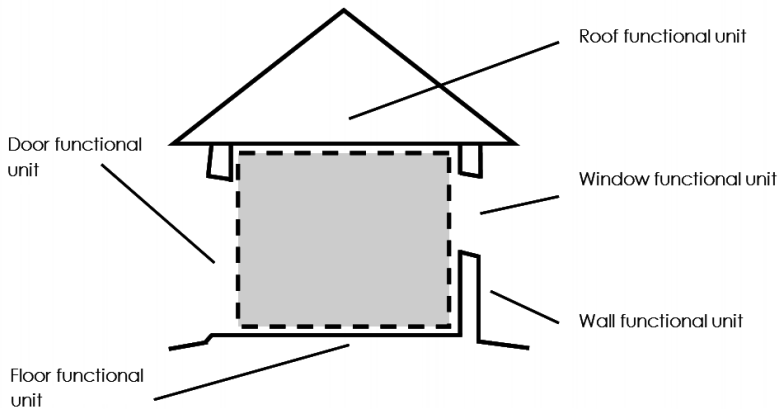


Figure 3: Building envelope functional units

Source: Author, 2014

4.4 Sustainable building material index

The final stage is the conversion of the sustainability impacts calculated per functional unit into an index. The index could consist of values from '0' to '5', with '5' being the worst performance and '0', the best performance. Index values could be calculated in the following way.

Sustainability impacts could be identified for each functional unit and '5' set as the value for average performance. The values for best performance can also be calculated in terms of optimum impacts. For instance, in the case of carbon emissions, this could be carbon neutrality, and would equate to a '0'. The values between '0' and '5' would then be equally spaced between these limits to define the respective index values between '0' and '5'. A graphical and tabular report on these index values for a material could then be developed, with an example provided in Figure 4.

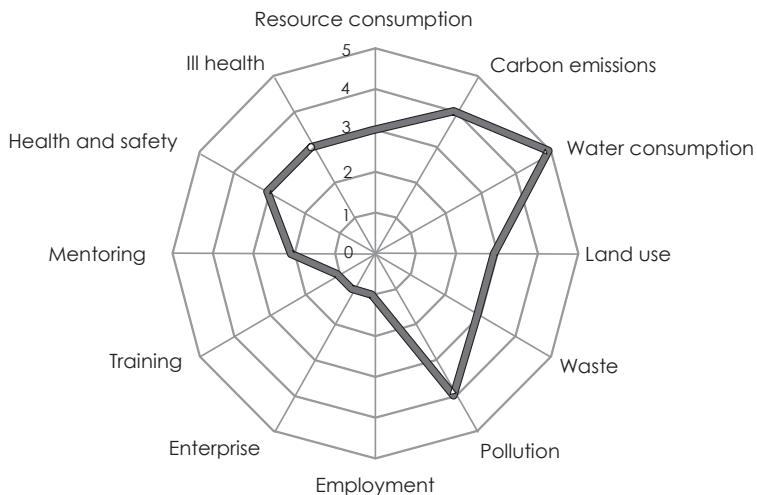
5. Discussion

A critical review of the SBMI methodology suggests that this has potential as a means for assessing building products and materials in terms of their sustainability impacts. However, the level of detail of the assessment is low compared to life-cycle assessment approaches. In addition, the SBMI does not assess the individual manufacturing processes that are used on a site and, therefore, it is not useful as a diagnostic tool for a building-product manufacturer wishing to improve these processes. Neither does it provide overall life-cycle impacts associated with different materials and products, which would be of interest to an architect and client.

However, by providing a high-level indication of sustainability impacts of materials, the SBMI does provide a manufacturer with a useful methodology for tracking the performance of production lines and plants. The methodology also lends itself to simple modelling, enabling a manufacturer to rapidly establish the impacts of different options. For instance, the ecological impacts of different processes can be calculated to inform decision-making. The methodology also provides a structured way in which manufacturers can assess their own products and, therefore, improve their sustainability performance over time.

The methodology offers a way for building designers to take sustainability into account when specifying products. Ecological and human development impacts of different products can be compared, in order to identify products with the most beneficial impacts. Minimum sustainability targets for materials can also be set and used as a way of improving manufacturing processes of building products and ensuring that required impacts are achieved.

SUSTAINABLE BUILDING MATERIAL INDEX (SBMI) V2	
Site address	Thulamela site
Analysis period	30 June 2013 - 1 July 2014
Analysis period (days)	365



Ecological	
Resource consumption per year (kg/year)	3
Carbon emissions per year (CO ₂ equiv/year)	4
Water consumption per year (kl/year)	5
Land use hectares (ha/year)	3
Waste per year (kg equiv/year)	3
Pollution per year (kg equiv/year)	4
Human development	
Employment per year (FTE employment years/year)	1
Employment in related enterprises per year (FTE)	1
Formal training per year (Formal training hours/year)	1
Formal mentoring per year (Formal mentoring hours/ year)	2
Health and safety incidents per year (Incidents/year)	3
Ill health per year (Absenteeism days/year)	3
Ecological	3.67
Human development	1.83
Overall	2.75

Figure 4: Sustainable Building Material Index (SBMI) V2 report

Source: Author, 2014

6. Conclusion

The SBMI methodology appears to have potential as a way of providing an indication of the sustainability impacts of building products. In particular, it is innovative as it provides a way of capturing simple socio-economic sustainability aspects related to building products, which has not been included in many other building-product assessment methodologies.

The escalating interest in sustainability and socio-economic impacts of building materials will make this methodology, and research in this field, increasingly relevant. It is recommended that further research be carried out to develop the methodology further and investigate how this can be applied to improve the sustainability impacts of building products.

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