ENVIRONMENTAL PERFORMANCE OF MARBLE TILE LIFE CYCLE
การประเมินผลกระทบต่อสิ่งแวดล้อมตลอดวัฏจักรชีวิตของกระเบื้องหินอ่อน

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Abstract

Accurate data and information about life cycle environmental impacts of building materials are critical for environmental-friendly building design. This paper reports the findings of environmental impacts assessment of marble tiles produced in Thailand. The life cycle assessment (LCA) approach was employed and the ecoindicator 95 methodology was used in the assessment. Six impact categories were assessed; global warming, acidification, ozone depletion, eutrophication, winter smog, and summer smog. The results show that manufacturing phase contributes the highest impacts compared with other phases of the marble tile life cycle, and the block cutting process is the greatest contributor. Transportation of finished products to building sites also contributes significantly to environmental impacts. Among the six impact categories assessed, acidification is the highest relative value followed by global warming and winter smog. It is suggested that to minimize environmental impacts of the life cycle of marble tiles, the production of marble should be improved and emphasis should be given on reduction of energy usage in block cutting. In addition, tiles from the sources nearest to building sites should be selected for reducing environmental impact values from transportation of finished products phase.

Keywords: life cycle assessment, marble tile, environmental impact, building material

บทคัดย่อ

รายละเอียดที่เกี่ยวกับผลกระทบต่อสิ่งแวดล้อมของวัสดุก่อสร้างที่มีความสำคัญสำหรับการออกแบบอาคารเป็นมิตรกับสิ่งแวดล้อม บทความนี้ได้แสดงผลการประเมินผลกระทบด้านสิ่งแวดล้อมของกระเบื้องหินอ่อนที่ผลิตในประเทศไทย การประเมินผลกระทบต่อสิ่งแวดล้อมของกระเบื้องหินอ่อนนี้ใช้วิธี ecoindicator 95 ในการประเมินตลอดวัฏจักรชีวิตของ

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กระเบื้องหินอ่อนซึ่งแบ่งเป็น 8 ช่วงชีวิต ได้แก่ การทำเหมือง การขนส่งวัตถุดิบ การผลิตหินอ่อน การขนส่งกระเบื้องหินอ่อน การติดตั้ง การใช้งานและการทำลาย การขนส่งเศษกระเบื้อง และการฝังกลบ โดยวิเคราะห์ค่าผลกระทบต่อปัญหาภาวะโลกร้อน ภาวะฝนกรด การลดลงของโอโซน การมีสารอาหารของพืชในน้ำเกินสมดุล และปัญหาหมอกควันในบรรยากาศ ผลการประเมินพบว่ากระบวนการผลิตหินอ่อนส่งผลกระทบสูงสุดเมื่อเทียบกับช่วงชีวิตอื่น ๆ ของกระเบื้องหินอ่อนโดยเฉพาะอย่างยิ่งขั้นตอนการตัดก้อนหินอ่อน ช่วงการขนส่งกระเบื้องหินอ่อนไปยังสถานที่ก่อสร้างถือเป็นประเด็นสำคัญอีกประเด็นหนึ่งที่ส่งผลกระทบต่อสิ่งแวดล้อมในปริมาณมาก นอกจากนี้ยังพบว่าผลกระทบที่เกิดขึ้นส่งผลต่อปัญหาภาวะฝนกรดมากที่สุด รองลงมาเป็นปัญหาภาวะโลกร้อนและปัญหาการเกิดหมอกควันในฤดูหนาว ดังนั้นเพื่อลดผลกระทบด้านสิ่งแวดล้อมจากวัฏจักรชีวิตของกระเบื้องหินอ่อน ผู้ผลิตควรปรับปรุงกระบวนการผลิตโดยการลดการใช้พลังงานในขั้นตอนการตัดก้อนหินอ่อน นอกจากนี้ผู้ออกแบบหรือเจ้าของอาคารควรเลือกใช้กระเบื้องหินอ่อนจากแหล่งที่ใกล้สถานที่ก่อสร้างมากที่สุดเพื่อลดค่าผลกระทบต่อสิ่งแวดล้อมจากการขนส่งกระเบื้องหินอ่อน

คำสำคัญ: การประเมินวัฏจักรชีวิตผลิตภัณฑ์, กระเบื้องหินอ่อน, ผลกระทบต่อสิ่งแวดล้อม, วัสดุก่อสร้าง

Introduction

Buildings contribute a great deal to environmental impacts both in terms of energy consumption and depletion of natural resources [1]. The impacts are generated both in the construction phase and the use phase. Efforts have been made to reduce environmental impacts of buildings by various parties in various ways such as improving construction methods, developing more appropriate methodologies and techniques for assessing environmental impacts of buildings, and selecting environmental–friendly materials. In order to assess the environmental impacts of buildings accurately, the life cycle approach has to be employed [1, 2]. Assessing the impacts of only part of the life cycle of buildings could result in misleading information about the impacts. If, for example, one selects materials that result in the reduction of energy consumption in the use phase but the production of such materials generates high impacts, one might end up generating higher impacts overall. As materials are essential components of buildings, knowledge of accurate values of environmental impacts of building materials is of critical importance for accurate assessment of overall environmental impacts of buildings.

Life cycle assessments (LCA) of various building materials including concrete , linoleum, vinyl, carpet, wood, brick, particleboard and so on have been performed by many investigators [3-10]. The types of materials that have been assessed are still limited, however, and there are numerous building materials that need to be investigated. Furthermore, the impact values in the literature for the same materials vary widely from one study to another. There are many factors that influence environmental impact values of building materials including plant locations and manufacturing technologies employed. There is a need therefore to assess environmental impacts of materials produced in various locations of the world in order to acquire accurate environmental impact values of specific building materials so that impact assessment of building can be accurately made.

Marble has been used as a building material for a long time and is quite popular among practicing architects in many countries including Thailand. Environmental impact assessment of marbles in Italy have been investigated by Nicoletti et al. [11] who found that the most important impact categories of the life cycle of marble tiles were global warming, human toxicity and acidification and Traverso et al. [12] who found that the embodied energy values of Sicilian marble tiles was 1,772 MJ/m^3. Environmental impact assessment of marble tile has never been conducted in Thailand where a substantial tonnage of marbles is produced and consumed annually. The objective of this research is to assess environmental impacts of marble tiles produced by a firm in Saraburi Province about 100 kms north of Bangkok, the largest marble tile producer in Thailand.

Marble tile life cycle of the study

The life cycle of marble tiles can be divided into 8 phases as shown in Figure 1. The first phase is mining which involves drilling holes in the x-,y-, and z- directions. Diamond saws are then placed in the holes for cutting the marble into large blocks. Flowing water was used as lubricant during cutting. The marble blocks are then 'pushed' out (pushing) using a jack hammer and a hydraulic ram before being split into smaller blocks (splitting) by a diamond saw.

The second phase, hauling, involves moving the marble blocks from the mine to manufacturing plants. In the case being investigated, the marble blocks are loaded in large trucks using hydraulic crane. The transportation distance between the mine and the plants is approximately 1 km.

The third phase is the marble tile production. Marble blocks are cut into sheets of required thickness and further cut into required sizes using gang saw. The tiles are then polished to specifications before being sorted colours of the tile and placed on pallets ready for transportation to customers or building sites which is the fourth phase of the life cycle.

The next four phases of marble tiles are; construction or installation, use phase, demolition, and end-of-life phases. The installation phase involves placing the tiles according to the required pattern using cement as binder. The use phase involves cleaning the tiles with tap water once a week throughout their useful life (about 40 years). The demolition and end-of-life phases include actual demolition and transportation of wastes to landfill sites where the marble tile wastes are finally buried.

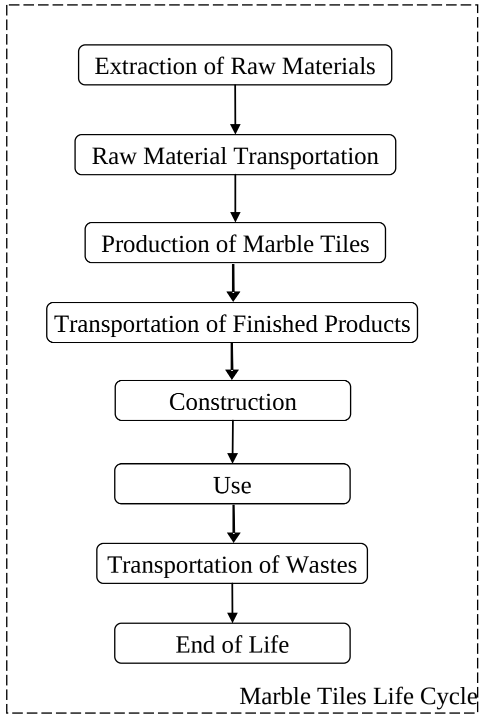

Figure 1 The life cycle phases of marble tiles

Methodology

The data were measured, collected and assessed using the LCA methodology in accordance with ISO 14040:2006 [13] and ISO14044:2006 [14]. The inventory data of the system were characterized, normalized and weighted according to the Ecoindicator 95 methodology [15].

Goal and scope

The goal of this study was to assess the LCA impact of marble tiles. The impacts corresponding to various life cycle phases were determined and those with high values noted. The impact values will be useful both for the assessment of marble tiles as a building material and for improving the impact values for this particular plant through appropriate measures such as modifications of manufacturing process.

The study was conducted in a marble tile firm in Saraburi Province, Thailand. All the life cycle phases, from cradle-to-grave, of marble tiles are included in the study. The functional unit used in this study is 1 ton of 30x60x1.9 cm^3 tiles (51.3 kg/m^2).

Assumption

All the machines and equipment as well as consumables used in the life cycle of marble tiles such as diamond saws and lubricants are not included in this study. Water used in the process is fully recycled but the water recycle process is excluded in this calculation. Moisture during the manufacturing process is in the air and is not considered because it is in a very small amount. The crushing of marble wastes from the production and the demolition of installed marble tiles are also excluded from the study. It is assumed that there are no chemicals in the process of installation and use phase. In the end-of-life phase, all of marble fragments are taken to the landfill.

Inventory analysis

Detailed inventory data of energy and materials consumption and the pollutions generated in the life cycle of 1 ton marble tiles are shown in Figure 2.

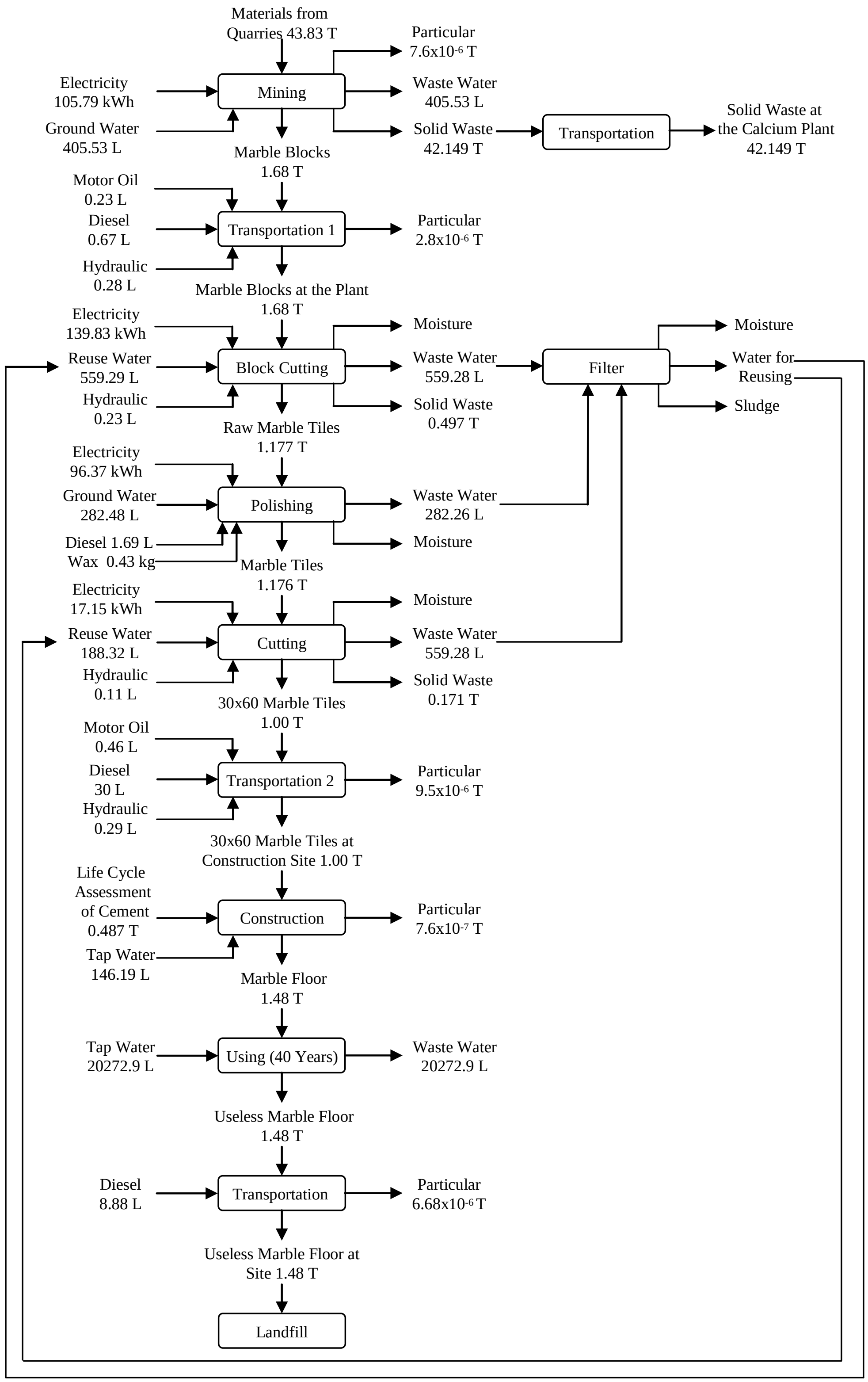

Figure 2 Inventory data for 1 Mg marble tile production

It can be seen in Table 1 that the manufacturing phase (block cutting, polishing and cutting) consumes the greatest amount of energy (2330 MJ) or 53% of energy consumed throughout the life cycle of the marble tiles. The block cutting is the unit process that consumes a large amount of energy (1286 MJ). Transportation of finish products to building sites (assuming the transportation distance of 30 km) consumes 1092 MJ of energy, the second largest amount. Energy consumption values of other life cycle phases are shown in Table 1.

Table 1 Energy consumption (per 1 Mg marble tile)

Life Cycle Phase	Electric Energy (kWh)	Diesel (L)	Total (MJ)	%	
Mining	105.79	NC	973.3	13.74	
Transportation I	NC	0.67	24.4	0.34	
Manufacturing					
Block Cutting	139.83	NC	1286.4	18.15	52.89
Polishing	96.37	NC	886.6	12.51	
Cutting	17.15	NC	157.8	2.23	
Transportation II	NC	30	1092.6	15.42	
Construction	NC	NC	NC	0.00	
Using	NC	NC	NC	0.00	
Transportation III	NC	8.88	323.4	4.56	
Landfill	NC	0.29	10.6	0.15	
Total	612.49	39.84	7085.9	100	

Source: Information from the business operator

1 kWh = 9.2 MJ

Diesel = 36.42 MJ/L

NC = No consumption

Impact assessment

Ecoindicator 95 was used to assess the environmental impacts of the marble tiles. Six impact categories were considered; global warming, eutrophication, ozone depletion, acidification, summer smog, and winter smog. The impact values are shown in Table 2.

Table 2 Environmental impact values of 1 Mg marble tile

Impact category	Unit	Amount
Greenhouse	kg CO_2	3.68E+02
Ozone layer	kg CFC11	1.57E-04
Acidification	kg SO_2	1.50E+00
Eutrophication	kg PO_4	1.60E-01
Summer smog	kg C_2H_4	1.81E-01
Winter smog	kg SPM	7.87E-01

Detailed examination of the impact values of various life cycle phases reveals that the manufacturing phase yields the greatest impact in 3 categories; global warming, acidification, and winter smog. Transportation of finished products to building sites yield the highest impact values in ozone depletion, eutrophication, and summer smog categories. Comparisons of the impact values of various life cycle phases in various impact categories are shown in Figure 3.

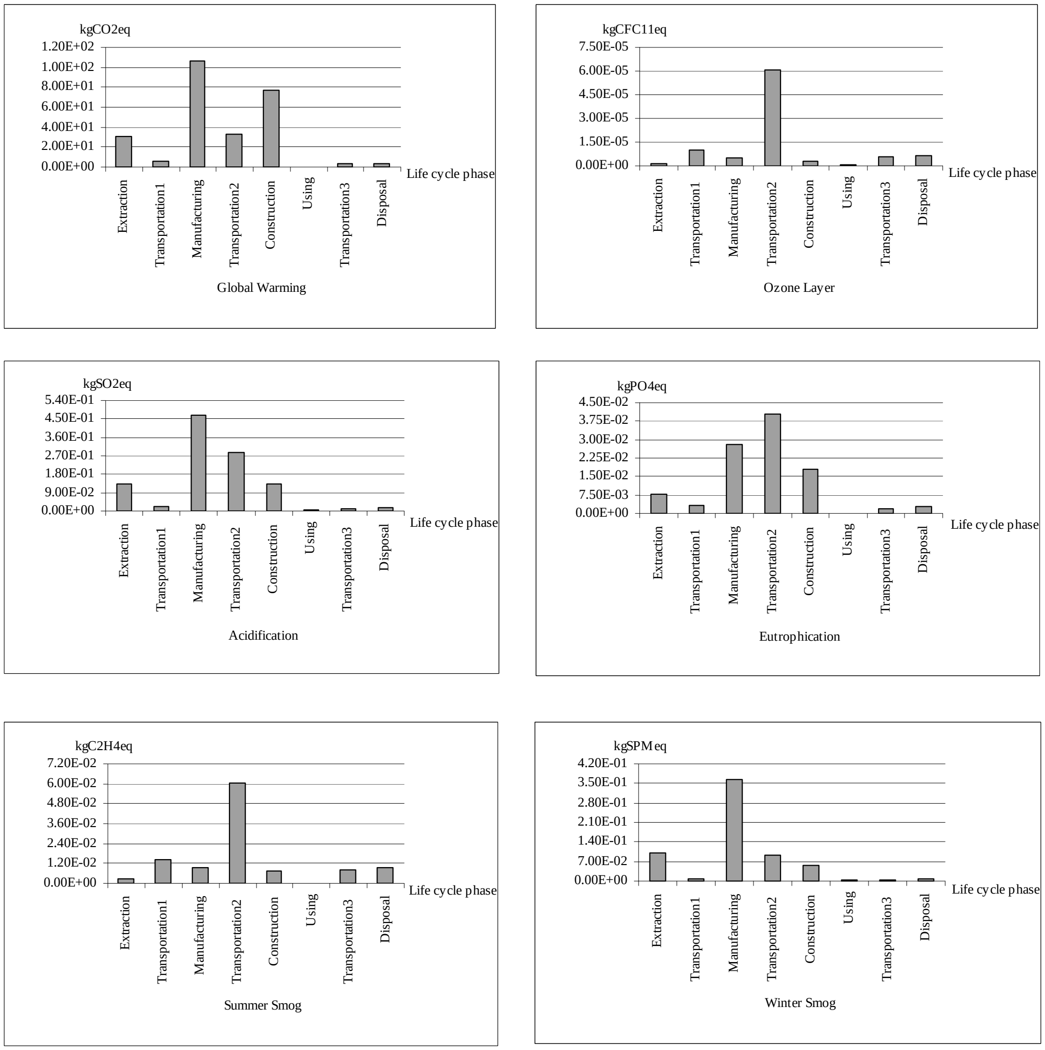

Figure 3 Comparisons of the impact values of various life cycle phases in the six categories being studied

Impact values of various processes in the manufacturing phase are shown in Table 3. It can be seen that block cutting contributes the greatest environmental impact due to high energy consumption by the process. Ozone depletion category is affected the most by polishing process due to large energy requirement in moving the tiles to polishing stations.

Table 3 Impact values in the marble tile production

Impact category	Unit	Block Cutting	Polishing	Cutting
Greenhouse	kg CO_2	57.36	40.22	8.28
Ozone layer	kg CFC11	2.41E-06	2.54E-06	3.47E-07
Acidification	kg SO_2	0.25	0.18	0.036
Eutrophication	kg PO_4	0.015	0.011	0.002
Summer smog	kg C_2H_4	0.0047	0.0041	6.79E-04
Winter smog	kg SPM	0.19	0.14	0.028

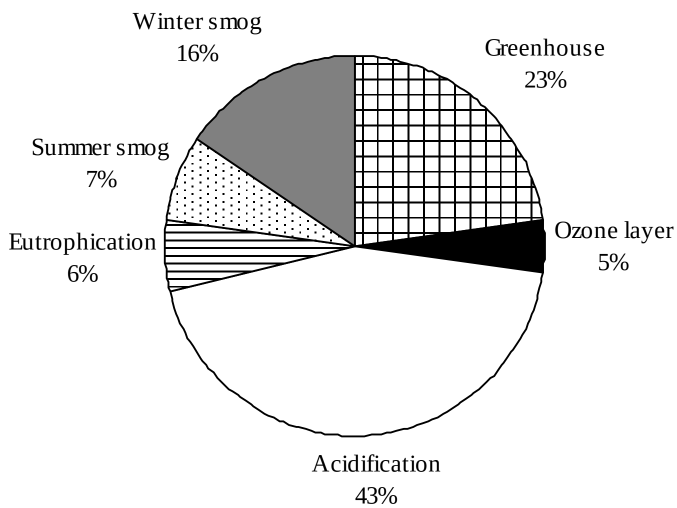

Figure 4 Percentage of various impact categories

Among the six impact categories assessed, acidification is the highest followed by global warming and winter smog. Relative values for other categories are shown in Figure 4. The normalization and weighting factors used in the calculation are shown in Table 4 [15]. The main reason for such results is the large energy consumption in the manufacturing phase.

Table 4 Normalization and weighting factors

Impact category	Normalization factor	Weighting factor
Greenhouse	0.0000765	2.5
Ozone layer	1.08	100
Acidification	0.00888	10
Eutrophication	0.0262	5
Summer smog	0.0558	2.5
Winter smog	0.0106	5

Discussion

The environmental impact values of marble tiles from this research can be used in impact assessment of buildings as well as for comparing with the values of other floor covering materials such as ceramic tiles. It would be beneficial to building designers who are keen to include environmental impacts consideration in their designs. The values can also be used for comparing environmental impacts of marble tiles from different sources. In comparing and using the impact values, however, one should be careful to compare the 'comparable' values and employ the full life cycle value for comparison where possible. The phase-by-phase presentation of impact data in this research would facilitate the use of the data for both comparison and impact assessment purposes.

The finding from this research that manufacturing phase contributes the highest impact values agrees with the findings of other investigators [11, 12] although the actual values are different. The impacts resulting from transportation of finished products to building sites or customers, hardly considered in other work, were also found to be quite significant in relation to the overall value in the present study. This means that in order to minimize the impacts of life cycle of marble tiles, manufacturers should reduce the energy consumed in their production processes, especially the block cutting, because this unit process takes a long time to cut each piece of marble block from the quarry [11]. Therefore, the technology for cutting marble blocks should be improved to reduce the energy consumption. In addition, designers or consumers should select locally produced marble tiles, which is very easy to do.

LCA is a complex process requiring numerous related data. In conducting the assessment of marble tiles in this project, several necessary data have not been specifically determined in Thailand, and the values of such data in the literature were employed. This is the key limitation of this research.

Conclusions

The ecoindicator 95 methodology was used in the life cycle impact assessment of 1 T of marble tiles. LCA of environmental impacts of marble tiles yields the following values; global warming 368 $kgCO_2$, ozone layer 1.57E-04 kgCFC11, acidification 1.50 $kgSO_2$, eutrophication 0.16 $kgPO_4$, summer smog 0.18 kgC_2H_4 and winter smog 0.78 kgSPM. The manufacturing phase results in the highest impact values due to large energy consumption and the block cutting process is the greatest contributor. Transportation of finished products to building sites or customers also contributes significantly to environmental impacts. Acidification category is the highest among the six impact categories assessed followed by global warming and winter smog. It is suggested that to minimize environmental impacts of the life cycle of marble tiles, the energy consumed in the production processes, especially the block cutting, should be reduced. In addition, designers or consumers should select locally produced tiles to minimized environmental impact values from transportation of finished products phase.

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