# ASSESSMENT OF EMBODIED ENERGY AND CARBON EMISSION OF BUILDING AND CONSTRUCTION PROCESSES IN MALAYSIA USING PROCESS-BASED HYBRID ANALYSIS

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The paper presents the ongoing research which aims to develop a life cycle energy assessment (LCEA) methodology for systematic estimation of embodied energy (EE) and carbon emission (CE) in building and construction processes in Malaysia. On top of that, this will include environmental and economic aspects of EE and CE, which involves of "carbon-added" and "value-added" at each stage of the supply chain. The paper purpose the methodology to identify and quantify the EE and CE in the construction in Malaysia. The methodology includes calculating environmental and economic impacts of life cycle carbon inventories, incorporating "carbon added" and "value-added" along the whole supply chains, accounting for the background economy in which activities are embedded. A particular novelty of this research is that it develops an integrated methodology and a set of tools that will systematically assess of environmental and economic implications at each stage of the supply chain.

*Keywords*: Embodied energy, Carbon emission, Building, Construction process, Malaysia, Hybrid analysis.

## 1. Introduction

Life Cycle Analysis (LCA) have been used to evaluate environmental impact, energy use and costs. It has significantly refined over the last three decades. According to Hunkeler and Rebitzer (2005), the use of LCA has shifted from pollution prevention and gate-to-gate concept which focus on individual product or processes to the larger extent that incorporates the inter industry relationship supply chain as well as downstream processes of a product. On top of that, LCA has been incorporated into energy analysis to assess environmental impact of construction materials, components and a building through the establishment of life cycle energy analysis methodology (LCEA) (Crawford, 2009; Fay, *et al.*, 2000; Gustavsson, *et al.*, 2010; Kofoworola and Gheewala, 2009; G. J. Treloar, 1998; Wu, *et al.*, 2012).

Traditionally, process analysis has been widely used to determine the energy and carbon embodied in products and it is usually undertaken at an industrial level through the measurements of energy and material flows during production processes. Another methodology, Input-output (I-O) analysis was developed by Leontief (1944) to model national economic production flow and further incorporated in energy analysis which includes embodied energy and carbon analysis (Bullard, *et al.*, 1978; Chang, *et al.*, 2010; Fay *et al.*, 2000; G. Treloar, 1997. Recently, hybrid embodied energy and carbon energy models was introduced in LCEA to combine the advantages of both process and Input-Output (I-O) analysis respectively (Crawford, 2008; G. J. Treloar, 1998).

In addition to that, however, there are lack of researches in this area especially developing countries like Malaysia as in the case in other countries in United Kingdom, Europe, Australia, United States, Japan, and China. As such, in view of

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the vast potential for building construction in the less developed world, this should be addressed as a matter of urgency (Khasreen, *et al.*, 2009; Ortiz, *et al* Sonnemann, 2009). Due to the increasing demand of building materials and various alternatives of building technology are expected to rise, the acceleration of environmental impact is inevitable. Therefore, this research will be conducted to develop a LCEA methodology for systematic estimation of EE and CE in building and Malaysian construction industry. The process-based hybrid analysis is employed to evaluate EE and CE of building and construction related to the different type of construction materials and components. This includes both environmental and economic aspects of EE and CE by estimating "carbon added" and "valued added" at each stage of the supply chain.

## 2. Life Cycle Energy Analysis (LCEA) Methodology

The development of LCEA methodology is based on the integration between LCA developed in ISO 14040 and energy analysis. The purposed methodology outlines four tasks to be performed which encompass:

(1) Task 1 - goal and scope definition,
(2) Task 2 - inventory analysis,
(3) Task 3 - impact assessment,
(4) Task 4 - interpretation.

Detailed discussion of each tasks are given in the following sections.

### 2.1. *Task 1: Goal and Scope Definition*

The research uses life cycle analysis tools and employs process-based hybrid analysis to expand the boundary completeness from cradle-to-site to the upstream process of material production processes of Industrialized Building System (IBS) components. The research goal is to quantify EE and CE in building and construction process using

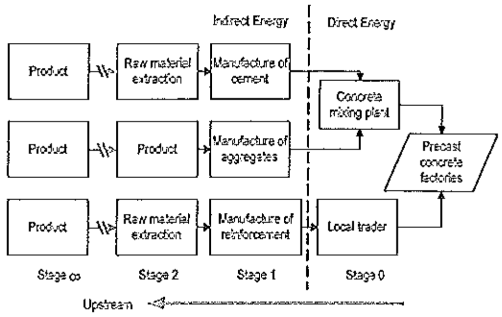


Figure 1. System boundary of construction materials and components.

IBS, comparing different approaches and conduct testing and improvement analysis for national carbon reduction.

There are two steps to clearly define the system boundary of this research. The first step is defining the boundary of building materials and components system by using hybrid approach in order to take the advantages of process-based analysis (engineering analysis) and I-O analysis (economic approach) so that inter-industry relationship of supply chain can be identified. In doing so, direct and indirect energy embodied in building materials and components in upstream processes can be traced accordingly. The detailed of system boundary for the building materials and a component is depicted in Figure 1.

The second step is identifying boundary of building and construction system by using simplified LCEA to reduce uncertainty and assumption that may affect the final results of this research. The cradle-to-site assessment is chosen in this research. The detailed of system boundary for building and construction processes is given in Figure 2. Among the life cycle phases, EE and CE from the operation and maintenance phases and demolition phase are not considered in this study. The system boundary of this research includes extraction of raw materials, transportation and manufacturing of building materials (prior to the factory gate before transportation to the construction site). The recurring embodied energy, which covers renovation and refurbishment of building mate-

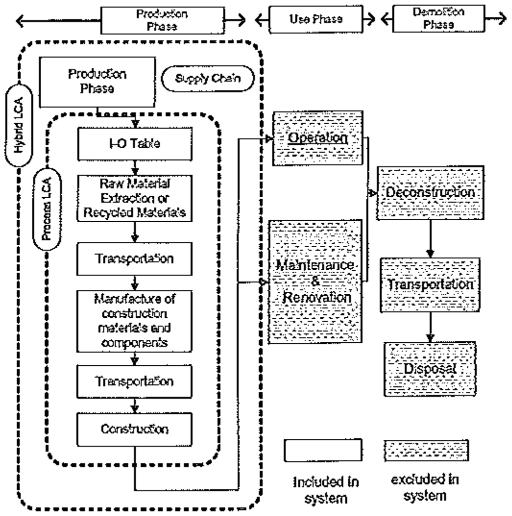


Figure 2. System boundary for Life Cycle Energy Analysis (LCEA) of EE and CE in Building and Construction process.

rials and processes, is not included in this research due to many assumptions to be made during the whole life span of a building. Therefore, energy and carbon emission embodied in materials and components replacement during whole life cycle of building is beyond the scope of this research and not be considered in analysis.

For the purpose of this research, the materials commonly used in Malaysian construction industry for building construction are classified into conventional and IBS. (Abdul Kadir, *et al* Ali, 2006). In Table 1, it is shown that the conventional materials include column beam and slab as framed structure and burn clay bricks as functional wall respectively. The rest are different alternative classified according to IBS structure system which include precast wall panel, hollow block and precast column and beam frame. Conventional building system is considered as a base case in the research.

## 2.2. *Task 2: Inventory Analysis*

### 2.2.1. *Derivation of Embodied Energy Coefficients*

The I-O analysis is based on the most recently published data of Malaysia

Table 1. Building materials and components classifications.

| Structure System | Type of Building Materials and components |
|---|---|
| Conventional Materials (Base case) | Column-beam-slab framed system with burn clay bricks as wall |
| Alternative 1 (Panel System) | Precast wall panel |
| Alternative 2 (Block System) | Hollow block |
| Alternative 3 (Framed system) | Precast column and beam frame |

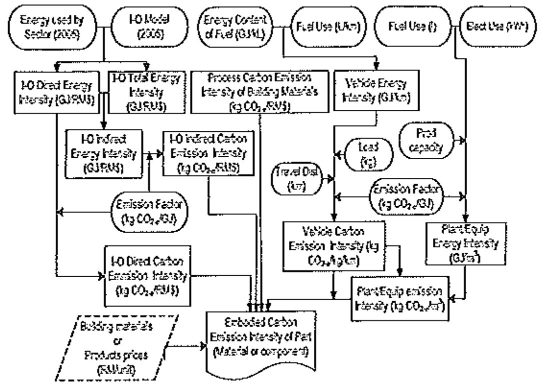


Figure 3. Flowchart of embodied energy and carbon emission of parts.

economic structure at the commencement of the research, namely I-O table for the year 2005 (DOS, 2011). This provides the indirect energy of EE component. The direct energy component of EE coefficient of the most common construction materials is obtained from the process analysis. The following subsections describe the development of I-O and process analysis method and final derivation of EE coefficient that are used in this research. The detailed figure of the derivation processes is illustrated in Figure 3.

### 2.2.2. *Input-Output Analysis for Indirect Energy Requirement*

Indirect embodied energy is not directly related to on-site construction but rather it is occur upstream system boundary of on-site construction and includes the construction procurement supply chain (energy used to manufacture building materials, excavation of raw aggregate, design, cement production, design team activities, etc.) The starting point for deriving indirect energy component based on I-O analysis is the Malaysia National Economic Structure integrated in the I-O table. Therefore, I-O energy coefficient is estimated using data from the Malaysia national I-O tables. Recent Malaysian Input-Output tables published by the Department of Statistic, Malaysia include 2000 and 2005 Input-Output Tables. The 2005 Input-Output tables are used in the calculations in this research as the base line year.

#### 2.2.3. *Process Analysis for Direct Energy Requirement*

The process analysis of construction materials will be identified in order to estimate direct energy requirement. The most current database for direct energy requirement is Inventory of Carbon and Energy database (ICE) developed by University of Bath, UK. The use of reliable life cycle inventory (LCI) database increase reliability and reduce uncertainty of LCA. However, the research scope focus on the building and construction processes in Malaysia, in which the local information on the manufacture of construction materials should be identified. Although the Malaysia's specific data is preferred, it is acknowledged that the inventory of energy and carbon emission is unavailable and currently scarce.

#### 2.2.4. *Derivation of Embodied Carbon Emission Coefficient*

To estimate embodied CE coefficient, national emission factors are employed to convert EE intensity to embodied CE intensity. For this purpose, embodied CE coefficient for a material will be evaluated using a similar technique based on the 2005 I-O table. Direct energy requirement coefficient and total energy requirement (produced from Leontief inverse matrix) are converted to carbon dioxide emission using national emission factor.

### 2.3. *Task 3: Impact Assessment*

The impact assessment is the third component of the LCEA. It aims to analyze and assess the environmental impacts of the interventions identified in the inventory analysis (ISO 14040, 2006). Previous research on building construction showed that much of the environmental impacts from building constructions are on the Global Warming Potential due to high carbon emissions (Gerilla, *et al* (2007). The impacts are calculated by multiplying the emission results by its corresponding equivalency factors. Equivalency values are found in the United Nations Environment Programme (United Nation Environmental Programme, 2007). After getting the characterization results, the effect of the environmental impacts should be compared with respect to the global emissions, this is called normalization. This is done by dividing the scores by the global figure for common environmental problems found in (United Nation Environmental Programme, 2007).

### 2.4. *Task 4: Interpretation or Evaluation*

Interpretation involves systematic evaluation of the results to reach conclusions and identify limitations. It also ensures that the findings are understandable, complete and consistent (ISO 14040, 2006).

The completed life cycle inventory (LCI) model provides a detailed inventory of energy use and emissions associated with each stage of building and construction processes using IBS components. The production of IBS component and construction processes which includes transportation and installation is then evaluated to identify steps high in energy consumption and/or carbon emissions releases. With high impact areas identified, process modifications are suggested. These hypothetical changes to the processes are then incorporated into the updated model to evaluate and quantify improvements.

## 3. Conclusion and Future Works

This paper explores the concept of EE and CE as one of the major objectives of an ongoing research to promote sustainability in the construction industry in developing countries. This preliminary work demonstrates that different methods in tracing energy paths are deemed capable to incorporate a wider range of paths such as the capital and services affecting a product. However, more process data is still needed in the literature to enhance the data inputs required for the hybrid analysis methods. The next stage of this study presents the empirical findings of embodied energy analysis of different types of new construction methods. Although the study focuses on Malaysia for inner depth investigation, the findings can be used for future comparative studies elsewhere in the developing countries where similar materials are employed.

## References


Abdul Kadir, M. R., Lee, W. P., Jaafar, M. S., Sapuan, S. M. and Ali, A. A. A., Construction Performance Comparison Between Conventional and Industrialised Building Systems in Malaysia. *Structural Survey*, 24(5), 412–424, 2006.

Bullard, C. W., Penner, P. S. and Pilati, D. A., Net Energy Analysis: Handbook for Combining Process and Input-Output Analysis. *Resources and Energy*, 1(3), 267–313, 1978.

Chang, Y., Ries, R. J. and Wang, Y., The Embodied Energy and Environmental Emissions of Construction Projects in China: An Economic Input–Output LCA Model. *Energy Policy*, 38(11), 6597–6603, 2010.

Crawford, R. H., Validation of a Hybrid Life-Cycle Inventory Analysis Method. *Journal of Environmental Management*, 88(3), 496–506, 2008.

Crawford, R. H., Life Cycle Energy and Greenhouse Emissions Analysis of Wind Turbines and the Effect of Size on Energy Yield. *Renewable and Sustainable Energy Reviews*, 13(9), 2653–2660, 2009.

DOS, *Input-Output Tables 2005: Malaysia*, Vol. 2, Department of Statistics, Malaysia, Putrajaya, 2010.

Fay, R., Treloar, G. and Iyer-Raniga, U., Life-cycle Energy Analysis of Buildings: A Case Study. *Building Research & Information*, 28(1), 31–41, 2000.

Gerilla, G. P., Teknomo, K. and Hokao, K., An Environmental Assessment of Wood and Steel Reinforced Concrete Housing Construction. *Building and Environment*, 42(7), 2778–2784, 2007.

Gustavsson, L., Joelsson, A. and Sathre, R., Life Cycle Primary Energy Use and Carbon Emission of an Eight-storey Wood-framed Apartment Building. *Energy and Buildings*, 42(2), 230–242, 2010.

Hunkeler, D. and Rebitzer, G., The Future of Life Cycle Assessment. *The International Journal of Life Cycle Assessment*, 10(5), 305–308, 2005.

ISO 14040, *ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework (Vol. ISO 14040:2006(E))*. Switzerland International Standard Organization (ISO), 2006.

Khasreen, M. M., Banfill, P. F. G. and Menzies, G. F., Life-Cycle Assessment and the Environmental Impact of Buildings: A Review. *Sustainability*, 1(3), 674–701, 2009.

Kofoworola, O. F. and Gheewala, S. H., Life Cycle Energy Assessment of a Typical Office Building in Thailand. *Energy and Buildings*, 41(10), 1076–1083, 2009.

Leontief, W., Output, Employment, Consumption and Investment. *Quarterly Journal of Economics*, 58(2), 290–313, 1944.

Ortiz, O., Castells, F. and Sonnemann, G., Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA. *Construction and Building Materials*, 23(1), 28–39, 2009.

Treloar, G., Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input-Output-based Hybrid Energy Analysis Method. *Economic Systems Research*, 9(4), 375–375, 1997.

Treloar, G. J., *A Comprehensive Embodied Energy Analysis Framework*. PhD thesis PhD, Deakin University, Australia, 1998, Retrieved from http://www.deakin.edu.au/dro/eserv/DU:30023444/treloar-comprehensiveembodied-1998.pdf

United Nation Environmental Programme, *Global Environment Outlook; Environment for Development (GEO-4)*, United Nation Environmental Programme (UNEP), Malta, 2007.

Wu, H. J., Yuan, Z. W., Zhang, L. and Bi, J., Life Cycle Energy Consumption and $CO_2$ Emission of An Office Building in China. *The International Journal of Life Cycle Assessment*, 17(2), 105–118, 2012.