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A NEW APPROACH TO GREEN SUPPLY CHAIN MANAGEMENT FOR TURKISH CONSTRUCTION SECTOR

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Abstract

Sustainability is an emerging issue for construction which is regarded as the most pollutant industry globally by causing huge greenhouse gas emissions and the greatest consumption of raw materials. Since materials is regarded as the main component of the construction projects, it is significant to reduce environmental impacts of materials-related activities during both design and construction phases. Supply chain management (SCM) is a sophisticated concept which contains all materials-related activities of construction projects. In the last decade, construction supply chain management (CSCM) has become a new challenge for both researchers and construction managers in order to reduce environmental impacts as well as the total project costs. Life cycle assessment (LCA) is being commonly utilized in order to evaluate the environmental impacts of a building material throughout its life cycle. In this paper, ecological aspects of CSCM are discussed. First of all, brief information, general framework and scope of the LCA technique are given. Then LCA tools that assess the environmental impacts of building materials are introduced. A new LCA approach for environmental impact assessment of building materials is suggested. Finally advantages the ecological perspective will bring to the Architecture, Engineering and Construction (AEC) industry are examined.

Keywords: Architecture, Engineering and Construction (AEC), Building materials, Construction Supply Chain Management (CSCM), Green Supply Chain Management (GSCM), Life Cycle Assessment (LCA).

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1. INTRODUCTION

The characteristics of the construction sector, such as high cost, long period and many different participants cause the difficulties on planning and management practices in the construction projects. This also applies to the material that constitutes an important part of the cost of construction projects. There may be various difficulties in material procurement without complete planning. Bertelsen (1993) suggested that a bad-planned supply chain increases the project total cost by approximately 10%. Building materials are required to be brought to the construction site in a way that optimizes the criteria of time, quality, cost and field conditions. But this process mostly becomes painful due to bad timing, lack of information and communication which all affects the management success of the project. Construction Supply Chain Management (CSCM) encompasses a very broad process starting from the customer's request to the demolition of the building at the end of its service life. CSCM is defined as a system in which suppliers, contractors, customers and other organizations work together in order to produce and use information for the purpose of producing materials, facilities, equipment and labor and other resources for construction projects (Hatmoko and Scott, 2010).

In the 1950s and 1960s, manufacturers adopted the fordist production model, which gave little flexibility to product and process flexibility. New product development activities have been slow and progressive, depending on in-house technology and capacity. Co-ordinated and strategic buyer-supplier relationships did not gain much value since technology and expertise are unacceptable due to the risky and insecurity of sharing. The purchasing function was generally seen as a service to production and managers did not pay much attention to purchasing issues (Tan, 2001). Quality revolution of the 1980s and the supply-chain revolution of the 1990s indicated that the best practices call for integration of environmental management with ongoing operations (Srivastava, 2007). While SCM increases the level of competition among companies, it is also a requirement to adapt to the trends of the era. These developments necessitate the transition from the classical SCM to Green Supply Chain Management (GSCM).

GSCM has emerged as an effective tool to ensure sustainability with a lower environmental footprint through the reduction of waste and carbon emission. GSCM integrates environmental thinking into supply chain management by including extensive stages from designing a product, material sourcing and selection, manufacturing processes, product delivery, and end-of-life management of the product (Srivastava, 2007). The term sustainability, which increasingly refers to an integration of social, environmental, and economic responsibilities, has begun to appear in the literature of business disciplines such as management and operations (Carter and Rogers, 2008). LCA is a prominent technique of assessing and comparing the environmental burden of products and services. According to the definition of EPA; LCA is a holistic concept and method used to determine the possibilities of a product, process or activity to realize environmental impacts and environmental improvements throughout the whole life cycle. The life cycle mentioned in LCA constitutes process of raw material extraction, production, use/reuse, maintenance and recycling/waste management (EPA, 1995). LCA measures the amount of spent energy, waste generation and disposal, the use and consumption of natural resources.

LCA is a technique used in order to determine, report and manage the environmental impacts of the different stages of the life cycle, starting with the acquisition of raw materials used in the production of a product or service, including the disposal of all relevant production, transportation, use and waste disposal. (Demirer, 2011). LCA examines the environmental inputs and outputs associated with a product or service life cycle from the cradle to the grave, which means from the raw material acquisition to the production, transportation and use phase, if necessary, to further processing, to the final disposal process (Khasreen et al, 2009). LCA studies show the mass balance between processes and sub-processes; explores in a fragmented way to identify inputs, outputs and emissions; thus, it can model the system and provide comprehensive information about the life cycle of services and products (Condeixa et al., 2015).

LCA method has its own standards. According to these standards, LCA studies consist of four stages: Aims and scope, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation (ISO 14040, 2006). Figure 1 illustrates the stages of LCA. The definition of purpose and scope includes the definition of the product or services, the selection of the functional unit for comparison and the identification of the required detail information. The life cycle inventory analysis deals with the collection and synthesis of information on physical material and energy flows at various stages of the product life cycle. In the life cycle impact assessment, the characterization factor is used to calculate the contribution of each of the components in different environmental impact categories (climate change, ozone consumption, ecotoxicity, human toxicity, photochemical ozone formation, acidification, eutrophication, resource consumption and land use). This phase consists of three elements: selection, classification and characterization of impact categories. The classification of life cycle impact results converts used emissions, wastes and resources into selected impact categories (e.g. CO2, CH4, CO) (Ortiz et al., 2009). Finally, life-cycle interpretation takes place at all stages of the life cycle assessment, and enables interpretation of both the life cycle inventory analysis and the results of the life cycle impact assessment (Cabeza et al., 2014).

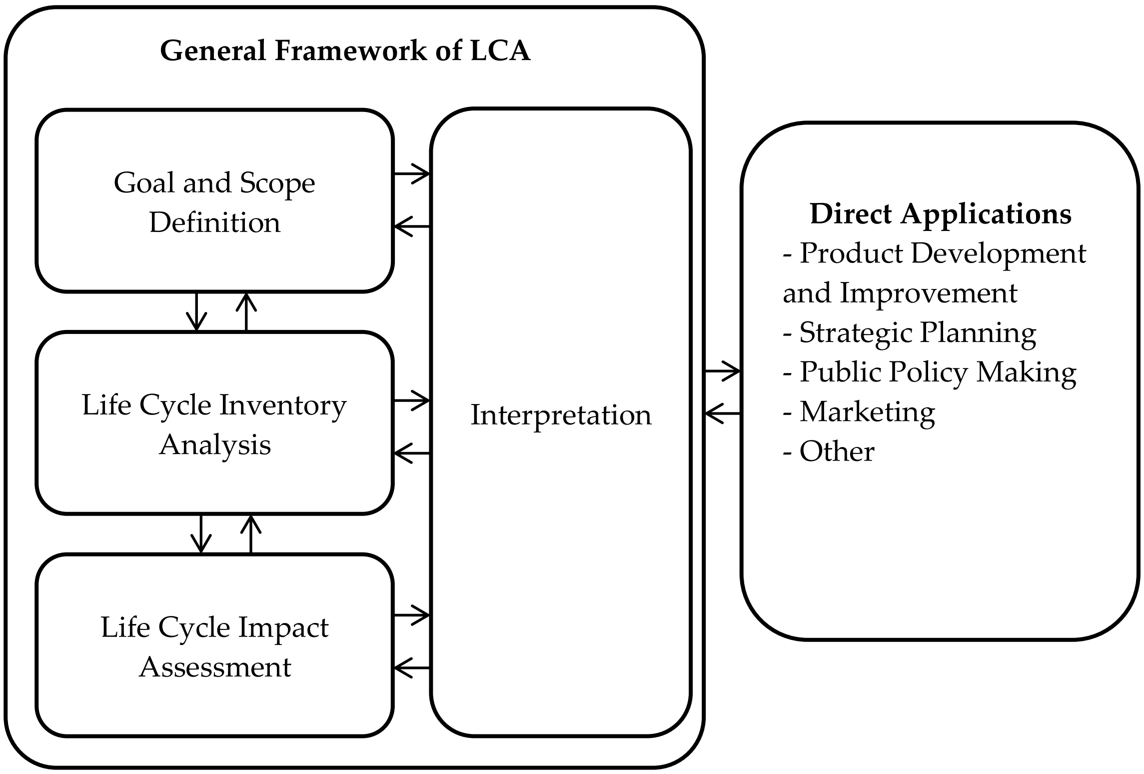

Figure 1: General Framework of LCA (ISO 14040, 2006)

LCA has been used in construction sector since 1990 and is an important tool for evaluating environmental performance of buildings. In 1998, the Society for Environmental Toxicology and Chemistry (SETAC), which works for the purpose of developing the LCA methodology, has formed a working group that examines the applications of LCA in construction sector. The purpose of this group is defining the specific characteristics of LCA, to propose a specific guideline or options for method based choices and to make predictions for future studies. The main objective of LCA studies is to compare the LCA results obtained from different studies and to provide meaningful choices in the construction sector (Özdemir, 2012).

There are green building certification systems which make environmental sensitivity measurements of the whole structure with LCA technique and there are tools to determine the environmental effects of building materials and provide ecological material decision support. BREEAM (UK), LEED (USA), BEPAS (China), and CASBEE (Japan) are the featured systems for assessing the environmental awareness of the entire structure. In addition, there are tools such as LISA (Australia), Envest (UK), ATHENA (Canada), BEE (Finland) developed for design decision support of the whole structure. BEES (USA), Gabi (Germany), SimaPro (Netherlands), TEAM (France) and LCAiT (Sweden) are the decision support systems developed for the evaluation of the environmental impact of building materials (Ortiz et al., 2009).

2. LCA TOOLS FOR CARBON EMISSION CALCULATION OF BUILDING MATERIALS

In recent years, various tools are developed in order to evaluate the environmental impacts of building materials and to make LCA method available for the selection of environmental-friendly building materials. These tools significantly improved the efficiency of analysis and expanded the implementation of LCA. Although these analysis tools shared the same theory, the functions' performance, the system framework and, even application are totally different, and the variety of these tools brings the problem of decision-making difficulties for the users (Fu et al., 2014). In a survey carried out in the USA in 2006, which was conducted for participants with private, public and academic staff, is revealed that 58% and 31% of the participants prefer Gabi and SimaPro software, while the remaining 11% prefer TEAM, BEES and other software (Cooper and Fava, 2006). These LCA tools will be introduced briefly as follows.

Athena Institute for Sustainable Materials in Canada has recently supported the use of the EcoCalculator, a free computing tool. This tool was able to analyze the simplified LCA in the context of the cradle-to-grave for construction materials. Impact Estimator for Buildings, developed by the Athena Institute in 2013, can also assess the environmental impact of the entire structure or assembly level by using the cradle-to-grave LCA approach. This LCA tool enables architects, engineers and researchers to assess the environmental impact of industrial, institutional, office-functional, multi-unit housing and single-family housing design (Fu et al., 2014).

BEES (Building for Environmental and Economic Sustainability) was developed by NIST (US National Institute of Standards and Technology), a software tool to measure the economic and environmental performance of building materials. The BEES analysis tool is based on standards and is designed in a practical, flexible and transparent manner. BEES has an online database available to everyone on the internet. The database covers real environmental and economic performance data for 230 building materials. It is intended for the use of designers, researchers and construction project participants, producers and trainers. BEES evaluates the environmental performance at all stages throughout the life of building materials using the cradle-to-grave LCA approach specified in the ISO 14040 series of standards. For the economic performance, the American Society for Testing and Materials (ASTM E917 - Life-Cycle Costing) is used. The processes covering the expenses in the initial investment, renewal, operation, maintenance, repair and destruction processes are calculated.

Another LCA tool, GaBi was developed in Germany in 1992 and is a worldwide leading LCA tool for modeling products and systems from a life cycle perspective. GaBi allows the creation of models based on physical process chains. Models can be formed by users, including system descriptions for building materials and raw materials and energy flows for the processes of building materials. It has an integrated product database covering 800 different energy and raw material flows developed from sectoral reviews and technical literature (Günaydın, 2011). The databases used by GaBi can be taken to remote service. In this case, the data directly to the client to update models, enables customers to efficiently manage their databases and to providing consistent databases (Fu et al, 2014).

SimaPro (System for Integrated Environmental Assessment of Products) enables users to conduct an LCA study with existing unit processes, built-in impact assessment methods and end-of-life options. Developed in the Netherlands in 1990, SimaPro provides a professional tool for collecting, analyzing and monitoring the environmental performance of products and services. SimaPro stands out with its flexibility to use different impact assessment methods. SimaPro covers a large database and links with external data sources are also possible. It is stated that the database can be changed, expanded and designed to be dependent on the customer's own needs (Fu et al., 2014). The analysis includes all life cycle processes as well as possible scenarios for dismantling and recycling after the end of the service life. Users can view the results in both text and graphics. The analyzes include greenhouse effect, energy, air, ozone depletion, toxicity, water pollution, solid waste (Günaydın, 2011).

3. SIMPLIFIED LCA APPROACH

In this paper, it is aimed to develop an environment-friendly approach on selection of building materials, thus reducing the carbon footprint of the construction industry, which is extremely environmental pollutant. A new and simplified LCA approach for evaluating the both economic and environmental impact of building materials is proposed. Figure 2 illustrates the framework of the proposed approach.

Simplified LCA is adopted from the cradle-to-grave LCA scope, and includes three main phases which are production, transportation and construction. Phases considered in LCA processes of building materials are evaluated at equal importance. Both the cost and carbon emission values have reached the final cost and final carbon emission values with cumulative totals of all three phases.

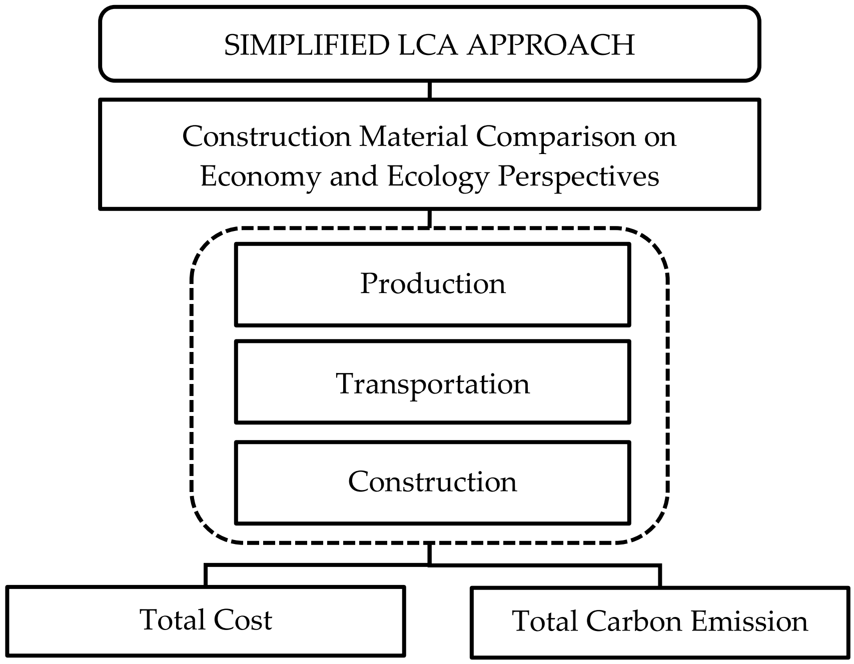

Figure 2: Framework of Proposed Approach

This suggested practical approach is called Penalty Score (PS). Economy penalty score of materials are calculated as follows:

$$PS_{materials-economy} = \left(C_{production} + C_{transportation} + C_{construction} \right) \quad (1)$$

Parameters are expressed as $PS_{materials-economy}$: Economy penalty score of building materials, $C_{production}$: Material production cost, $C_{transportation}$: Material transportation cost, and $C_{construction}$: Material implementation cost.

Ecology penalty score of materials is calculated as follows:

$$PS_{materials-eco\log y} = \left(CO_{2\,production} + CO_{2\,transportation} + CO_{2\,constr.} \right) \quad (2)$$

Parameters are expressed as $PS_{materials-ecology}$: Ecologic penalty score of building materials, $CO_{2production}$: Material production carbon emissions, $CO_{2transportation}$: Material transportation carbon emissions, and $CO_{2construction}$: Material implementation carbon emissions. Cost and carbon emission values at each phase of the simplified LCA method are calculated on the basis of unit material and the functional unit is determined as square meters (m^2).

In simplified LCA proposed approach, the cost equation of the building materials at the production stage is as follows:

$$C_{production} = \left(m * C_{unit-production}\right) \tag{3}$$

Parameters are defined as: $C_{production}$: Material production cost, $C_{unit\ production}$: Unit production cost of material (TL/m2), m: Quantity of material (m^2).

The carbon emission value of the building materials during the production phase

is calculated using Equation 4:

$$CO_{2\,production} = \left(m * CO_{2\,unit-production}\right) \tag{4}$$

Parameters are defined as: $CO_{2production}$: Material production carbon emissions (kg

CO_2-eq), $CO_{2unit\ production}$: Unit material production carbon emissions (kg CO_2-eq/m2), m: Quantity of material (m^2).

In the proposed approach, the cost of transportation of building materials includes both the cost of ordering and physical transport of the materials, as well as the resulting cost of fuel consumption of the motor vehicle used to transport the materials to the site. Transportation cost is calculated using the following equation:

$$\begin{aligned} C_{transportation} &= \left(m * C_{unit-order}\right) + \left(m * C_{unit-transportation}\right) \\ &+ (2 * N * D * C_{unit-fuel} * \frac{FC}{100}) \end{aligned} \tag{5}$$

Parameters are defined as: $C_{transportation}$: Material transportation cost (TL), $C_{unit\ order}$: Profit of supplier from the unit order (TL/m^2), $C_{unit\ transportation}$: Unit material transportation cost (TL/m2), m: Quantity of material (m^2), N: Number of expedition, D: Distance between site and supplier (km), $C_{unit\ fuel}$: Unit fuel cost (TL/lt), FC: Average fuel consumption at 100 km (lt-100 km).

Carbon emission value of the building materials at the transport phase is also dependent on the mass of the material, differs from the amount of material, the number of expedition, distance between site to suppliers, the average fuel consumption of the motor vehicle and the transport cost equation. Carbon emissions at the transport phase are calculated as follows:

$$CO_{2\,transportation} = (2 * N * D * \frac{FC}{100} * f_{vehicle}) + \left(\frac{M * D * f_{type-of-transport}}{1000}\right) \tag{6}$$

Parameters are defined as: $CO_{2transportation}$: Material transportation carbon emissions (kg CO_2-eq), N: Number of expedition, D: Distance between site and supplier (km), FC: Average fuel consumption at 100 km (lt-100 km), $f_{vehicle}$: Carbon emission factor of motor vehicle (kg CO_2-eq/lt), $f_{type\ of\ transport}$: Carbon emission factor of material transport type (kg-CO_2-eq/ton km), M: Mass of material (kg). In the second part of the equation, the variables are divided by 1000 and the tonal value in the material carbon emission factor is converted to kilogram.

In this model, the cost of construction is calculated similar to the cost of production equation:

$$C_{construction} = \left(m * C_{unit-labour}\right) \tag{7}$$

$C_{construction}$: Material implementation cost (TL), $C_{unit\ labour}$: Labour cost of unit material (TL/m^2), m: Quantity of material (m^2)

In the proposed approach, the annual carbon emission value per capita in the greenhouse gas emission statistics published by TURKSTAT was used. According to TURKSTAT, the annual per capita carbon emissions for Turkey in 2015 are declared as 6.07 tons / person (TURKSTAT, 2017). Implementation durations of building materials are calculated by performance measurements and man / hour tables of construction activities are produced. Since these measurements are made on the time basis, the annual carbon emission per capita is divided by the number of hours per year. Accordingly, the carbon emission factor in construction phase is calculated as follows:

$$F_{construction} = \left(\frac{6.07 * 1000}{365 * 24}\right) = 0.693 \tag{8}$$

In the light of this information, the carbon emission equation for the material construction phase is structured as follows:

$$CO_{2\ construction} = \left(m * MH * f_{construction}\right) \tag{9}$$

$CO_{2\ construction}$: Material implementation carbon emissions (kg CO_2-eq), m: Quantity of material (m^2), MH: Man/hour value of construction activity (hour/m2), $f_{construction}$: Material implementation carbon emissions factor (0,693).

4. CONCLUSION AND SUGGESTIONS

In this paper, simplified LCA approach for environmental impact assessment of building materials is suggested. This approach focuses on production, transportation and construction phases and facilitates total cost and carbon emission comparisons of building materials. It is concluded that proposed approach is able to utilize in a decision support system which enables LCA based decision support for architects and construction managers during both design and construction phases of projects. It also enables cost and carbon emission reduction during production, transportation and application stages of building materials. GSCM in construction is a featured research field which needs to be contributed. Besides, proposed approach is open to be developed and integrated with another decision support models. Due to the fact that there is a huge gap in the literature on GSCM in construction, it is suggested to deepen researches on this field. As a conclusion, simplified LCA should be employed in more sophisticated decision support systems which provide economy and ecology optimization.

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