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Towards an Integrated Tool of a Life Cycle Assessment for Construction of Asphalt Pavements in Egypt

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Abstract

The complexity of climate change and research on its causes and impacts has resulted in new developments and approaches to decrease the life-cycle greenhouse gas (GHG) emissions connected with construction and maintenance of roads. Tools and databases have developed by national agencies to facilitate the measurement using life-cycle approaches that account for acquisition and production of raw material, construction, use, maintenance, and end-of-life of roads. There are several tools established or commercialized for the performance of life cycle assessment (LCA) like SimaPro, GaBi, PaLATE, ROAD-RES, UK model, CHANGER, asPECT, Athena Impact Estimator for Highways, PAS 2050, and Umberto each of them special country specific. From abovementioned, Egypt do not have LCA tool to estimate emissions from construction of asphalt pavements, thus the paper highlights on UK model to take advantage from it, moreover to be a guide in creating LCA tool. Therefore, the fundamental objective of this paper is to build up a tool to evaluate the life cycle inventory for construction of asphalt pavements in Egypt. The paper presents the methodology that will be followed for the development of an Egyptian LCA tool for construction of road pavements.

Keys-words: road construction, life-cycle assessment, air pollutants, pavement, Egypt.

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1 Introduction

The roads construction is continually seeking resolutions to increase construction efficiency, enhance pavement performance, protect resources and advance environmental protection. Because of the continuous increase in the population, economic and social development worldwide, it has become an urgent need for development and increase of road networks. Roads construction could cause negative environmental impacts and pollution effects of air, water and soil (Ghazy et al., 2016).

Egypt is one of the most populous countries in Africa and the Middle East. Because of the continuous increasing in population and Urban Development, there is a marked expansion in the construction of road networks. The road network in Egypt has a total length of 121.4 thousand km consists of 108.8 thousand km paved roads with percentage 90% and 12.6 thousand km unpaved roads with percentage 10% (ESCWA, 2015). All type of roads existed in the road network.

The construction of roads causes emissions and pollution to surrounding environment. The emissions occur during the raw materials extraction, manufacture and transportation, manufacturing and transportation of asphalt mix, as well as construction and maintenance processes. Therefore, towards an integrated tool to estimate the life cycle inventory for construction of asphalt pavements in Egypt is the main goal of this paper.

Life Cycle Assessment (LCA) is a tool for assessing the ecological impact of a product through every step of its life (cradle to grave) from the extraction of natural resources to the final disposal. For instance, five phases often considered in a pavement system (Santero, 2009). These include the acquisition and production of raw material, construction, use, maintenance, and end-of-life phases. In its 14040 series, publications the International Standards Organization (ISO, 2006) outlines four phases for execution an LCA encompass: 1) *goal and scope definition*; defining study goal, system boundaries, functional unit, and determine data collection method. 2) *Inventory analysis*; include all of the environmental inputs and outputs data associated with a product. 3) *Impact assessment*; is to convert and dividing the life cycle inventory (LCI) results into impact categories (e.g., global warming potential, acidification, and human toxicity) to understand their environmental significance. 4) *Interpretation* is the final phase to analyse results, reach conclusions, provide recommendations, identify analysis improvements, as well as aid in the decision-making operation. These four steps illustrated in Figure 1. Based on the different system scopes and theory, LCA can be classified as *process* LCA, *input–output* LCA and *hybrid* LCA (Lenzena et al., 2003).

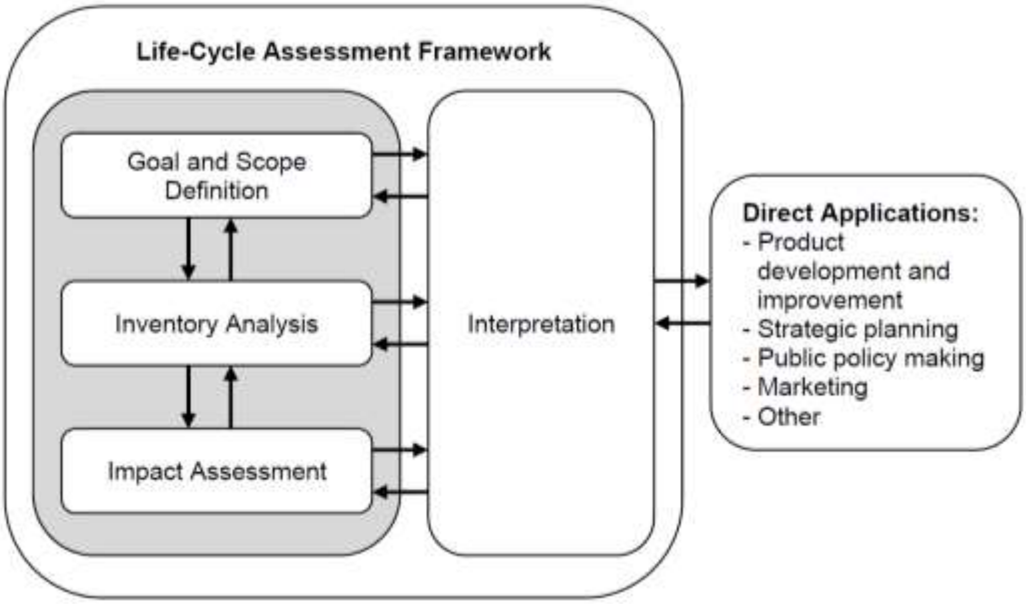

Figure 1. Basic LCA framework (ISO, 2006)

2 Pavement LCA Literature

Roads are responsible for more than 80% of the final energy used in Europe caused by transportation (European Commission, 2010). Moreover, energy use and emissions of GHG are in increasing trend within the transport sector while most of economy sectors have a decreasing trend (European Commission, 2010). Thus, measures need to take to decrease the environmental impact and energy demand in the transport sector. In addition, a considerable amount of energy used in construction and rehabilitation of the highway infrastructure can be saved by selecting road surface characteristics and road alignment that can reduce fuel consumption of vehicles (ECRPD 2010).

The area of pavement engineering had a number of LCA studies, with various LCA models proposed. In general, each model is partitioned into different modules, which carry disparate functionalities to contribute to the final results. A module, also named as part, component, phase, or stage in various LCA studies, is the unique term to represent the functional block of LCA model in this research. The specific modules in the LCA study vary greatly and have not reached consensus among the pavement community (Yu, 2013). Different practitioners disaggregate LCA models into different modules. For instance, Roudebush (1999) evaluated the environmental impacts of asphalt and concrete highway pavement systems by dividing the LCA model into ten modules, including: natural resource formation, exploration and extraction, material production, design, component production, construction, use, demolition, natural resource recycling, and disposal. Santero (2009) split the LCA model into five individual modules, including material, construction, use, maintenance, and end-of-life (EOL). Zhang et al. (2010) preferred to view the LCA model as six-fold, including material, construction, distribution, congestion, usage, and EOL modules.

Yu (2013) stated that a complete LCA model should consist of material, construction, maintenance, congestion, usage, and EOL modules. However, most LCA models are incomplete, with focus mainly on material and construction modules while ignoring others, especially the usage module. According to the findings from research that did incorporate usage module, it would dominate analysis results or at least is a counterpart to the material module (Häkkinen and Mäkelä 1996; Zhang et al. 2010; Santero 2009). Thus ignoring the usage module would also ignore a great portion of environmental burdens in LCA model (Yu, 2013).

As have been pointed out by Santero (2009), many of the so-called pavement LCAs are, strictly speaking, LCIs, meaning lack of impact assessment. Even without a further impact assessment step, LCIs follow the same process as performed by the LCA models, provide valuable data for further research, and will not differentiated from LCA models in this review.

There are several previously LCA studies to evaluate the environmental impact of different road materials or road construction types for whole or specific life-cycle phases (Häkkinen and Mäkelä 1996; Horvath and Hendrickson 1998; Roudebush 1999; Berthiaume and Bourchard 1999; Mroueh et al., 2000; Striple 2001; Chappat and Bilal 2003; Treloar et al. 2004; Kendall 2004; Zapata and Gambatese 2005; Hoang et al. 2005; Athena 2006; Chan 2007; Weiland 2008; Huang et al. 2009; Weiland and Muench 2010; Zhang et al. 2010; ECRPD 2010; Gschosser et al. 2012; Yang 2014).

3 LCA Tools and Databases

The European Commission site for the Joint Research Centre (JRC) contains a homepage with a list of a several LCA databases and tools, few of them are free to download. *SPINE@CPM* database is open source LCA database developed by the Swedish Life Cycle Centre, where data is transparent and quality reviewed (www.cpm.chalmers.se.). These databases and tools is proper for LCA-studies of pavements and roads but no evaluation made on it (Carlson, 2011).

Some tools developed specifically intended at roads and pavements through recent years. In light of the consequence of their research, Mroueh et al. (2001) established an Excel program for road construction. It overlays all phases from raw material production to maintenance of road.

A model, called Road Model constructed by Stripple (2001), was developed using Excel and focused largely on compiling a comprehensive inventory. Data collected for both material and construction processes, specific to the Swedish context. The entire life cycle analysed without impact assessment, and the use phase marginally considered traffic, as the inventory collection was the focus of the report.

Two of pavement LCA tools have been released in 2004 and 2005. The *Pavement Life cycle Assessment Tool for Environmental and Economic Effects* (PaLATE) is an open-source spreadsheet tool that covers the entire life cycle except for the use phase (Horvath, 2003). First released in 2004 by California University, Berkeley, the tool followed a hybrid LCA approach by supplementing primary and literature data with economic IO-LCA. In 2005, Birgisdóttir (2005) described an LCA software model based on Paradox database and C++ called ROAD-RES. Which can assess leaching impacts of waste residues in road construction. The LCI included data from Danish contractors and producers as well as European literature sources.

Hoang et al. (2005) developed LCA model called ERM/GRM (*Elementary Road Modulus/Global Road Modulus*) model. The extraction of raw material and EOL phases excluded from the model. The system boundaries include manufacturing and transportation of raw material to construction site. In addition, construction and maintenance tools.

LCA tool developed by Huang et al. (2009) based on spreadsheet in Excel excluding the use and EOL phases. A case study also investigated, that involved using recycled waste glass and Recycled Asphalt Pavement (RAP). It comprises of five spreadsheets for estimating and presenting results of the inventory. There are calculation formulas linked these spreadsheets. The tool designed to analyse pavements in the UK.

Zhang et al. (2010) detailed an LCA tool for pavement overlay systems that covered the entire life cycle, with special care to traffic delay, roughness, and the use of Engineered Cementitious Composites (ECC) in Portland Cement Concrete (PCC). Each of the three pavement types considered (asphalt, PCC, and PCC with ECC) given different distress indexes over time based on their maintenance schedules and predicted deterioration.

PAS 2050 tool was developed for calculating the GHG emissions of goods and services (BSI, 2011). It contains a methodology that can also be used in other areas, and it is used in wide rang in Europe and the UK (Sinden, 2009).

The asphalt Pavement Embodied Carbon Tool (asPECT) was first released in 2010 to calculate the carbon footprint of asphalt pavements (TRL, 2010). The asPECT tool calculates GHG emissions for all phases of the life cycle, specially dealing with asphaltic material processes and thus omitting the use phase.

CHANGER (*Calculator for Harmonised Assessment and Normalisation of Greenhouse gas Emissions for Roads*) first released in November 2009. It was developed by International Road Federation (IRF) in Geneva. It enables calculation of emissions of roads construction activities. Its database covers a comprehensive range of construction processes and materials, including impacts from (pre-construction, on-site, materials, and machinery) (Huang et al., 2013).

Athena released the Athena Impact Estimator for Highways software in 2013, which is currently the most developed and accessible pavement LCA tool (Athena, 2013). The entire life cycle accounted for, including impacts from fuel consumption in the use phase due to stiffness and roughness of the pavement surface layer. The inventory is proprietary and includes collected data relevant to the North American region.

Gabi (GaBi, 2013) and SimaPro (SimaPro, 2013) are the most prominent LCA software packages. These programs evaluates the environmental impact of certain products or processes from cradle to grave.

4 Development of Egyptian LCA Tool (EGY-LCA TOOL)

From abovementioned, Egypt do not have LCA tool to estimate emissions from roads construction, EGY-LCA Tool must include roads life cycle, and be devised to permit input and output of Egyptian LCI database for the relevant phases of this life cycle. Moreover, allow comparison between alternatives is necessary, and to display the results of analyses. The research will study UK model (Huang's model) to take advantage from it, furthermore to be a guide in creating EGY-LCA Tool. EGY-LCA Tool should have these inputs to developed; fuel efficiency and transport distance, energy consumption of each processes, materials recipe, pavement dimension, and the materials tonnage in the project.

Huang's LCA model based on spreadsheet in Excel consists of five worksheets as shown in Figure 2. These worksheets are used for calculation and graphical presentation of inventory results in this model and linked by calculation formulas. '*Process parameters*' and '*Pavement parameters*' worksheets contain specific project data. '*Unit inventory*' worksheet is made of calculating formulas and the LCI for each unit process. '*Project inventory*' worksheet presented the LCI results for the overall pavement project. '*Characterisation results*' worksheet presented the inventory results after classification and characterisation for impact assessment. The framework of the LCA model followed the ISO14040 standards.

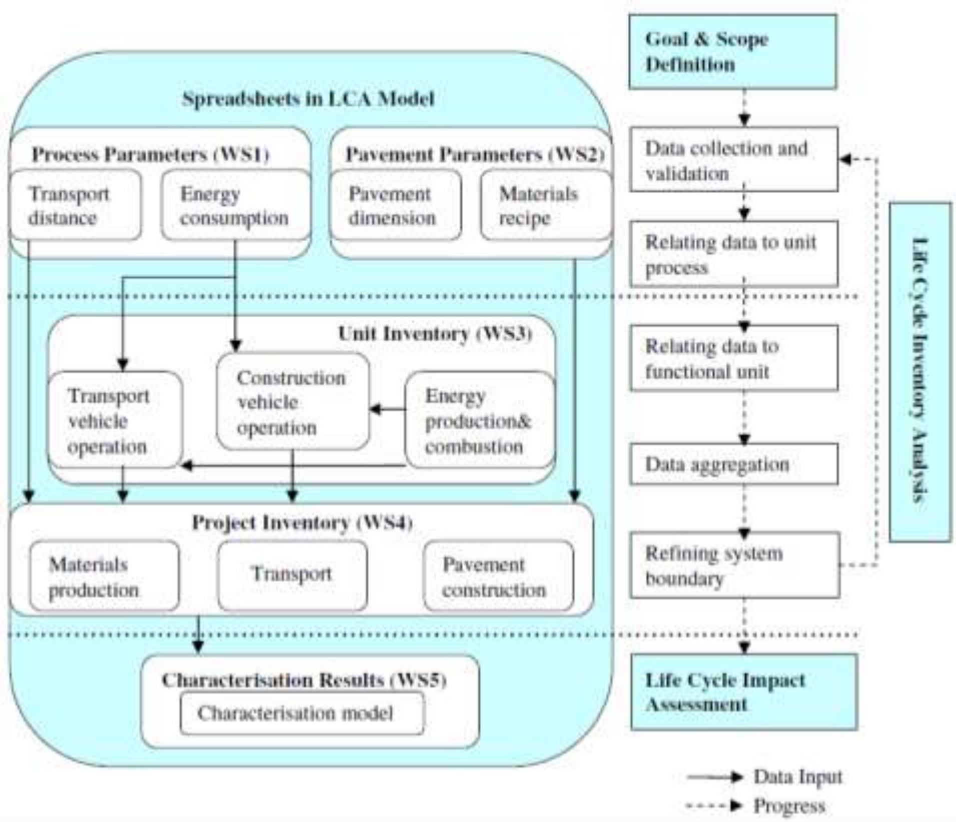

Figure 2. Overview of the Huang's model (Huang et al., 2009).

In order to achieve the research objectives, a research methodology is set consisting of the following phases:

Phase One: Developing of EGY-LCA Tool: LCA model cannot be implemented directly from one country to another because of different construction systems, pavement materials, and the validity and applicability of data. Therefore, a new EGY-LCA Tool will be generated, based on Huang's model (Huang, 2007). This model was established in accordance with the ISO14044. Firstly, this model will be applied and tested on a real pavement in the UK, as a case study. The primary sources of process data comes from the UK plants and contractors, as well as other LCA literature. Secondly, the results will be compared with other software's results to validate the model. Finally, this model will be implemented in Egypt after developing a national LCI database.

Phase Two: Developing of Egyptian National LCI Database: includes the collection of quantitative data on the inputs and outputs of materials, energy and transportation associated with a product over its entire life cycle so that its whole-life environmental impacts can be determined.

This stage will be done by doing field surveys in Egyptian agencies of Energy and Environmental studies and performing questionnaires with pavement engineers of General Authority for Roads, Bridges & Land Transport (GARBLT), and factories that manufacture the mainly pavement construction materials in Egypt.

Phase Three: Applying the Data in EGY-LCA Tool: The collected data from the second phase will be the input data of the new Egyptian tool as a web-based tool. Figure 3 shows the suggested framework of EGY-LCA Tool to calculate emissions from roads construction in Egypt.

Phase Four: Verification and Validation of the Egyptian Tool: This phase concern with applying the tool after finishing the modelling in roads construction in Egypt, as a case study.

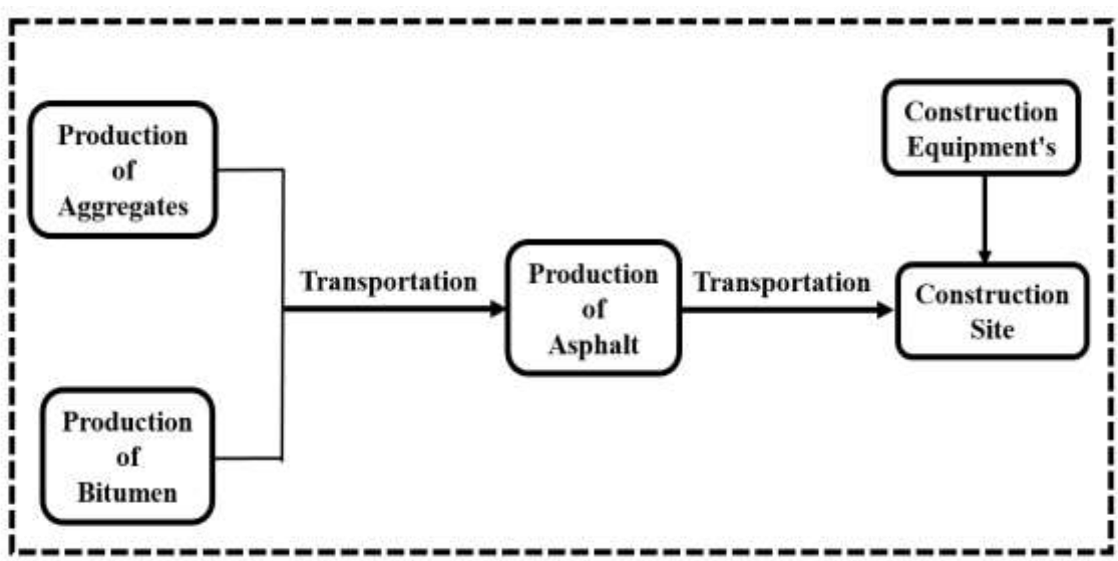

Figure 3. Suggested framework of EGY-LCA Tool: Construction phase

5 Conclusion

LCA tools became significant for assessing the environmental impact of materials and products. The ISO 14040 series outlines how to execute an official LCA in which the materials production, construction, use, maintenance, and EOL of road construction, beside illustration of resources consumption and released emissions. These results are useful to road designers, site engineers, contractors, and government interested in expecting environmental impacts during pavement's life.

The findings of this research will help to bind air pollution measurements from traffic to life cycle modelling of construction in order to undertake transport-related air pollution assessment.

The review can summarize that calculation of emissions and energy consumption from pavement construction in Egypt from LCA view is more difficult because Egypt does not have any LCA tool/program to estimate emissions from road construction. EGY-LCA Tool must include a road's life cycle, and be devised to permit input and output of Egyptian LCI database for the relevant stages of this life cycle. The findings from this review study can be used to standardize the study of life cycle assessment concept in Egypt because it has a lack of LCA studies and to put the base of Egyptian tool framework EGY-LCA Tool to build more cleanly environment from air emissions.

FURTHER WORK

Simulation software will be used to measure the environmental impacts of road maintenance works and the disrupted traffic on it. The simulation results will be fed into a traffic emissions model. The emissions from road works and the distributed traffic will be compared.

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