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A plant based LCA of high-strength prestressed concrete elements and the assessment of a practical ecological variant

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ABSTRACT

In the context of the rising awareness regarding sustainability, a Belgian producer of high-strength prestressed concrete elements for structural and civil applications aimed to clarify several aspects of ecological certifications and standards, and the application of these items within the company. In a first part of this paper, a life cycle assessment (LCA) for the precast element production up to delivery on site is presented, in which accurate company information and specific data from internal and external databases is used. The LCA determines that although reinforcing steel and cement dominate the impact contributions, other factors such as transport by road, maintenance, aggregates, element fabrication and concrete waste are non-negligible. Subsequently, a study of an ecological variant, presented in the second part of this paper, shows that several adaptions within the manufacturing process can potentially reduce the impact on the environment with 20–30%, depending on the assessment method used.

1. Introduction

In general, the construction industry unfortunately is among the largest consumers of materials and energy, and it is a significant polluter [1]. Especially concrete, the world's second most consumed material after water [2], contributes to this pollution, since every year about 25 billion tonnes of concrete are produced worldwide [3].

Within concrete as a material, cement is an essential component, and is applied in large amounts as well. In 2014 the global production of cement was 4.3 billion tonnes [4]. The production of one tonne of cement requires about 1.5 tonnes of raw material and about 4000–7500 MJ of energy. Additionally, each tonne of cement involves the emission of approximately one tonne of CO_2 [5]. For typical normal strength concrete mixes using Portland cement as the only binder, the Portland cement is found to be the primary source of CO_2 emissions, being responsible for 74%–81% of total CO_2 emissions for concrete production. Subsequently coarse aggregates are the next major source of CO_2 emissions, contributing to 13%–20% of the total CO_2 emissions [6].

This environmental impact of concrete has become an important issue in the industrial world for the reason that many major infrastructure owners require environmentally sustainable designs, and many customers consider different ecological options with a critical view. As a response, more and more product manufacturers using concrete as raw material provide environmental product declarations (EPDs) and develop the capabilities necessary to manage sustainability [7]. In this respect, it is clear that the various branches in the construction sector are concerned about the environmental impact of their activities.

This is the case for a Belgian producer of high-strength prestressed concrete elements for structural and civil applications, for whom in this paper a life cycle assessment (LCA) study is presented. The LCA evaluates the possible environmental footprint and the applied resources in the company, starting from the raw materials, over the production and use phase, up to the waste and recycling phases [8]. The choice for the LCA method derives from the fact that

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LCA is recognized as an innovative methodology which improves sustainability throughout all stages of a products life cycle. It has a broad international acceptance as a means to improve environmental processes and services [9]. The introduction of LCA in the construction industry is of significant importance since the system is capable of measuring each ecological impact systematically and objectively [10]. Although, next to LCA, there are several other interesting options such as parametric associative models [11] or eco-cost/value models [12,13], these models seem not yet sufficiently developed to assess sustainability.

Many recent LCA studies regarding the construction industry have focused on the maintenance and operational phases of construction projects, since these phases generally account for the largest part of the energy consumption during the life cycle of buildings. However, the production phase, transportation and onsite construction should not be disregarded. At least one study which investigated the production, transportation and construction phases concluded that the production stage has the largest amount of energy consumption and greenhouse gas (GHG) emissions [14]. This is, next to the large interest of the industry, also a reason why in this paper we take a closer look at the production phase of concrete elements. Next to this, due to new regulations, new buildings become more energy efficient, and thereby the environmental burdens of the operation phase, for example due to heating and/or cooling, decrease significantly. In this way the other phases of the life cycle gain in importance, e.g., choice of materials, construction, end-of-life and water use [15].

As mentioned above, in a first part of the presented study the activities of a specific manufacturer of high-strength prestressed concrete elements were scrutinized. For this, a life cycle analysis based on an average production of the company over one year is performed. To develop this LCA, the data were applied in a cradle to gate approach in which also the maintenance, waste and recycling phases are incorporated. This approach is further in this study referred to as a cradle to gate approach “with options”. Next to this first part, several options to produce more sustainable high strength prestressed concrete elements in this specific case study were assessed in the LCA, yet maintaining the standards of for example NBN EN 206 as applicable for concrete. In a third part, a comparison was made between the three main types of structural elements constructed in the company based on their load bearing capacity and material content. During the research, attention was paid to the interaction between the concrete strength, durability and sustainability, and the use of several standards in Belgium and Europe.

2. Research relevance

The three parts of the study mentioned in the introduction section constitute together an interesting and specific application of LCA in the construction sector. Its added value to the existing literature on LCA of concrete mainly lies in the fact that the analyses have been conducted in close collaboration with industry. Unlike other more theoretical LCA studies in this research field, the calculations in this paper are based on reliable first-hand inventory data regarding the actual operation of a precast concrete plant and the typical concrete products produced by it. In addition, the study represents a realistic strategy towards a higher sustainability because it accounts for all limitations imposed by the applicable regulations and standards on a European level as well as other practical circumstances of the specific Belgian national context.

Furthermore, the paper can serve as an example for future studies: several choices that have to be made when performing an LCA can be based on the choices made in this study, while the input data used in this study as well as the output results can be used to fill data gaps. Next to this, the paper presents a clear example of how a producer of prefabricated concrete elements is structured, which can be used in for example the development of product category rules (PCRs).

Moreover, insight is provided into the fact that the material ‘concrete’ does not have only one environmental impact score. In contrast, the environmental burden depends on the concrete mixture, the type of concrete element and the specific situation such as the need for a load bearing capacity. In addition, the paper identifies potential improvements for the environmental impact and which changes will have the greatest effect.

3. Research approach

The ISO_14040 standards prescribe how to create each LCA in four steps: the definition of the goal and scope, the life cycle inventory, the life cycle impact assessment, and the interpretation [8,16]. Since these standards offer useful guidelines to compose an LCA, they are applied in this study. In the following the goal and scope of this particular study are clarified.

3.1. Goal

In this context, the goal of the study is to present a specific example of the application of LCA in the concrete industry. For this, the goal is divided into three parts. First, an analysis of the current processes in the concrete company has to be executed. Subsequently, a more ecological version of these current processes has been based on previous findings in literature. This ecological version is composed and analyzed in reference to the traditional way of working in the concrete company. In this, it has to be determined which factors are important and which are less relevant. Thirdly, a comparison has to be made between the three structural elements in the concrete company: beams, TT-elements and floor slabs. The comparison is analyzed according to the load bearing capacity of each element and their material content.

3.2. Scope

The definition of the scope is very important, since in the scope all boundary conditions of the LCA are defined. In this way, the comparability of different LCA's depends on their respective scope definitions. This comparability is of great importance, because the results of an LCA are not directly intended to be used individually, but become more interesting when they can be compared with LCA results for similar subjects [15,17]. This is the reason why, for this specific study, the life cycle assessments of the traditional concrete production and the ecological version are developed according to the same scope definition. For the whole analysis, the SimaPro7 software package and the Ecoinvent 2.0 database [18] were used. In the following paragraphs the scope will be defined according to the functional unit, system boundaries, allocation principles and the life cycle impact assessment methodologies.

The functional unit is seen as the reference unit of the product system for which the environmental impact will be calculated. In the building industry different functional units can be interesting, such as a certain surface area or a predefined volume of the product under study, an element providing the defined load bearing capacity, the occupancy, …In this study, the functional unit had to correspond to the overall production of the concrete company with the possibility to evaluate the relative impacts of the different contributing processes. Next to this, the assumed service life can influence the results, so it was desirable to incorporate the service life for which the company mostly calculates the concrete elements. For these reasons, the functional unit was set to be one m^3 of