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Towards an automated approach for compiling hybrid life cycle inventories

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Abstract

There is an urgent need to reduce the environmental effects associated with the built environment. While a life cycle approach is considered essential for ensuring that these effects are not simply shifted from one life cycle stage to another, not all life cycle assessment methods provide the same level of detail. Three main approaches are currently used to compile a life cycle inventory capturing data on the inputs and outputs associated with a particular good or service: process, input-output and hybrid analysis. While process analysis is recognised for its specificity, it typically involves a truncation of the system boundary. Conversely, input-output analysis is systemically complete, but aggregates data at the economic sector or commodity level. Combining these two methods in a hybrid analysis has the potential to reduce their limitations, while maintaining their benefits. However, combining process and input-output data remains a highly manual and time-consuming process. The development of an automated approach for compiling life cycle inventories is a critical step in the uptake of hybrid analysis methods. This study aims to explore automating the hybridisation of process and input-output data using the Path Exchange method. Major practical barriers that usually prevent automating the integration of process and input-output data in hybrid life cycle inventories are discussed and a case study focusing on concrete is used for the purpose of illustrating the approach.

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Keywords: Life Cycle Assessment; hybrid analysis; construction; automation; industrial ecology virtual laboratory

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1. Introduction

There is an urgent need to reduce environmental effects associated with the built environment. In 2003, the OECD estimated that the building sector accounted for around 25 to 40% of final energy use and 30 to 50% of commodity flows in OECD countries [1]. More recently, the Intergovernmental Panel on Climate Change found that *"the building sector accounted for around 32% of final energy use and 8.8 Gt CO_2 emissions, including direct and indirect emissions"* [2]. The built environment is therefore a significant contributor to global anthropogenic greenhouse gas emissions, and thus to on-going human induced climate change effects. Reducing these effects is paramount, and effective means for measuring these is a critical step in this direction.

Using a life cycle approach is now considered essential in environmental assessments, for ensuring that strategies aimed at mitigating environmental effects are not simply shifting them from one life cycle stage to another. For example, in Australia, the Green Building Council (GBCA) now provides credit in its green building rating scheme for a life cycle assessment (LCA) to be conducted [3]. The LCA method enables a clearer picture of the environmental effects arising at different stages of the life cycle for any given product system – including buildings, the identification of hotspots on which to focus efforts, and an assessment of the benefits of alternative practices.

Three approaches are currently used to compile a life cycle inventory: process analysis, input-output analysis and hybrid analysis. These methods have been described in detail in the literature and the review of their strengths and weaknesses falls outside the scope of this paper. A brief description is provided below, but readers are referred to previous publications for a more detailed overview [inter alia 4, 5-11].

1. **Process analysis** requires the system analysed to be broken down into a series of processes representing the life cycle of the product. It uses specific production process data collected directly from manufacturers or industries. Typically, process analysis relies on the use of background databases managed by specialised institutions such as ecoinvent, who focus on collecting average data for a range of processes [12]. A process analysis is considered specific, and can be used to compare production systems. On the other hand, it suffers from a systematically truncated system boundary, and is therefore likely to underrepresent the total environmental effects analysed.

2. **Input-output analysis (IOA)** is a method based on the use of macroeconomic data collected by national statistics agencies in the form of input-output tables [13, 14]. These tables are combined with sector-based environmental data referred to as satellites (e.g. national energy accounts) to form an environmentally-extended input-output analysis (EEIOA). The systematic manner in which data is collected means that it provides a complete overview of the economy. Every transaction between every sector is recorded. Used for the purpose of LCA, its upstream system boundary is virtually infinite. On the other hand, it suffers from being aggregated at the sector level. Moreover, it relies on prices, which may affect the results in a way that is not representative of reality. This makes it difficult to assess specific products, and impossible to draw comparisons between practices taking place within the same economic sector.

3. **Hybrid analysis** combines process and input-output analysis to address the shortcoming of both methods while retaining their strengths. Four hybridisation techniques have been developed: tiered hybrid [8], path exchange [4, 15], matrix augmentation [9, 16, 17], and integrated hybrid [10].

2. Aim

While the scientific literature is rich in applications of hybrid methods, none have made their way into mainstream applications. The purpose of the project described in this paper is to develop a model to facilitate the application of hybrid methods during the compilation of a life cycle inventory. In particular, the project focuses on the Path Exchange method (PXC), first proposed by Treloar [4], validated by Crawford [18], and formalised by Lenzen and Crawford [15].

The first step of the PXC method is to mathematically disaggregate the input-output (IO) matrix into a series of mutually exclusive nodes, each representing a good or service provided by a particular IO sector. Node to node