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Carbon mitigation in the built environment: an input-output analysis of building materials and components in the UK

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Abstract

The circular economy has set out a new paradigm for a much needed shift from eco-efficiency to eco-effectiveness. Buildings are top contributor globally for resource use and waste creation. Therefore, any improvement in an effective use of building materials would have significant effects when scaled up. However, some interventions are better than others; in the sense that they can maximize the reduction of negative environmental externalities with minimal impact on the economy. This paper investigates the most effective strategies for the reduction of environmental impacts from building material and components within the context of the UK. It uses the most recent input-output table to establish the link between the reduction of environmental externalities and the impact on the various economic sectors. In doing so, an informed trade-off is achieved and intervention strategies that would yield the most beneficial effect for the environment with minimal impact on economic growth are identified.

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Keywords: Circular economy; buildings; input-output analysis; sustainable production and consumption.

1. Introduction

The construction sector is the world's largest consumer of raw materials, and accounts for 25-40% of global carbon dioxide emissions [1]. In the past decades there have been numerous initiatives to improve those figure, but with little success.

More recently, it was accepted that the sole focus on the operational stage of buildings would not help reduce the overall environmental impacts, and whole life approaches are becoming increasingly mainstream as the right path to sustainability [2].

However, life cycle assessment (LCA) of buildings is far more complex than that of standard manufactured products, because built assets are characterized by long life-spans and numerous components that interact both temporally and dynamically [3]. Due to this complexity the suitability of LCA to guide significant improvements in the building sector is being questioned [4], even if it remains the most comprehensive tool to evaluate the life cycle environmental impacts of buildings [5].

Meanwhile, the new paradigm of the circular economy is increasingly gaining momentum, as a means to overcome the traditional contradiction between environmental consciousness and economic growth [6]. A recent review of existing research on the circular economy in the built environment can be found in [2], which also provides a research framework for future works in the field. However, the uptake of circular economy thinking within the built environment is still in its infancy, and this is likely due to the same reasons that make LCA hard to apply consistently, transparently, and rigorously.

Notwithstanding the difficulty of the task, it is evident that enabling circular economy in the built environment is a very worthwhile aim to pursue, for even small interventions that

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improve the effectiveness of resource use in the building sector would have significant environmental benefits.

To this end, this paper sets out to investigate which interventions are better than others, i.e. the most effective strategies for the reduction of environmental impacts from building material and components within the context of the UK. This materializes in a two-part problem:

1. Which interventions maximize the reduction of negative environmental externalities with minimal impact on the economy; and,
2. Which interventions maximize the economic growth given a target of accepted negative environmental externalities.

The paper unfolds as follows. Section 2 presents the methodology developed for and adopted in this research, while Section 3 presents and discusses the results in two separate sub-sections. Section 4 concludes the article and highlights future research directions.

2. Methodology

Given the whole-economy coverage that input-output (IO) tables provide, they represent a useful tool for circular economy research.

IO tables map, and allow to analyze, the industrial structure of an economy and its intersectoral links [7]. Additionally, if the simplifying assumption that average relationships between inputs and outputs apply at the margin, IO multipliers can be "used to quantify the impact of economic change" [7].

Over the years, IO tables have been enriched with satellite accounts, which include the negative environmental externalities of each economic sector. As such, they are often used in an environment-economic input-output framework [e.g. 8], and the expectation for the future is of a steady significant growth of research in the area [9]. In fact, it was already Wassily Leontief – who invented IO tables and received for this reason the Nobel Prize in 1973 – to highlight the possibility to assess environmental repercussions from the analysis of the economic structure [10].

Traditionally, IO tables present two main limitations:

- Very different sub-sectors (e.g. wheat and rice grains) are aggregated into a single sector (e.g. agriculture) and sector-specific impacts can be lost
- Different countries develop IO tables with different levels of granularity (i.e. different number of sectors, and what they include), thus increasing the difficulty to account for international trade

However, both limitations have been overcome in recent years by international teams of researchers who developed harmonized databases of IO tables for the whole world, with high level of granularity. One such database is EORA World MRIO [11, 12], which has been used in this research. Specifically, the most recent IO table available for the UK was used (IO_GBR_2013_BasicPrice).

The EORA IO table includes all intersectoral links between all sectors of the UK economy, as well the transaction between each of those sectors with the other countries of the world. All such transactions are expressed in '000 US Dollars. In addition, for each sector of the economy another matrix called 'satellite account' is available, which shows – for instance – energy inputs [TJ] and GHG emissions [Gg of CO_2, CH_4, N_2O] among others [12]. Due to the length requirement of the paper, the focus of this research is limited to CO_2 emissions only.

The IO table used features 511 different sectors for the UK and therefore the first necessary task was to identify those sectors more directly related to buildings. Thirteen sectors were identified, and their description is given in Table 1.

Table 1: Industrial sectors analyzed in this research

Sector classification	Sector No.
Timber	1
Bricks	2
Concrete	3
Plaster products for construction purposes	4
Steel	5
Mining, quarrying, and construction	6
Construction of commercial buildings	7
Construction of domestic buildings	8
Construction of civil engineering constructions	9
Construction of motorways, roads, and airfields	10
Construction of water projects	11
Other construction work involving special trades	12
Other building completion and finishing	13

It should be noted that there were two sectors ('Renting of construction or demolition equipment' and 'Renting of construction and civil engineering machinery and equipment') that were excluded due to their service nature and the high dependency on the other sectors already identified above.

Transactions and satellite accounts are expressed in IO analysis in matrix form. The first one is called transaction matrix and is square by definition because rows and columns refer to the same elements (sectors and industries). This is then transformed into a matrix of technical coefficients by dividing each input to its output [13] and in IO LCA is generally referred to as matrix **A**. The second one is called the satellite matrix (**B**) and contains the environmental flows for each element of the transaction matrix [10]. The matrix **A** is linked to the final demand vector **y** and the total output vector **x** of an economy through the famous Wassily Leontief's equation:

$$x = (I - A)^{-1} y \quad (1)$$

where $\mathbf{I}$ is the identity matrix, and $(\mathbf{I} - \mathbf{A})^{-1}$ goes under the name of the Leontief inverse matrix [14].

The powerfulness of IO analysis lies with its capability to account for impacts occurring in upstream layers of the supply