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Energy consumption-based accounts: A comparison of results using different energy extension vectors

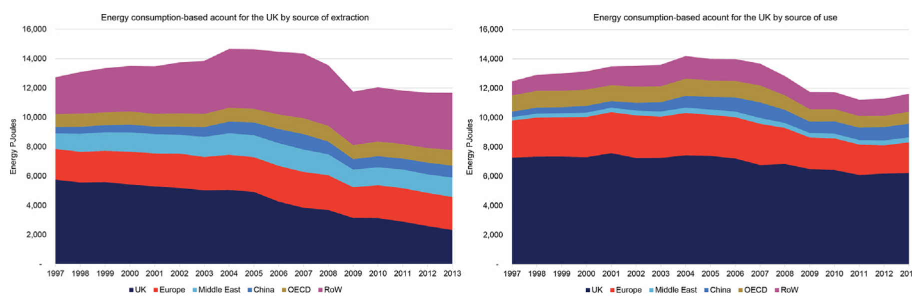
Anne Owen *, Paul Brockway, Lina Brand-Correa, Lukas Bunse, Marco Sakai, John Barrett

Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK

HIGHLIGHTS

- Energy policy increasingly requires an consumption-based accounting (CBA) approach.
- But multi-regional input-output (MRIO) models lack robust input energy vectors.
- In response we complete the first empirical MRIO analysis testing 2 energy vectors.
- Energy-use and energy-extracted vectors give insight to different policy questions.
- MRIO models should provide both vectors to encourage consistent CBA energy analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

Increasing attention has been focussed on the use of consumption-based approaches to energy accounting via input-output (IO) methods. Of particular interest is the examination of energy supply chains, given the associated risks from supply-chain issues, including availability shocks, taxes on fossil fuels and fluctuating energy prices. Using a multiregional IO (MRIO) database to calculate energy consumption-based accounts (CBA) allows analysts to both determine the quantity and source of energy embodied in products along the supply chain. However, it is recognised in the literature that there is uncertainty as to the most appropriate type of energy data that should be employed in an IO framework. Questions arise as to whether an energy extension vector should show where the energy was extracted or where it was used (burnt). In order to address this gap, we undertake the first empirical MRIO analysis of an energy CBA using both vectors. Our results show that both the energy-extracted and energy-used vectors produce similar estimates of the overall energy CBA for the UK—notably 45% higher than territorial energy requirements. However, at a more granular level, the results show that the type of vector that should be employed ultimately depends on the research question that is considered. For example, the energy-extracted vector reveals that just 20% of the UK's energy CBA includes energy extracted within the UK, an issue that is upmost importance for energy security policy. At the other end, the energy-used vector allows for the attribution of actual energy use to industry sectors, thereby enabling a better understanding of sectoral efficiency gains. These findings are crucial for users and developers of MRIO databases who undertake energy CBA calculations. Since both vectors appear useful for different energy questions, the construction of robust and consistent energy-used and energy-extracted extension vectors as part of commonly-used MRIO model databases is encouraged.

* Corresponding author.
E-mail address: a.owen@leeds.ac.uk (A. Owen).

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1. Introduction

The 1970s oil crises led to increased attention on energy accounting, with input-output (IO) being one method utilised [1]. Early energy consumption-based accounts (CBAs) [2–4] used Single-Region IO (SRIO) tables, applied to various energy-related topics. For example, in the mid-1970s, Bullard and Herendeen [2] used IO tables to calculate the full energy costs of a car, an electric mixer and the import-export balance of the US. Other energy-related IO topics studied at that time included sectoral energy intensities [5,6] and net energy use [7]. In this respect, Casler and Wilbur's book Energy input-output analysis [8] remains a seminal contribution. Concerns over the environment led to the wider use of IO as a method to study flows of industrial wastes [9] and emissions [10]. However attention is now focussing more on the use of IO for energy accounting, as we face an increasingly uncertain future where energy supply chains are at risk from availability shocks, taxes on fossil fuels and fluctuating energy prices [11,12].

To calculate an energy CBA, an extended energy vector needs to be created which assigns joules of energy to the industrial sectors that match the sectoral breakdown in the IO table. The analyst therefore needs to decide whether the extended energy vector should be based on extracted-energy (i.e. primary energy sources such as oil, coal, natural gas) or used-energy by industry (i.e. final energy such as electricity, diesel). The implications of this choice are highlighted by the SRIO (US) study by Costanza and Herendeen [13]. This 1984 paper is the only study we could find which tests the implications of using both extracted and used energy vectors. Subsequent SRIO studies opt for solely using vectors for energy-extracted (see [14–16]) or energy-used (see [4,17–20]) and the rationale behind the choice has received little attention. It is also uncertain as to whether energy losses are included in any of the energy-used vectors.

By the early 2000s, increased computing power and data availability led to the extension of input-output models that include multiple countries/regions, via multi-regional input-output (MRIO) frameworks. The 'big 5' MRIO models[1] in common use are Eora [21], developed by the University of Sydney; EXIOBASE [22], developed by a consortium of European partners; GTAP [23], the Global Trade Analysis Project; OECD ICIO [24], the OECD's Inter Country Input-Output database; and WIOD [25], the World Input-Output Database. Arguably, the main application of MRIO databases has been to develop robust CBA emissions estimates for countries [26], cities [27,28], individual sectors and products/supply-chains [29]. The advantage of using an MRIO database over the Single-Region IO table is that the original source of the emissions in a country's greenhouse gas (GHG) CBA can then be determined. This means, for example, that it is possible to calculate the GHGs released in China to meet the UK's consumption of goods and services.

The recent development of MRIO databases, coupled to the renewed interest in energy IO analysis, has seen a number of new papers which allow for a more accurate calculation of the energy embodied in traded goods and also the comparison of the energy consumption-based accounts between countries (see [12,30–32]). However, compared to GHG emissions studies, the application of MRIO methods to energy consumption-based accounts (CBAs) has received little attention. Arto et al. (p141, 142) [32] noted that "studies estimating the world energy footprint of nations are scarce". Two key limitations are proposed. The first is related to the quality of available energy extension vector datasets. Arto et al. (p141, 142) [ibid] asserted that there was an "absence of global MRIO databases extended with energy accounts able to assess the energy embedded in the flow of goods and services worldwide". However, of the big 5 MRIO databases, only the OECD-ICIO does not publish an accompanying energy extension data set. Therefore, the real issue is that significant differences exist regarding the nature of the energy extension vectors supplied. In other words, there is a lack of robust, consistent energy datasets across MRIO models.

The second limitation is that there is a lack of guidance to energy modellers in the literature as to which energy extension vector should be used. While this distinction has not been a cause of great concern in single-country studies that estimate the full energy costs of products, when using an MRIO database and taking into account the myriad of information it provides, the distinction becomes crucial. We argue that the use of different vectors ultimately depends on their appropriateness to address different research questions. For example, energy security is becoming a growing focus of research (e.g. [33]) and the decision as to whether to use the energy-extracted or energy-used approach will greatly alter any assessment of the original source of the energy in a country's CBA. Of the big 5 MRIO databases, GTAP and WIOD provide energy-used vectors, Eora provides energy-extracted vectors, and EXIOBASE is the only database to provide both an energy-used and an energy-extracted vector, but there is little documentation as to the difference between them or guidance as to when to use each.

These limitations point to the need for conducting more research into the methodology and implications of using different energy input vectors. This research gap forms the basis for our paper. In this novel analysis, we provide a case study highlighting the implications of using each vector. We first demonstrate how data from the International Energy Agency (IEA) can be used to construct both an energy-extracted and energy-used vector to match the sectors from an MRIO database. The MRIO model, input data and methodology developed to study the two energy vectors are described in Section 2. Secondly, we conduct energy CBA calculations using the energy-extracted and energy-used vectors. Energy CBA results for the UK are presented in Section 3. These results are broken down by source sector and source region to allow a comparison of the two methods[2]. Discussions including implications and modelling uncertainties are also provided in Section 3, before conclusions are drawn in Section 4.

2. Data and methods

Our method is based on the use of an MRIO model, combined with an energy vector input extension. The details of these are given in Sections 2.1 and 2.2.

2.1. The UKMRIO database

The University of Leeds (UoL) calculates the UK's officially reported CBA for CO_2 and all other GHG emissions [34]. To calculate the CBA, UoL has constructed the UKMRIO database. Since the CBA is a National Statistic[3], the MRIO database must be built using IO data produced by the UK's Office of National Statistics (ONS). This data is supplemented with additional data on UK trade with other nations and how these other nations trade between themselves from the University of Sydney's Eora MRIO database [21]. The ONS produces Supply and Use tables (SUT) on an annual basis at a 106 sector disaggregation [35]. The use tables are combined use tables, meaning that the inter-industry transaction table

[1] For example, refer to http://www.environmentalfootprints.org/mriohome.

[2] Note there is a parallel debate occurring in the GHG emissions literature, for example Davis et al. [45] and Peters et al. [46] discuss the potential for accounting for emissions associated with carbon extraction where the emissions are attributed to the place where the fuel is extracted.

[3] https://www.gov.uk/government/statistics/uks-carbon-footprint.