Applied Energy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Identifying critical supply chains and final products: An input-output approach to exploring the energy-water-food nexus

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HIGHLIGHTS

- Global supply chains demonstrate complicated energy-water-food relationships.
- Multiregional input-output analysis maps global connectivity and resource use.
- Use structural path analysis to identify supply chains with high EWF resource use.
- Identify policy intervention points and the potential for UK food waste policy.

ARTICLE INFO

Keywords:
Multiregional input-output databases
Global value chains
Consumption-based accounting
Structural path analysis
Energy-water-food nexus

ABSTRACT

Recent advances in detailed multiregional input-output databases offers new opportunities to use these environmental accounting tools to explore the interrelationships between energy, water and food–the energy-water-food nexus. This paper takes the UK as a case study and calculates energy, water and food consumption-based accounts for 1997–2013. Policies, designed to reduce the environmental impact of consumption of products, can intervene at many stages in a product's whole life-time from 'cradle to gate'. We use input-output analysis techniques to investigate the interaction between the energy, water and food impacts of products at different points along their supply chains, from the extraction of material and burning of energy, to the point of final consumption. We identify the twenty most important final products whose large energy, water and food impacts could be captured by various demand-side strategies such as reducing food waste or dietary changes. We then use structural-path analysis to calculate the twenty most important supply chains whose impact could be captured by resource efficiency policies which act at the point of extraction and during the manufacturing process. Finally, we recognise that strategies that aim to reduce environmental impacts should not harm the socioeconomic well-being of the UK and her trade partners and suggest that pathways should be targeted where the employment and value added dependencies are relatively low.

1. Introduction

Since the middle of the last century it has been recognised that multiple interlinked factors contribute to environmental change and argued that suites of composite indicators can be used to measure socio-economic and environmental wellbeing. From Boulding's Spaceship Earth essay in 1966 [1], Daly's work on steady state economies [2], Wackernagel and Rees' ecological footprint [3] and Rockström et al.'s planetary boundaries concept [4], scientists have attempted to measure humanity's relationship to and impact on the environment. Lately, the term 'nexus' has been used to describe the dynamic linkages and interdependencies [5] between two or more earth systems—for example the Bonn 2011 conference titled 'The Water, Energy and Food Security Nexus' [6].

The concept of a nexus emerged in recognition of increasing societal pressures competing for natural resources [7]. Numerous authors have studied the interrelationships and dependencies between energy, water and food since these resources are limited and depleting, whilst at the same time being fundamental for human-natural systems [8–13]. Traditional sector and country-bound governance structures often leaves energy, water and food in competition [14] but adopting a multi-centric nexus lens means that we are able to consider a system as a whole and not as a subset of isolated resources, productive sectors and consumers [5,8].

The liberalisation of trade has made the relationships between energy, water and food more complex as materials and resources are traded globally along multifaceted supply chains. Such challenges

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http://dx.doi.org/10.1016/j.apenergy.2017.09.069
Received 24 October 2016; Received in revised form 17 August 2017; Accepted 10 September 2017

require innovations in accounting methods and governance practices that recognise global interconnectedness. Multiregional input-output (MRIO) analysis has been suggested as one such accounting method that could prove beneficial in understanding these global interconnectivities, including the role of trade, industries, products and final consumers. The MRIO databases centre on the evaluation of trade flows between regions and industrial sectors, using a flow matrix approach. MRIO analysis is capable of quantifying the full environmental impact of a product's supply chain, (regardless of where in the world production processes take place) consequent on a nations' final demand for goods and services. In the past decade, advances in data availability and computational power have led to the development of several MRIO databases. Using MRIO databases to understand the role of trade in greenhouse gas (GHG) emission accounts is by far the most prominent area of research [15–17] in this field, but in this paper, we argue that consumption-based approaches, calculated using MRIO analysis, have great potential in understanding and quantifying energy-water-food nexus relationships.

The latest audits of MRIO databases [18] show numerous environmental and socio-economic extension data is now available for calculating consumption-based accounts[1] (CBAs). The four main environmentally-extended MRIO databases, Eora, EXIOBASE, GTAP and WIOD, contain emissions, employment, energy, resource use and water extensions. Consequently analysts have calculated consumption-based accounts from each of these indicators. While many studies focus on single indicator carbon [19], material [20], labour [21] or water [22] 'Footprint of Nations' type studies, there are a number of examples of where two or more indicators are analysed together. Galli et al. [23] introduce the concept of a 'footprint family' of indicators comprising the ecological, carbon and water footprint and present the OPEN:EU MRIO database based on GTAP. The authors argue that by providing evidence to monitoring the biosphere, atmosphere and hydrosphere allows for a more comprehensive approach to measuring the environmental element of sustainability. However they also note that "several environmental, economic and social issues are not tracked" [p108 17]. Fang et al. [24] later add energy to the footprint family and discuss how CBAs can contribute to the calculation of planetary boundaries.

Studies linking footprint calculations from input-output analysis and 'nexus' include Vanham [25] who investigates if the water footprint concept can be used to address the water-food-energy-ecosystem nexus. Vanham argues that by tracing both the volume of water involved in the supply chain of agriculture and food products and the water used for industry and energy, important insights into the energy-water-food nexus can be gleaned which might have been missed under other water management studies [25]. Wang and colleagues realise this approach by calculating energy-related water consumption and water-related energy consumption [26] using input-output (IO) approaches and Beijing as a case study. Fang and Chen also use Beijing IO data and linkage analysis to calculate the water and energy directly and indirectly consumed by industrial sectors and find that the real estate sector is an important water-energy nexus node [27]. Holland et al. (2015) use MRIO analysis to trace freshwater consumed to satisfy global energy demands, identifying where, at the river basin level, freshwater is being depleted in areas where water is scarce [13]. Duan and Chen use take a network approach to understand global dependencies between countries for water and energy trade [28]. White and colleagues extend MRIO approaches to also consider food and use the IDE-JETRO MRIO database to find final demand products with high land (food), energy, water and scarce-water footprints [29]. The authors find Construction and Agricultural products to be the largest water-energy-food consumers.

Consumption-based indicators have great potential to measure progress in indicators relevant to the energy-water-food nexus. However, since detailed MRIO databases are relatively new developments [18], few studies have exploited the full wealth of data available. Galli et al. [23] also note that commentary on the socio-economic impacts is often missing from approaches that claim to include a comprehensive suite of indicators. This paper aims to extract information about the energy-water-food related impacts relating to UK consumption that could be used as evidence in policies which are designed to reduce environmental impacts. To do this we use a UK specific MRIO database to calculate the CBAs for energy, water and food materials for the time period 1997–2013. In addition we also calculate employment and gross value-added (GVA) CBAs to provide socio-economic context. Policies, designed to reduce the environmental impact of products, can intervene at many stages in a product's whole life-time from 'cradle to gate'. We therefore use further IO analysis techniques to investigate the interaction between the energy, water and food impacts of products at different points along their supply chains. Whilst there is no commonly agreed definition of a 'nexus' we define it here by considering the points of interaction between a number of environmental and social-economic spheres [5].

In Section 2 we introduce the data and methods used in this study. Section 3 presents the energy, water, food and employment CBAs for the UK between 1997 and 2013. This section then calculates the product-based impacts for the year 2013 to identify those products where the full supply chain impact is large for energy, water and food combined. To start to understand supply-chains, an analysis shows, for each CBA, how far removed from the point of consumption in the UK the impacts lie and where in the world these impacts are felt. This is followed by analysis of individual product value chains with the aim of highlighting those chains with high environmental (energy, water, food) but low socio-economic (employment, GVA) impact. In the discussion Section 4 we argue that policy, while reducing environmental impact, should not hurt the economies of the UK and her trading partners and the high environmental impact low socio-economic value chains should be preferentially targeted. Environmental impacts should be reduced without compromising social wellbeing. Section 5 concludes the study and presents thoughts about future work in this field.

2. Data and methods

2.1. The UKMRIO database

The University of Leeds (UoL) calculates the UK's officially reported CBA for CO_2 and all other GHGs [30]. To calculate the CBA UoL has constructed the UKMRIO database. Since the CBA is a National Statistic,[2] 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 [31]. The ONS produces Supply and Use tables (SUT) on an annual basis at a 106 sector disaggregation [32]. The use tables are combined use tables, meaning that the inter-industry transaction table is the sum of both domestic transactions and intermediate imports, and the final demand table shows the sum of both domestic and imported final products. On a 5-yearly basis, the ONS produces a set of analytical tables where the use table is domestic use only. Final demand is also split to show domestic purchases separately. Taking proportions of domestic versus imports from the analytical tables, we are able to extract domestic and data from the annual SUT tables. Imports to intermediate industry is now a single row of data and exports to intermediate and final demand is a single column of data.

Data from the Eora MRIO database [31] is used to disaggregate the import and export data to further sectors from other world regions. Data from Eora is also used to show how foreign sectors trade with each

[1] CBA are also known as footprints.

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