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A structural decomposition analysis of global energy footprints

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HIGHLIGHTS

- We present a SDA of energy footprints for 186 nations using a detailed MRIO database.
- We quantify drivers for a changes in global energy footprints from 1990 to 2010.
- Affluence and population growth are driving up energy footprints worldwide.
- Countries with high per-capita GDP import energy-intensive goods from other nations.

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ABSTRACT

Understanding the drivers of past and present energy consumption trends is important for a range of stakeholders, including governments, businesses and international development organizations, in order to prepare for impacts on global supply chains caused by changes in future energy price or availability shocks. In this paper we use environmentally-extended input–output tables to: (a) quantify the long-term drivers that have led to diversified energy footprint profiles of 186 countries around the world from 1990 to 2010; (b) identify which countries and sectors recorded an increase or decrease in energy footprints during this time period; (c) highlight the effect of international outsourcing of energy-intensive production processes by decomposing the structural and spatial change in energy footprints; and (d) discuss the implications for national economic policy for the identified drivers. To this end, we use a detailed Multi-Regional Input–Output database and three prevalent structural decomposition analysis methods. To reduce biases in the results due to time lapse and currency variations, we convert input–output tables to common US$ and 1990-constant prices. This study provides a broad overview of the magnitude and distribution of the drivers for energy footprints across countries. The results of this study demonstrate that for almost all countries affluence and population growth are driving energy footprints worldwide, which is in part counteracted by the retarding effect of industrial energy intensity. In particular, this study demonstrates that with increasing per-capita GDP, the total energy footprint of a country is increasingly concentrated on imports or consumption.

1. Introduction

Developed countries are becoming increasingly reliant on developing countries for supplying goods and services. However not only are energy markets becoming more globalized, but also supply chains in general, raising the question whether energy is increasingly exchanged as energy embodied in internationally traded goods. The interconnection between energy requirements and international trade means that energy security has now become a more complex policy issue for governments in particular. This is because energy security is not only expressed in terms of direct trade of coal, oil and gas, but also in terms of the dependence of global supply chains on domestic energy availability. It is in this context that we seek to understand the driving forces of regional and worldwide energy consumption through the development of a global energy footprint.

To better understand how worldwide energy consumption has changed over time, we use structural decomposition analysis (SDA). SDA is a technique that utilizes input–output (IO) databases to break down observed changes in physical variables (such as energy footprint) over time, into changes in their physical and economic determinants (e.g. energy intensity or final demand structure). Using this methodology, we can also quantify the influence of these determinants on changes in energy consumption. The changes in these determinants are understood to be driving the

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changes in the variables, either as accelerators or as retardants. By using SDA to quantify determinants of changes in energy use the real drivers of energy consumption can be discovered. SDA has become a widely accepted analytical tool for policymaking on energy issues at a national level, and to develop our understanding of the global energy footprint.

2. Methodology and data

In the following section we describe the methods and data used for this study, focusing in detail on novel contributions, and providing references where material has been extensively dealt with in the existing literature. In particular we provide a detailed overview of structural decomposition analysis (Section 2.1), explain how we convert the Eora MRIO time series data into constant prices (Section 2.2), introduce the SDA decomposition form and methods (Section 2.3), demonstrate the spatial decomposition of international supply chains (Section 2.4), mention the data sources utilized for this study (Section 2.5), and provide recommendations for SDA method selection (Section 2.6).

2.1. Structural decomposition analysis – An introduction

Table 1 provides a summary of the key features and developments of energy SDA from work conducted between 1990 and 2010. Of the 31 energy SDA studies listed here, 75% contain a decomposition of changes in energy footprints over time in one or two single-region countries. Nine studies include international trade between countries and regions in their SDA of the energy footprint [1–9]. All of the studies listed apply only single-region input–output frameworks to carry out the SDA, even when the study involved groups of countries. Only Kagawa and Inamura [3] employ a multi-region input–output (MRIO) framework in their study, using the China–Japan inter-country IO tables to measure the effects of changes in energy demand. Table 1 also shows that in most studies a significant time lag exists between the year of publication and the data base year.

SDA is particularly well covered in *Applied Energy*. For example, Yuan et al. [10] used SDA to investigate the regional variations of impacts of urbanization, consumption ratio and consumption structure on residential indirect CO_2 emissions in China during 2002–2007. Inglesi-Lotz and Blignaut [11] conducted a sectoral decomposition analysis of electricity consumption for the period 1993–2006 to determine the main drivers responsible for an increase in South Africa's electricity consumption.

The novel aspects of our study are:

- *Detailed presentation of deflation procedure* – when SDA is carried out over time, it is vital to separate the quantity effects and the price effects that are aggregated in current-price IO tables, and use IO tables with constant prices [16]. International comparative analysis requires the original aggregates in local currency units to be deflated and converted into a common currency in a constant price so they may be compared over time and across countries. Many SDA papers gloss over this procedure. In the Appendix, we present a detailed account of our deflation procedure as a contribution to greater understanding of this issue within the practice of SDA.

Table 1
Specific features of SDA studies of energy footprint (1990–2010).

Publication		Application		Drivers	Decomposition method
Year	Authors	Region	Period		
1990	Schipper et al.	United States	1973–1987	3	Ad hoc
1990	Chia-Yon et al.	Taiwan	1971–1984		
1991	Howarth et al.	8 OECD	1973–1987	4	LMDI
1991	Rose et al.	United States	1972–1982	4	D&L
1992	Schipper et al.	Norway	1973–1987	3	Ad hoc
1992	Islam and Morison	Australia	1974–1975 1980–1981	5	Ad hoc
1992	Park	Korea	1973–1989	3	D&L
1993	Park et al.	26 countries	1973–1980 1980–1988	3	D&L
1993	Howarth et al.	5 OECD	1973–1988	3	Ad hoc
1994	Ang and Lee	Singapore Taiwan	1974–1990 1971–1991	3	D&L
1994	Wilson et al.	Australia	1973–1990	5	Ad hoc
1994	Han and Lakshmanan	Japan	1975–1985	4	Ad hoc
1995	Lin and Polenske	China	1981–1987	4	D&L
1997	Ang and Choi	Korean	1981–1993	4	LMDI
1997	Campos Machado and Miller	United States	1963–1987	3	Ad hoc
1998	Ang et al.	Singapore, China, Korea	1985–1990	3	LMDI
1998	Sun	Worldwide	1973–1990	3	SSA
1998	Wier	Denmark	1966–1988	6	D&L
1999	Unander et al.	13 OECD	1971–1995	3	Ad hoc
2000	Jacobsen	Denmark	1966–1992	6	D&L
2000	Sun and Ang	15 European countries	1973–1995	4	SSA
2001	Shigemi and Hajime	Japan	1985–1990	4	D&L
2003	Choi and Ang	Singapore and Taiwan	1980–1990	2	LMDI
2003	de Nooij et al.	8 OECD	1990	5	D&L
2003	Zhang	China	1991–1997	3	D&L
2004	Alcántara and Duarte	14 European countries	1994–1995	3	D&L
2004	Kagawa and Inamura	China and Japan	1985–1990	6	Ad hoc
2005	Cohen et al.	Brazil	1995	–	Ad hoc
2006	Ediger and Huvaz	Turkish	1980–2000	3	LMDI
2008	Ma and Stern	China	1980–2003	5	LMDI
2009	Wachsmann et al.	Brazil	1970–1996	6	LMDI

Notes: The D&L method was developed by Dietzenbacher and Los [12]. The Shapley–Sun–Albrecht (SSA) method was proposed by Sun [4] and first applied in decomposition by Albrecht et al. [13]. These two methods, along with the Logarithmic Mean Divisia Index (LMDI) method [14,15] are explained in Appendix B.