Energy Policy 119 (2018) 339–348

Contents lists available at ScienceDirect

Energy Policy

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

Policy implications from (revealing consumption-based carbon footprint) of major economic sectors in Japan

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ARTICLE INFO

Keywords:
Consumption-based accounting
Input-output analysis
Japan
Life-cycle assessment
Household consumption

ABSTRACT

In Japan, the Great East Earthquake caused numerous casualties and the subsequent suspension of operations at the Fukushima Daiichi Nuclear Power Plant continues to have an adverse impact on the national energy supply chain. The structural changes in energy supply have served to reinforce the importance of national emissions accounting in promoting overall CO_2 reduction policies. However, traditional approaches for evaluating industrial emissions have been criticized for their production-based perspective, which fails to consider emissions embodied in sectoral indirect consumption. The purpose of this study is therefore to understand the sectoral emission transfer. By applying economic input-output tables, detailed sectoral economic interactions can be usefully identified. It was found that the emissions embodied in final consumption generated largely by households. Besides, although emission intensity of manufacturing sector is extremely high in direct emission, agriculture sector is found to exceed other sectors in indirect emission intensities. From the consumption-side, these findings strongly suggest that a high priority be given to mitigation efforts aimed at reducing residential consumption, whist policy priorities are expected to be located on agriculture-related sectors from production-side. The study hence provides insights into how we can better allocate emissions responsibility and set reduction priorities among major economic sectors.

1. Introduction

Global warming is a crucial environmental issue that continues to attract widespread attention. It is emerging as one of the greatest challenges ever to face humankind, not only because of its apparent adverse effect on global climate stability but also because of its connection to numerous climate-related disasters and its obstruction to sustainable development (Liu et al., 2015a; Wei et al., 2017). Today's environment faces overwhelming pressure from anthropic activities that have been blamed for a series of climatic issues. Ever-increasing demand for natural resources has placed unsupportable burdens on environment capacity and has pushed our society to unsustainable levels of consumption-related emissions. Energy is a crucial but scarce resource, and its consumption has large environmental consequences (Zhang et al., 2015b). As a consequence, policymakers continue to look for reliable environmental indicators that can be used to evaluate current energy utilization and help set reduction goals to prevent further adverse effects brought about by the imbalance between natural capacity and anthropogenic emissions. In partial response, a number of footprint studies have been conducted to evaluate the environmental burden of a single product, taking into account the entire life span of the product (Hasegawa et al., 2015; Steen-Olsen et al., 2016; Virtanen et al., 2011; Wiedmann et al., 2016). Fang et al. (2014) evaluated the performance of recent footprint-style indicators, including water footprint, ecological footprint, energy footprint, and carbon footprint, and indicated that carbon footprint is an indictor capable of capturing a broad spectrum of sustainability issues. Considering its strong emphasis on climate change and application on a full life cycle perspective, we thus selected carbon footprint as the environmental indicator for our study to illustrate energy flow-related environmental issues.

From the perspective of life-cycle assessment (LCA), environmental problems are ultimately driven by the consumption of products and services (Tukker et al., 2006; Weinzettel et al., 2014). Hence consumption is of great importance in evaluating current and prospective emissions situations and potential capacity. Because energy flows and associated emissions can be concealed behind economic transactions among sectors, various methodologies for capturing sectoral emissions embodied in sectoral economic transactions have been proposed. Under

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https://doi.org/10.1016/j.enpol.2018.04.052
Received 5 November 2017; Received in revised form 17 April 2018; Accepted 24 April 2018

the framework of the Kyoto Protocol, a straightforward approach to account for carbon emissions has been put forward, but it has been criticized for failing to assign emissions responsibility across boundaries. Many existing studies have applied production-based emissions to define single country district emissions (Li et al., 2017; Shan et al., 2016; Yu et al., 2012), but virtually all have faced criticism for ignoring cross-regional or cross-sector carbon leakage. Compared with traditional production-based emissions accounting, consumption-based emissions accounting has received increasing attention since it deals effectively with the carbon leakage phenomenon (Liu et al., 2015b). Under the principle of “those who consume should bear responsibility,” Fan et al. (2016) assert that a consumption-based perspective is crucial for the reasonable allocation of emissions responsibility. Lin et.al (2010) also point out that a careful consideration of domestic consumption-induced emissions would provide a fair and complete picture of carbon emissions distribution. Additionally, when an evaluation is conducted under a consumption-based framework, emissions can be traced to the various types of consumption. Among those consumption types, household consumption has been discussed in-depth in several previous studies (Brizga et al., 2017; Jones and Kammen, 2014; Liu et al., 2011; Long et al., 2017), all of which proposed CO_2 reduction from the household side. Considering the unbalanced contribution of the various consumption types, we further detach household consumption from the other consumption types in making our calculations.

LCA is considered as providing to quantify the aggregate consumption of a nation and expose important differences between production-based emissions accounting and consumption-based emissions accounting (Munksgaard and Pedersen, 2001). To evaluate consumption emissions under an LCA framework, an input-output (I-O) model can be used to identify the emissions embodied in final consumption. The economic I-O analysis framework and its practical application to environmental issues were first proposed by Leontief (Leontief, 1970). I-O analysis is based on the application of I-O tables or inter-sectoral tables, whose main feature is the ability to describe an economic system (Mongelli et al., 2006), which is extremely useful in national emissions accounting by sector.

Table 1 shows a number of studies in which country-scale emissions were calculated using I-O analysis since 2001. The listed studies inspired this study in the term of national emission accounting and embodied emission quantification methodology. In detail, to capture the carbon leakage from domestic industries, the environmentally-extended I-O model shows several advantages in evaluating emissions from a consumer-based perspective. Using this methodology, prior studies have examined the emissions embodied in areas such as trade (Machado et al., 2001), consumption (Druckman and Jackson, 2009; Kerkhof et al., 2009), and investment (Xie, 2014). Compared with previous studies, there is an obvious knowledge gap between studies in Japan and other counties, especially among national major economics by revealing sectoral emission transfer. Inspired by such studies, we applied I-O tables to evaluate the CO_2 emissions embodied in Japanese consumption and make comparisons to other components of final demand (i.e., investment and exports). As an improvement of previous studies, we provide the results by both total emission distribution and emission intensities analysis. A discussion on energy structure is made according to sectoral primary energy variation and dominant final demand change.

Japan, the target country in this study, has been in a structural energy transition period since the Fukushima Daiichi Nuclear Power Plant accident. As the pivotal year, 2011 takes on a special importance in setting the direction of future energy policy. In particular, carbon emissions accounting for the major Japanese economic sectors in 2011 is highly relevant to the planning of future national and sectoral energy structural adjustments and the allocation of mitigation responsibly. Related to this effort, determining how best to monitor the CO_2 released from Japan's various economic sectors has been a major task of government in recent years (MOE, 2011). The ongoing debate has given rise to an active discussion of the implications of production-based emissions versus consumption-based emissions.

Table 1
Partial list of studies involving national emissions accounting based on I-O models.

Description	Study area	Methodology and major conclusions
(Machado et al., 2001)	Brazil	This study applies input-output techniques to the Brazilian economy to evaluate the total impact of international trade on energy use and CO_2 emissions.
(Mongelli et al., 2006)	Italy	Here an input-output model was used to calculate the intensities of energy consumption and related GHG emissions for each Italian economic sector.
(Fan et al., 2007)	China	This paper introduces a model and corresponding software for modeling China's Energy Requirements and CO_2 emissions analysis system (CErCmA).
(Druckman and Jackson, 2009)	UK	This study uses a disaggregated framework for attributing CO_2 emissions to the high-level functional needs of people, taking into account all CO_2 emissions arising from energy used in the production of goods and services to satisfy UK household demand.
(Kerkhof et al., 2009)	Netherlands	This paper evaluates the relationship between household expenditure and various environmental impact categories—acidification, eutrophication, and smog formation—by combining household expenditures with environmentally extended input-output analysis.
(Chen and Zhang, 2010)	China	A concrete inventory covering CO_2, CH_4, and N_2o is established and associated with an input-output analysis to reveal the emissions embodied in final consumption and international trade.
(Lin and Sun, 2010)	China	The authors analyze the embodied CO_2 emissions in China's imports and exports, and find that production-based emissions in China exceed consumption-based emissions.
(Liu et al., 2010)	China	This paper uses decomposition analysis to identify five key factors relating to the changes of energy embodied in exports.
(Virtanen et al., 2011)	Finland	This study analyses emissions from the food chain and points out that in the consumption phase between 8% and 47% of the climate change impact can be associated with homemade items, while the ready-to-eat industry and retail phases accounted for 25–38% of the climate change impact.
(Zhu et al., 2012)	China	Based on the input-output model and the comparable price input-output tables, the paper investigates the indirect carbon emissions from residential consumption in China in 1992–2005, and examines the impacts on the emissions using the structural decomposition method.
(Xie, 2014):	China	This study shows that China's current energy use is driven by investment-led demand. Between 1992 and 2007, the three main final demand categories contributed 1/3 each to changes in total energy use. Between 2007 and 2010, 1/3 of energy consumption changes came solely from investment.
(Su and Ang, 2015)	China	This paper introduces four models to calculate a country's aggregate carbon intensity using an input-output framework. Multiplicative SDA and attribution analyses are applied to each I-O table.
(Zhang et al., 2015a)	China	This study finds that indirect energy consumption and associated CO_2 emissions constitute the main parts of total energy consumption and CO_2 emissions caused by household consumption and that indirect CO_2 emissions indicate an increasing trend mainly driven by per capital household consumption and energy intensity. It identifies five sectors with relatively high direct or total CO_2 emission intensity as the key sectors for reducing CO_2 emissions in China.