Energy Economics 48 (2015) 81–88

Contents lists available at ScienceDirect

Energy Economics

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

Promises and pitfalls in environmentally extended input–output analysis for China: A survey of the literature

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ARTICLE INFO

Article history:
Received 12 August 2014
Received in revised form 4 December 2014
Accepted 9 December 2014
Available online 20 December 2014

JEL classification:
C67
D57
F18
O53
Q4
Q5

Keywords:
China
Environmentally extended
Input–output analysis

ABSTRACT

As the world's largest developing economy, China plays a key role in global climate change and other environmental impacts of international concern. Environmentally extended input–output analysis (EE-IOA) is an important and insightful tool seeing widespread use in studying large-scale environmental impacts in China: calculating and analyzing greenhouse gas emissions, carbon and water footprints, pollution, and embodied energy. This paper surveys the published articles regarding EE-IOA for China in peer-reviewed journals and provides a comprehensive and quantitative overview of the body of literature, examining the research impact, environmental issues addressed, and data utilized. The paper further includes a discussion of the shortcomings in official Chinese data and of the potential means to move beyond its inherent limitations.

1. Introduction

Environmentally-extended input–output analysis (EE-IOA) has, from the earliest stages of its development in the 1960s and 1970s by Leontief, Ford, Hannon, Bullard and Herendeen, been used to study air pollution and energy (Bullard and Herendeen, 1975; Hannon, 2010; Herendeen et al., 1981; Leontief, 1972). Since then, it has become a valuable tool for calculating CO_2 emissions in countries throughout the world in a wide variety of ways. Within the last 10 years, it has seen increasing use in determining the embodied energy and CO_2 emissions in China (Chen and Chen, 2013; Li et al., 2007; Liu et al., 2012; Shao et al., 2013; Su and Ang, 2010, 2013; Su et al., 2010). This paper provides a comprehensive overview of the use of EE-IOA to analyze Chinese environmental impacts, surveying the entirety of the literature through 2013.

Following the opening of China to trade in 1978, the country has exhibited economic growth on a scale unparalleled by any other in the same recent time period. As China's input–output data is available as far back as 1981, EE-IOA can and has been used to measure the effects of economic growth and its associated environmental impacts nearly from the beginning of this period of expansion. As one of the world's largest economies, the magnitude of environmental impacts associated with China's economy has global implications and EE-IOA provides researchers with the ability to study system-wide effects in China, and through multi-region input–output models (MRIOs), impacts related to its trade with other nations. EE-IOA allows researchers to effectively capture the direct and indirect impacts of changes without having to set arbitrary boundaries. Additionally, EE-IOA provides a foundation for the use of other tools, such as structural decomposition analysis (SDA) to identify the drivers affecting environmental impacts, input–output life cycle assessment (IO-LCA) and hybrid life cycle assessment (hybrid LCA) for examining products from cradle-to-grave.

This review of the literature provides insight into how EE-IOA is being used to look at environmental economic issues in China and how these tools can be improved in the future. While EE-IOA would seem a natural tool to capture both the direct and indirect contributions of China's economic growth to environmental impacts, the methodology is hindered by the reliability and resolution of data. This review illustrates the range of environmental topics authors have addressed using EE-IOA and how authors have coped with the limitations of official Chinese data. With China's recent history of economic growth, its role in the global economy, and the magnitude of the country's environmental impacts, both domestically and internationally, it is crucial to examine the contributions of EE-IOA research specific to China, as well as identifying the weaknesses inherent in EE-IOA for China.

Section 2 (Methods and Materials) of this paper describes the boundaries of the body of literature for Chinese EE-IOA and how articles were chosen to be included in this survey. Section 3 (Results) provides a

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http://dx.doi.org/10.1016/j.eneco.2014.12.002
0140-9883/

quantitative survey of the body of English-language, published EE-IOA journal articles, describing the research impact of published articles, the range of environmental issues analyzed in the literature, the data sets utilized, and the level of sector and spatial resolution and aggregation in the data used. Section 4 (Discussion) presents perspectives on how EE-IOA for China can be expanded and improved. Finally, Section 5 (Conclusions) offers a view on how these factors tie together within the state of the Chinese EE-IOA literature and what can be done to further develop and grow the field of Chinese EE-IOA research.

2. Material and methods

A comprehensive listing of articles studying China using environmentally extended input–output analysis (EE-IOA) was compiled using Rutger Hoekstra's EIO Archive and the Thomson Reuters Web of Science search tool (Hoekstra, 2013). Hoekstra assembled a comprehensive listing of all EE-IOA articles published in peer-reviewed journals in a 2010 conference paper. Hoekstra's listing was current through 2009 with 360 published articles, but his online EIO Archive is current through 2011 (Hoekstra, 2010, 2013). Hoekstra's criteria for inclusion in the database include only articles from English peer-reviewed journals that analyze environmental impacts. The articles must include the Leontief inverse represented mathematically, empirical results showing the application of the Leontief inverse, the EE-IOA literature or methods, or descriptions of potential future EE-IOA work or methodologies.

The criteria exclude corrigenda, errata, announcements, book reviews, articles dealing solely with the economic impacts of environmental issues (although papers that include this along with an investigation of environmental pressures are included), and environmental accounts describing only data structure and compilation. Also absent from Hoekstra's database are non-peer reviewed literature such as conference proceedings and working papers. Hoekstra's search criteria have yielded 510 EE-IOA papers from 1969 to 2011.

Hoekstra found that EE-IOA research in the general body of literature was dominated by the analysis of energy use in the United States in its early years, but expanded in the decades hence to cover a variety of environmental topics and locations. While it is important to understand the historical context of EE-IOA in China as represented by the studies accounted for in Hoekstra's database, Hoekstra's 2010 review is insufficient to illustrate the use of EE-IOA currently used to study topics in China. For this survey, Hoekstra's 510 listed EE-IOA papers were reviewed for content about China. Articles providing quantitative EE-IOA analysis for China, either by itself or in conjunction with other nations, were extracted from Hoekstra's database for further analysis. Of the 510 articles listed in the EIO Archive, 60 articles included analysis for China, the first of which was published 1995.

As Hoekstra's database is current only through 2011, this literature survey utilized Hoekstra's search, selection, and exclusion criteria to identify articles from 2012 and 2013. Using Web of Science and searching specifically for studies on or including China, this search yielded 42 additional articles for 2012 and another 44 articles for 2013. As indicated in Fig. 1, the articles from 2012 and 2013 represent explosive growth in the field of using EE-IOA for China. The articles from 2012 and 2013 more than double the articles published up to that point and now comprise the majority of material published on the subject. Searching with Web of Science for 2012 and 2013 also yielded 5 conference proceedings on EE-IOA in China. As these proceedings represent a marginal portion (approximately 5%) of the English-language Chinese EE-IOA studies, it is unlikely that this material would substantially alter the results determined in the sections below. Keeping with Hoekstra's original selection criteria, these proceedings have been left out of the survey of the literature. While it is important to understand the historical context of EE-IOA in China as represented by the studies accounted for in Hoekstra's database, Hoekstra's 2010 review is insufficient to illustrate the use of EE-IOA currently used to study topics in China (Hoekstra, 2010). The survey presented in this text amasses the most recent research and observes the trends, movement, and momentum of the current body of work.

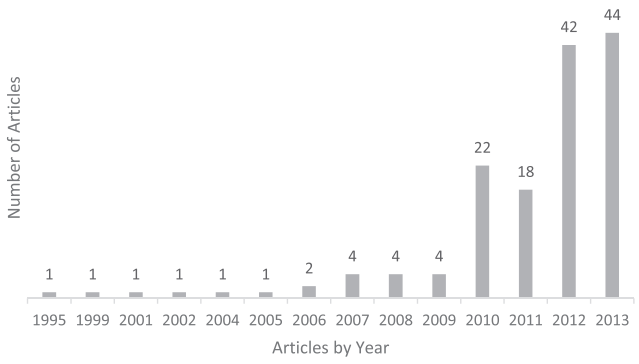

Fig. 1. Number of Chinese EE-IOA articles (1995–2013).

3. Results

Combined with the articles extracted from Hoekstra's database of the general EE-IOA literature for the period from 1969 to 2011, the 2012 and 2013 articles make a total of 146 Chinese EE-IOA papers in peer-reviewed journals. Articles were contributed by 276 authors in 51 journals between 1995 and 2013. Appendix A includes a table listing all of the EE-IOA papers addressing Chinese issues published between 1995 and 2013 and a complete bibliography of the listed papers.

Hoekstra notes a period of quick expansion in the EE-IOA literature between 1995 and 2009, with particularly rapid expansion between 2005 and 2009 (Hoekstra, 2010). A similar period of expansion is reflected in the numbers for Chinese EE-IOA articles, although expansion in the Chinese studies appears shifted to lag approximately five years behind the rest of the body of literature. Within Hoekstra's own archive collection between 1969 and 2011, Chinese EE-IOA papers make up 12% of the total number of papers. Hoekstra noted that the majority of EE-IOA articles focused on topics within the United States and Europe, but that the number of studies in China was clearly growing and gaining attention (Hoekstra, 2010).

3.1. Journals, authors, and citations

Chinese EE-IOA papers follow some of the trends described by Hoekstra in his 2010 review with regard to journals and authors, but particularly with the rapid expansion of the literature in 2012 and 2013, increasing specialization is leading to divergence among Chinese EE-IOA authors from the rest of the EE-IOA literature. The influence of journals and authors are examined here along with impact of citations with respect to authors and environmental issue areas.

3.1.1. Journals

Chinese EE-IOA articles between 1995 and 2013 have been published in 51 different journals. Table 1, lists the top ten journals for Chinese EE-IOA papers by the number of articles published. With 38 of the 146 total studies, *Energy Policy* has published more Chinese EE-IOA papers than any other journal. The top ten journals shown in Table 1 have published 67% (100 of the 146 papers) of Chinese EE-IOA articles to date. Hoekstra's 2010 literature review identified *Ecological Economics* one of the most influential journals for publishing EE-IOA papers with *Energy Policy* and *Economic System Research*, similarly supporting the field, but to a lesser degree (Hoekstra, 2010). As shown in Table 1, for Chinese EE-IOA literature, *Ecological Economics* provides a valuable outlet for publishing, though substantially less than *Energy Policy*. Similarly, the influence of *Journal of Industrial Ecology* is greater for publishing EE-IOA articles specific to China than in the general EE-IOA literature (Hoekstra,