G Model
RECYCL-3369; No. of Pages 10
ARTICLE IN PRESS
Resources, Conservation and Recycling xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Resources, Conservation and Recycling
journal homepage: www.elsevier.com/locate/resconrec

Full length article

Energy-related CO_2 emissions in the China's iron and steel industry: A global supply chain analysis

Jiaying Peng[a,b], Rui Xie[a,b,*], Mingyong Lai[a,c]

[a] College of Economics and Trade, Hunan University, Changsha 410006, China
[b] Collaborative Innovation Center of Resource-Conserving and Environment-Friendly Society and Ecological Civilization, Changsha 410012, China
[c] College of Economics and Management, Changsha University of Science & Technology, Changsha 410004, China

ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form 9 September 2016
Accepted 13 September 2016
Available online xxx

Keywords:
Final demand
Iron and steel industry
CO_2 emissions
Structural path analysis

ABSTRACT

Given the increasing pressure on China to lower the emissions of carbon dioxide (CO_2), as the largest manufacturing energy user and main industrial CO_2 emitter worldwide, the country's iron and steel industry is vital for making energy savings. Most of the existing researches have used single-sector data (i.e., cross-sectional data or data from multiple time series) to look into the driving forces of the industry's CO_2 emissions at the national level, typically overlooking the impacts of final demand and the relationship among industries. This study is based on the global multi-regional input-output table and energy-related data. Structural path analysis is used to identify the critical supply chain paths that influence the emission of CO_2 from China's iron and steel industry. These supply chain paths can be used to analyze the extent to which different types of final demand and the IO relationship among industries affect CO_2 emissions in this sector. The results show that both direct demand for the output of China's industry on iron and steel and indirect demand via consuming products from other industries (e.g., construction and electrical and optical equipment) have lead to a great consumption of coke oven gas in China's iron and steel industry, which result in considerable CO_2 emissions. Further more, in order to meet the demands of their manufacturing sectors and final demand, US, EU, South Korea, Japan, together with some other developed countries, have imported a great sum of goods from China's iron and steel industry, including some other manufacturing sectors, which helps them reduce their own CO_2 emissions. But this action has left China with considerable energy consumption and CO_2 emissions issues.

1. Introduction

In 2013, China's carbon dioxide (CO_2) emissions were around 9 billion tons, making up 28% of the total emissions worldwide (International Energy Agency, 2015). Given China's disproportionate share of CO_2 emissions, its efforts to reduce energy use are facing increasing international pressure. Owing to the rigid energy demand caused by rapid industrialization and urbanization, industrial sectors have become the largest energy consumers and thus pollution emitters in China (Lin and Ouyang, 2014). In particular, being the largest energy user in manufacturing (National Bureau of Statistics of the P. R. China, 2015), the third largest industrial CO_2 emitter globally (Zeng et al., 2009; Zhang et al., 2012), and a nation to contribute 10% global emissions, China's iron and steel industry (ISI) has started to play a bigger role in the rapid growth of the country's CO_2 emissions. Therefore, investigating the features of the ISI's CO_2 emissions would help policymakers formulate effective emission reduction policies and achieve China's CO_2 emission reduction targets.

China contributes almost half of the iron and steel products sold worldwide and its steel exports are the largest in the world (World Steel Association, 2015). Existing research shows that participating in international trade causes considerable CO_2 emissions in China (Wang and Watson, 2007; Pan et al., 2008). To meet the global demand of construction and manufacturing sectors as well as final demand (e.g., fixed capital formation and household's final consumption), China's ISI has consumed a massive amount of iron ore, coal, and other resources, which has led to high CO_2 emissions. Consequently, identifying the impacts of international demand on ISI's CO_2 emissions is of vital significance for industrial upgrading and CO_2 emission reduction in China's ISI.

A great amount of studies are based on four major research methods to address the main causes for CO_2 emissions in China's

* Corresponding author at: College of Economics and Trade, Hunan University, Changsha 410006, China.
E-mail address: xrxrui@126.com (R. Xie).

http://dx.doi.org/10.1016/j.resconrec.2016.09.019
0921-3449/

Please cite this article in press as: Peng, J., et al., Energy-related CO_2 emissions in the China's iron and steel industry: A global supply chain analysis. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.09.019

ISI. First, index decomposition analysis (IDA) methods are used to classify CO_2 emissions of the ISI into the effect of energy efficiency product structure, fuel share, and other factors (Kim and Worrell, 2002; Ozawa et al., 2002; Sheinbaum et al., 2010). Of these approaches, the method of logarithmic mean Divisia index decomposition is widely utilized to look into the driving forces behind alterations in CO_2 emissions (Sun et al., 2011; Tian et al., 2013; Hasanbeigi et al., 2014; Liu et al., 2016).

Second, bottom-up analyses such as climate change policy models have been used to survey the different effects on CO_2 emissions in Germany, China, and Japan, including the best available and most innovative technologies (Schumacher and Sands, 2007; Moya and Pardo, 2013), energy efficiency (Morrow et al., 2014; Karali et al., 2014; Hasanbeigi et al., 2016), the scope and direction of investment (Lutz et al., 2005), and carbon tax and carbon prices (Gielen and Moriguchi, 2002; Schumacher and Sands, 2007).

Third, the system optimization method is used to analyze the reduction potential of CO_2 emissions in the ISI (Han et al., 2014; Nakaso et al., 2015), the effect of investment scale and direction (Pauliuk et al., 2012; Milford et al., 2013), and the impact of policy in this area (Rock et al., 2013; Pellegrino et al., 2015).

Finally, data envelopment analysis (DEA) models are used in calculating the degree to which energy use efficiency, CO_2 emission reduction efficiency, and carbon emission trading schemes affect the ISI's CO_2 emissions (He et al., 2013; Morfeldt and Silveira, 2014; Riccardi et al., 2015) as well as evaluating regional carbon emission potential in China (Guo et al., 2011; Choi et al., 2012).

Notwithstanding the simplicity and convenience of the operationalization of IDA methods, as well as the fact that necessary data is easy to obtain, the role of the implicit factors behind complex economic relationships cannot be easily revealed. Majority of the existing IDA studies examine the main causes of CO_2 emissions of certain region or an industrial sector. However, few of them would link one country's CO_2 emissions of a certain industry with the economic behavior in other countries or regions from a regional view. Similarly, while bottom-up models and the system optimization method are able to insulate the effect of technological drivers for CO_2 emissions, limited implications about the relationship between CO_2 emissions and economic aspects can be concluded. In addition, the DEA model is suitable for evaluating carbon emission efficiency and forecasting the potential of emission reductions. However, DEA is less suitable in examining the effects of influential factors for a lack of a specific functional form and the possibility that inefficiency might be overestimated by this method.

Disadvantages of the above methods can be counterbalanced by the input-output (IO) model as it demonstrates the overall relationships among industrial sectors by linking industrial emissions to different types of final demand to calculate both the direct and indirect effects of CO_2 emissions. Especially when using the global multi-regional input-output (GMRIO) model, researchers have ability to link the CO_2 emissions of China's ISI with economic behavior in other countries so as to analyze the causes of such emissions in a regional level.

Based on the IO model, two major methods are widely applied to analyze the environmental effects of industrial sectors, namely structural decomposition analysis (SDA) and structural path analysis (SPA). The IO-SDA method is capable of identifying the interactive causes for CO_2 emission changes in industrial sectors at an aggregate level (i.e., the direct and indirect effects; Peters et al., 2007; Guan et al., 2008; Feng et al., 2012; Zhang and Lahr, 2014; Gui et al., 2014). While SPA offers a complete industrial path from upstream demand to downstream industry, SDA approach cannot. The basic principal of the SPA approach is unfolding the Leontief inverse by its series expansion (Wood and Lenzen, 2003) and then separating each supply chain including direct and indirect demand for a sector's output by final demand to form a complete industrial path. Hence SPA is able to identify production chains contributing most to a particular consumption-based emission, and supply chain paths are then categorized according to their numbers of industrial sectors (Owen et al., 2016).

SPA was initially introduced by Defourny and Thorbecke (1984) and Crama et al. (1984), who combined SPA and multiplier decomposition to apply to social accounting matrix analysis. Wood and Lenzen (2003) compare the consumption-based account of two Australian research institutions by applying IO analysis to the ecological footprint methodology, while Lenzen (2003) finds that short order paths ranked the highest when energy use and gas emissions are considered. In regards to production chains, SPA is also profoundly used for life cycle assessment. Treloar (1997) utilizes IO-SPA to analyze the incorporated energy paths of Australian home construction industry. Strømman et al. (2009) have come up with a method to compile inventory and adjust double counting by combining life cycle assessment and IO-SPA. Built on the data associated with both an MRIO table and life cycle assessment, Acquaye et al. (2011) discussed how SPA can identify carbon "hot spots," or to be put in another way, the path with the highest carbon intensity within the upstream supply chain for biodiesel. Tao et al. (2015) studied the reduction of industrial carbon footprint by using the multi-period closed-loop supply chain method. In addition, SPA was used by Peters and Hertwich (2006a,b) to examine supply chain paths inside a trade model. In the latest trend, SPA was used on researching greenhouse gas emissions to further map the CO_2 emissions with each life cycle supply chain path (Iris et al., 2006; Cherubini et al., 2011). For example, Skelton et al. (2011) analyzed the percentage of final products in global greenhouse gas emissions.

In short, on account of analyzing causes of CO_2 emissions, the IO-SDA and IO-SPA are better than previous methods. However, studies using IO-SDA and IO-SPA focus on analyzing CO_2 emissions at the national level, whereas few studies research CO_2 emissions in the ISI from an international or regional perspective. To bridge this knowledge gap, study answers the following questions: the extent to which (i) different types of final demand and (ii) the IO relationship among industries affecting CO_2 emissions in China's ISI through the critical supply chain path, based on the GMRIO model and SPA approach.

The rest of this paper contains the following parts. Section 2 presents the theoretical model of the SPA approach and describe the content of data sources. In Section 3, we report and discuss the results from the critical supply chain paths that alters CO_2 emissions in China's ISI. Section 4 concludes the study and offers our suggestions on policies to reduce CO_2 emissions in China.

2. Methodology and data sources

Previous researches emphasized on the continuous improvement of IO model since Leontief proposed it in 1936. We applied the SPA approach to Leontief's IO model to unravel the Leontief inverse using its series expansion (Waugh, 1950; Wood and Lenzen, 2003). The purpose of this study is to quantify the demand-driving CO_2 emission volume in industrial sectors from the perspective of supply chain paths.

2.1. Data sources

The World Input-Output Database was used in the study as the source of the GMRIO table and energy-related data. The GMRIO table includes 14 main countries or regions such as the United States, Japan, EU-27, China, and the rest of the world as a whole (ROW), including 35 industries for each country according to the ISIC Rev3.1 criterion from UNSO. Final demand in the GMRIO table has four categories: household demand, government demand,