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Chapter 6

General discussion

6.1. Introduction

As indicated in Chapter 1, LE technologies have a significant potential to reduce the total carbon emissions in China. Yet, in existing research, most authors analyzed such implications for China as a whole rather than the amount of carbon embodied in the products and services for China’s exports. We took a regional approach, since the implementation of LE and the production of products and services for China’s exports very heterogeneously distributed over the various Chinese regions. Current studies also tend to neglect the carbon emissions related to the investments in LE. Against this background, Chapter 1 formulated 4 research questions which were addressed in the following 4 chapters. Since we wanted to take into account regional differences in the electricity and industrial production structures of China, MRIO was used as a core methodology. In this way, inter-regional linkages and spillovers could be covered. Since the available Chinese MRIO does not distinguish different electricity production techniques, another contribution of this thesis was constructing a hybrid MRIO that discerns individual energy technologies.

In the next section, we want to answer the research questions posed in the introduction. Section 6.3 provides some methodological reflections and discussions. Section 6.4 then concludes with an outlook.

6.2. Answers to the research questions

6.2.1. Carbon emissions in China

Research question 1 was formulated as follows.

1. How are carbon emissions distributed across sectors from the perspective of inter-sectoral linkages? What spillovers occur via supply chains, particularly between the electricity sector and other production sectors?

The analysis of multi-sectoral carbon emissions in China has become a hot issue. Yet, the analysis of inter-sectoral production linkages including spillover and feedback emissions have received little attention. Applying an extended, IO-based, time-series decomposition approach to analyze inter-sectoral carbon relationships allowed us to gain a better understanding of each sector’s role on national carbon emissions. By tracing the four emission components (direct, internal, spillover and feedback), key sectors and relevant carbon transactions were identified, allowing for a characterization of the patterns of sectoral emissions in China.

Among the 26 economic sectors analyzed, the sectors of electricity and heavy manufacturing were key sectors in output-induced carbon emissions, while the equipment manufacturing, construction, and services sectors were the key emission sectors from the perspective of demand. Spillover components of the equipment manufacturing, construction, and services sectors were largely responsible for the rapid carbon emission growth in the electricity and heavy manufacturing sectors. Therefore, carbon emissions in
China were mainly transferred from the basic industrial sectors (e.g. electricity sector) to the equipment manufacturing, construction and services sectors. The electricity sector also ranked top in the feedback component shares, which means that the intermediate inputs of many economic sectors depend on the production of electricity sector. Since the production of upstream sectors (e.g. electricity sector) increased the total energy consumption and total carbon emissions, the design of policies to control the carbon emissions in the electricity sector would help to reduce a large part of carbon emissions in China. Moreover, the internal component of the electricity sector was larger than that of other sectors. This implies that the internal efficiency and production structure changes in the electricity sector were the most important factors in curbing its rising trend of carbon emissions. Therefore, developing low-carbon electricity (LE) is conducive to reducing the carbon emissions in the electricity sector and to consequently achieving the goal of carbon emission reduction in China.

6.2.2. LE development and carbon emissions in exports

Research question 2 was formulated as follows:

2. How will the development of low-carbon energy across regions impact carbon emissions embodied in China’s exports? What is the role of electricity transmission and supply chains in regional emission reductions?

Comparing the historical LE expansion against a counterfactual in which the LE expansion of 2002-2014 did not take place, shows that the ongoing transition of China toward LE has substantially contributed to reducing carbon emissions embodied in China’s exports, resulting in a net emissions reduction of 203 Mt (11.5% of the total carbon emissions embodied in exports), 244 Mt (14.9%), and 259 Mt (19.5%) in 2007, 2010 and 2014, respectively.

Since there are significant differences across regions in China, it is essential to compare the regional effects of LE development on the carbon emissions embodied in exports. A multi-regional investigation shows that the carbon impact of LE expansion generally followed the regional distribution of export-embodied emissions, because most provinces with great LE impacts were mainly affected by the intra-regional effect, and the intra-regional effects matched up well with LE resource across regions in China. Jiangsu, Zhejiang, and Guangdong, the important trade provinces in China, had the largest carbon emission reductions. However, Hebei and Shandong had a relatively smaller carbon impact of LE development than Sichuan and Hubei, even though their export-embodied emissions were larger. This is because wind power played an important role in alleviating carbon emissions in Hebei and Shandong, while the proportion of wind power in electricity mix was still low. In contrast, Sichuan and Hubei faced the greatest increases in hydropower generation such that the LE effects in these two regions became much larger.

Given the existence of inter-regional linkages, there were three district modes regarding the carbon impacts of LE expansion: the intra-regional effect, the electricity transmission effect and the supply-chain effect. In total, electricity transmission infrastructure led to emission reductions of 50 Mt in 2007, increasing to 62 Mt in 2014. Regionally, the exported electricity in the central and southwestern regions showed significant effects on alleviating the emissions in the eastern and southern regions. The exported electricity in the northwestern region also had a positive effect on reducing the carbon emissions in the
northern region. Specifically, electricity transmission was responsible for the very large embodied-carbon savings in Shanghai, which comprised over 48% of the total LE impacts in Shanghai from 2007 to 2014. The significant penetration of LE in adjacent provinces was necessary to reduce export-embodied carbon emissions in Hebei. In 2014, the electricity transmission effect in Hebei comprised 40.1% of the total carbon impact of LE development.

In addition to the electricity transmission effect, the carbon impact of LE development was influenced by the supply-chain effect. The supply-chain effect resulted in a maximum reduction of 41 Mt in 2010, then dropped to net savings of 39 Mt in 2014. The comparatively high share of supply-chain effects in the southern and eastern regions was attributable to the LE development in the central and western regions. This was because the coastal regions, which suffer chronic resource shortages, depend strongly on the supply of energy and materials from the western and central regions. The supply-chain effect was particularly large for Shanghai and Hebei, in which the supply-chain effect shares were, respectively, 49% and 38% in 2014. Moreover, the impact of LE development on the carbon flows from neighboring provinces to Hebei and Shanghai could be utilized efficiently to reduce the export-embodied carbon emissions in Hebei and Shanghai. This calls for a significant improvement in the electricity mix in the surrounding regions of Hebei and Shanghai.

6.2.3. Carbon impacts related to investments in LE technologies

Research question 3 was formulated as follows:

3. How do the carbon emissions from investments in LE infrastructure compare to the reduction of carbon emissions during the use of LE? How are the carbon impacts of this infrastructure distributed within China?

A comparison between historical emissions and a counterfactual scenario shows the total operational impact of LE drove increasing mitigation of emissions of 48.84 Mt, 81.83 Mt and 129.48 Mt CO₂ in 2002, 2007 and 2010, respectively. However, electricity investment activities also have short-term effects on carbon emissions from other sectors, for example shaping the carbon emissions of construction and manufacturing. Since LE infrastructure tends to have higher upfront inputs than fossil-fuel electricity in the infrastructure stage, China’s LE investments drove a net emission increase of 16.21 Mt in 2002, 28.71 Mt in 2007 and 46.29 Mt in 2010.

The carbon impact of LE investments exhibited significant regional differences, as the carbon intensity of LE installation was not uniform across all regions in China. The magnitude of net impacts of LE investments in Guangdong, eastern and southwestern provinces, which are endowed with hydro and nuclear power resources, was smaller than that of net operational impact of LE. However, in several northern, northeastern and northwestern provinces (e.g. Gansu and Inner Mongolia), with abundant wind power resources, the net emission reductions from LE operation could not offset their net emission increases from LE investments for the period examined.

Also, as MRIO models captured the emissions associated with any intermediate inputs between regions, the inter-regional spillover effects of LE investments could be identified. The majority of carbon emissions from LE investments in the developed eastern region resulted from the inter-regional spillover effect. This means that the carbon impact of LE
investments was moved from downstream regions to upstream regions, as the developed eastern region depends heavily on the intermediate inputs from the western and central regions.

6.2.4 Projected carbon impacts from the expansion of LE infrastructure

Research question 4 was formulated as follows:

4. How will the carbon impact from the expansion of LE infrastructure evolve in the future?

Mitigation scenarios reported by international (IEA) and national (NDRC) bodies, which are used to investigate how carbon emissions reductions can be achieved, usually show a substantial contribution of the LE expansion in the electricity sector. However, the carbon overheads from the expansion of LE infrastructure may have negative implications for the effectiveness of the carbon emission reductions from LE operation in the future. Thus, it is important to derive a projection of the carbon impact of the expansion of LE infrastructure.

Due to learning effects, the carbon intensity of LE installation decreases as the electricity sector installs more capacity. This is because LE sectors learn how to build infrastructure more efficiently, often termed an experience curve. The carbon impact of LE investments over time were based on the experience curve of historical data, which was projected forward using the future capacity in the scenarios of IEA and NDRC. The projected results indicate that, during 2015-2040, the carbon emissions associated with the expansion in LE infrastructure will not represent more than 4% of the projected total carbon emissions in the same year. In the IEA-sustainable development scenario, the total carbon emissions are lower, and the annual average carbon impact of LE investments was less than 2% of the total carbon emissions up to 2040. Out of all the scenarios examined, the IEA-sustainable development scenarios led to the highest carbon reductions. Despite the fact that LE investments increase rapidly in the NDRC-High Renewable Penetration scenario, the carbon impact of LE infrastructure expansion will peak during 2030-2035 and decrease thereafter. Overall, the result shows that it is necessary to take into account the carbon impact of LE investments, but it should not be considered an argument to halt the development of LE.

6.3. General discussion

As discussed in Chapter 1, a key obstacle to previous research was the lack of detail on LE technologies in the existing Chinese MRIO tables. The economic-energy hybrid, MRIO model proposed in Chapter 3 helped to solve this problem. Therefore, it is essential to discuss the advantage of this model and its possible contribution to future studies. Chapter 4 showed the regional differences in the expansion in LE infrastructure, from which policy implications need to be discussed. Finally, although a multi-regional carbon impact of LE development in China was developed, the thesis still has certain uncertainties need to be highlighted.

6.3.1. A disaggregation of carbon impact of LE development

The primary contribution of Chapter 3 was to introduce a novel economic-energy hybrid, MRIO model. This model is based on a model of primary energy use from Guevara and Rodrigues (2016). Compared to conventional MRIO models, the hybrid model has a
detailed description of carbon flows based on energy in physical units and non-energy production processes of the economy in monetary units. It characterizes the vector of the total carbon emissions as a function of six driving forces (carbon intensity of primary energy, electricity mix, electricity transmission, electricity intensity, economic structure and final demand), which can improve the conclusions obtained within the conventional MRIO framework. Moreover, since the electricity sector in most MRIO tables is highly aggregated, the proposed model could provide better insights to the carbon impact of LE development by investigating energy use mechanisms in the economy. Specifically, it extends MRIO application to the consideration of inter-regional electricity transmission and economic linkages between regions, such that the estimation of the carbon impact of LE development is more accurate.

Additionally, based on this novel model for China, Chapter 3 compared a counterfactual scenario without LE expansion against the historical LE expansion. Then, within a theoretical framework that combined the economic-energy hybrid MRIO model and scenario analysis, a decomposition analysis could be performed to obtain more detailed insights into the core mechanism for the carbon impact of LE development. The carbon impact of LE development was systemically calculated by categorizing intra-regional effect, electricity transmission effect and supply-chain effect. Thus, not only the effect of intra-regional LE development, but also the inter-regional impact, which is supported by the electricity transmission system or wide economic linkages, could be identified. In such case, the electricity transmission system is one way in which the carbon impact of LE from a region to other regions. Meanwhile, the carbon impact of LE development also can occur along the entire supply chains in export-related goods and services. These are essential in determining which region’s LE development have the greatest potential for emission mitigation.

6.3.2. Intra-regional and inter-regional effects of LE investments

Chapter 4 established a comprehensive analytical framework to explore the carbon impact of LE investments. It offered an MRIO approach for comparing the carbon impact of LE investments with the operational impact of LE development. MRIO models were used to quantify the carbon impact of LE investments from consumption-based perspective considering both intra-regional and inter-regional impacts. The intra-regional impact shows that the expansion of domestic LE infrastructure had a strong effect on embodied carbon emissions in each region, while the spillover effect further clarified the impact of LE investments on inter-regional carbon flows along the supply chain. The method presented could be helpful for the macro-analysis of carbon impacts of LE investments in China on the regional level.

The results show the regional characteristics of carbon impact of LE investments, which is valuable for decision making of emission reduction strategies. The intra-regional carbon impact took up a large proportion of the total carbon impact in the western and central regions, whereas a large inter-regional spillover impact can be found for the eastern region. Moreover, the analysis of carbon flows shows that the western and central regions had the largest outflows and the eastern region was the largest receiver. This means that the eastern region used more intermediate products provided by the western and central regions to satisfy its demand for LE infrastructure, such that the corresponding emissions occurred in the western and central regions through a spillover effect in the supply chain of the eastern region. This phenomenon is similar to the findings of Yan et
Thus, the technological improvements in the manufacturing in the western and central regions can not only help reduce their own carbon impacts of LE investments, but also decrease the carbon impact of LE investments in the eastern region. Moreover, a region tends to transfer its impact of LE infrastructure to neighboring regions. Feng et al., (2014)’s studies provided a possible explanation for this phenomenon, which argued that a region tends to consume more intermediate inputs from neighboring regions due to transportation costs, thus transfers more emissions to neighboring regions.

**6.3.3. Uncertainty**

In order to derive the estimates of carbon impacts of LE investments in Chapter 4, a demand-driven MRIO model (Hedi, 2016) was developed, which will necessarily induce a variety of uncertainty due to its top-down nature. First, some assumptions were applied due to the lack of relevant statistical data. For example, the investment cost structure of an electricity technology for different periods and regions was assumed to be identical, which should be improved in the future along with the enrichment of data source. Second, the effect of sectoral aggregation in the MRIO framework may give biased results, as emission data refer to the average of sub-products in the broader sector (Su et al., 2010, Zafrilla et al., 2014). Thus, more detailed disaggregations could further enhance the calculation’s accuracy and reliability. Third, due to data limitations, the estimate of carbon emissions was based on fossil fuel combustion and cement production. However, Wiedmann et al, (2011) have highlighted that, in order to more accurately assess the impact of LE infrastructure, carbon emissions from plastics can be included.

Moreover, Chapter 5 applied experience curves to project the trend of carbon impacts from LE investments. The concept of experience curves provides a transparent tool to contrast the production capacity and reduction potential of carbon emissions from LE installation. However, this method does not consider other important constraints. For example, more LE investments, would result in an electricity sector with lower emissions in the operation phase, which might decrease the carbon emissions from LE investments, as LE investment activities are supported by the production of the electricity sector itself via feedback effect. However, the carbon intensity of electricity generation has become relatively stable in recent years, such that the effect of electricity sector itself on LE investments would tend to reduce in future years. Thus, using the experience curve without considering carbon intensity of electricity generation is a reasonable approximation.

**6.3. Outlook**

There are still at least three important questions which need answering in future work.

First, although the analysis in Chapter 3 covers the impact of LE development on the export-embodied carbon emissions at the regional level, the impact of China’s LE development on carbon emissions in specific trade countries/regions has not been explored. Liu et al., (2015) has argued that the changes in primary energy consumption in some targeted provinces could drastically reduce global emissions. Thus, the impact of LE development on specific carbon leakage between China and a major trade country is worthy of further attention. Moreover, consumption-based accounting can be used as an alternative carbon accounting method, so an interesting future analysis would be
investigating the impact of LE development on carbon leakage between China and specific developed countries in the context of global value chain.

Second, in Chapter 4, the accuracy of the estimated carbon impact of LE investments depends on the aggregation level of the economic activities in MRIO tables. Further research would be needed to link detailed process-specific information to the MRIO model in order to improve accuracy of estimates.

Finally, although Chapter 5 have offered an approach to predict the reduction of the carbon overhead of LE infrastructure up to 2040 using experience curves, we were unable to account for the fact that LE expansion will reduce the operational carbon emissions. That is, the operational impact of LE development in the future has not been explored. Thus, future research could give more insights into the ex-ante projections of operational impact of LE development.
References


