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Mapping and benchmarking regional disparities in China's energy supply, transformation, and end-use in 2010

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HIGHLIGHTS

- West-China and Central-China produced about 89% of the country's coal in 2010.
- About 50% of coal fired power generation and 90% of refining was located in East-China in 2010.
- East-China's industry sector consumed about 70% of oil; 58% of coal and 53% of electricity in 2010.
- Inconsistencies between China's national and provincial statistics in 2010 are huge, in particular for coal.

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ABSTRACT

China's past economic development policies resulted in different energy infrastructure patterns across China. Regional disparities in China's current energy flow are rarely visualised and quantified from a system-wide perspective. This study therefore constructs Sankey diagrams for three sub-regions of China in 2010, benchmarks those to the corresponding national Sankey diagram, and quantifies the following major regional disparities: (i) West- and Central-China account for about 89% of the country's coal production. (ii) About 50% of coal fired power generation and about 90% of refining can be mapped to East-China. (iii) East-China also dominated the country's industrial energy consumption, accounting for about 70% of oil, about 58% of coal and about 53% of electricity consumption in industry. This paper highlights the need to combine national and regional energy planning to account for this spatial heterogeneity in China's energy infrastructure, such as future energy intensity and CO_2 emission reduction targets. More comparable statistical research is needed to better understand inconsistencies between China's provincial and national energy statistics, in particular for coal. We find data differences of up to 46% for coal, which are due to statistical inconsistencies and assumptions in our methodology.

1. Introduction

China is the world's largest energy consumer and energy sector decisions in China have global implications [1]. China's past economic development policies resulted in a large degree of regional disparity. China's successful economic development policies, which were laid out in the 7th five year plan (1986–1990), targeted different regional patterns of industrialisation and production for East-, Central-, and West-China [2]. The coastal provinces of China have been in the focus of China's economic development policies since many years, amongst others due to their favourable geographic location for international trade and foreign investments [3]. China's past economic development policies resulted subsequently in different energy infrastructure investments across China. China's current energy infrastructure is thus showing different regional characteristics in energy supply, transformation, and end-use, such as in the status of energy transmission/distribution systems and the location of major load centres.

Many China-focussed research areas are in the process of switching from national level to regional and provincial level analysis, in order to get a more detailed picture of China's regional disparities and provide better targeted policy recommendations. China-specific research at a sub-national level highlights large disparities between the highly developed coastal provinces and other provinces in the central and western regions of China. Regional disparities in China's energy system are being analysed more frequently in recent years, as the following examples show:

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regional inequity in CO_2 emissions and emission leakage within China is considerable and requires both national and regional oriented policy instruments [4]. About 57% of China's emissions in 2007 were related to goods that are consumed outside of the province where they were produced [5]. Jiangsu province, one of the highly developed coastal provinces, relied in its energy supply in 2009 about 91% on energy imports from other Chinese provinces or foreign countries [13]. China's provincial and national energy productivity and energy efficiency indicators in 2007 varied considerably across China and inter-provincial energy trade was high [1]. This suggests more targeted research on China's regional energy infrastructure disparities, also in view of sharing of best practises with other countries [1].

To the best of our knowledge, there is currently no regional energy flow analysis for China available, which calculates and visualises regional disparities in China's energy system from a combined national and regional system perspective. Such an analysis would require accounting for all major fuels and energy carriers in energy supply, energy transformation, and end-use. Whilst national level energy flow charts for China are being used in many strategic studies for China's future energy system [6–8], regional energy flow analysis for China was only recently suggested as a research priority by China's National Energy Administration [9]. Furthermore few studies combine an energy system analysis for China with a detailed discussion of the underlying national and provincial statistical and data quality issues.

Application areas for this China-specific regional energy flow analysis presented here are thus targeting a broad and interdisciplinary audience. The results of this study could contribute to the following energy research areas:

(i) the analysis of regional disparities in China's current energy system [10–14];
(ii) the development of national, regional and provincial policy instruments in the water–air-energy nexus, such as air quality policies and energy efficiency targets [1,4,15–18];
(iii) the modelling of future economic, energy, and emission scenarios for different sub-regions in China [6–8,19–21];
(iv) the communication of China-specific scientific results to a broad audience, including the visualisation of data issues in China's national and provincial energy statistics [22–25].

This paper is structured as follows: Section 2 describes the theoretical framework of this research, the analysis of energy flows. This is applied in Section 3 to conduct a regional energy flow analysis for China. Section 4 presents the results of our calculations, describing energy flow charts for East-, Central- and West-China's energy supply, transformation, and end use in 2010. The discussion of major regional energy system disparities in China takes place in Section 5, followed by a discussion of statistical and data quality issues in Section 6. The author's conclusions for policy- and decision-makers are provided in Section 7. Appendix A provides the data tables behind the regional analysis whilst Appendix B provides the national energy flow analysis for easy comparison.

2. Theoretical framework: energy flow analysis

Energy flow analysis has a long history, dating back more than 100 years. The first Sankey diagram was developed by the Irish engineer R. Sankey in 1898 [26]. Energy flow diagrams, often also called Sankey diagrams, are nowadays a standard methodology to visualise and analyse complex systems in different application areas in science and in engineering. The system boundaries for energy flow analysis can be defined in a very flexible way, from a very small system size (such as a product, a technical system and a value chain) to a very large or even global system (such as for a country or a continental region). In the area of energy system analysis and modelling, energy flow diagrams are often used as a reference tool when comparing a country's current energy system with potential future energy scenarios [14,27]. Sankey diagrams are also a helpful and intuitive tool when communicating technical complex aspects across different disciplines and to the general public [26].

The use of energy flow charts and Sankey diagrams in China is increasing since 2005. Most of the energy flow charts for China are mapping the national energy system and are usually based on official government statistics released by the National Bureau of Statistics (NBS) [14,27,35]. China's Energy Research Institute started mapping the energy flow of China in 2010, however without providing for a reference for the underlying methodology [6]. One fuel specific energy flow diagram is also available for China, which is tracing the national use of crude oil and petroleum products in 2009 [11,12]. An energy flow chart for China in standardised international units is annually published by the International Energy Agency, the most recent one is available for 2011 [36]. This internationally comparable Sankey diagram of China was recently used as a starting point for energy security analysis [28]. Different national energy flow charts are thus available for China, depending on the underlying data source and statistical definitions. A few examples of provincial energy flow analysis for China exist currently, namely for Jiangsu Province in 2008 [13] and Shandong Province in 2009 [29].

For the case of China and the caveats of official energy statistics, energy flow charts proved in particular useful to identify, classify, and sort comparable energy statistical data [11,12,13]. Some researchers started to adjust the official national energy statistics with additional data sources and methodologies to allow for a more detailed mapping of China's national energy flow and associated energy demand drivers [11,12]. Limited research is available that allows to precisely compare China's national energy statistics in the unit of tons of coal equivalent with energy statistics from other countries in standardised international units [11,12,13,22].

3. Practical application: analysing regional energy system disparities in China

3.1. Defining system boundaries of East-, Central-, and West-China

China's official statistics disaggregated the country since the 1980s frequently into three different regions or "belts", namely "the East," "the Centre" and "the West". Over the past three decades, China's regional modernisation and economic development policies have been focussed on the East, which subsequently leads to the current regional disparities in economic, energy and emission indicators within China. This paper uses the most recent official regional definitions of East-, Central- and West-China for the 12th Five-Year-Plan [30] to assign the available provincial units of China to one of these three regions. East-China consists of Liaoning, Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan. Central-China consists of Heilongjiang, Jilin, Shanxi, Henan, Anhui, Hubei, Hunan and Jiangxi. West-China consists of Inner Mongolia, Shaanxi, Gansu, Ningxia, Xinjiang, Qinghai, Sichuan, Guizhou and Yunnan (Fig. 1). A similar regional definition of China is used amongst others by Dai and Mischke [19], Li et al. [14], He and Huang [31], Feng et al. [5], Todd and Huang [32], Auffhammer and Carson [18].

Some China-specific energy system and power sector studies with a different regional boundaries of China exist, reaching from two sub-regions (East, West) to eight sub-regions (Northeast, Beijing-Tianjin, Northern Coastal, Eastern Coastal, Southern Coastal,