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Carbon emissions of urban power grid in Jing-Jin-Ji region: Characteristics and influential factors

Wendong Wei [a, b, 1], Xibo Wang [c, 1], He Zhu [d], Ji Li [e], Sili Zhou [f, g], Zhiyi Zou [a], J.S. Li [f, g, *]

[a] *Business School, University of Shanghai for Science and Technology, Shanghai 200093, China*
[b] *Innovation Consortium for Jing-Jin-Ji Collaborative Development, Beijing 100871, China*
[c] *Institute of Software, Chinese Academy of Sciences, Beijing 100190, China*
[d] *Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[e] *China Academy of Building Research, Beijing 100013, China*
[f] *State Key Laboratory of Coal Combustion, School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China*
[g] *Department of New Energy Science and Engineering, School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, China*

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A B S T R A C T

Rapid urbanization drives the expansion of urban power girds, which involves enormous energy intensive products such as steel and concrete and inevitably results in a great quantity of carbon emissions. However, little has been done to investigate urban power girds' impact on carbon emissions. To solve this problem, this study makes efforts to calculate the carbon emissions of urban power grid in Jing-Jin-Ji region, one of the most populous and economically dynamic regions in China, in light of the hybrid method. Moreover, the depreciation life of urban power grids is taken into consideration for the first time, which avoids the underestimation of the accumulated carbon emissions of urban power grid due to depreciation. The results show that the accumulated carbon emissions of urban power grid in Jing-Jin-Ji region are 2.71E+06 t CO_2 eq. in 1993. When it comes to 2014, this figure increases by over 7.2 times. The majority of the carbon emissions by typical urban substations and transmission line projects are contributed by electrical equipment, steel and construction industries. 4 scenarios are set to predict the future carbon emissions by power grids in Jing-Jin-Ji region. The highest accumulated carbon emissions in 2020 are projected to be 7.63E+07 t CO_2 eq. under the condition shortest depreciation life (SDL) in the First Year Finished (FYF) scenario. Regression analysis is also carried out to show some influential factors such GDP's influence on power grids' carbon emissions, suggesting that the correlation between carbon emissions and regional economic development becomes more significant after *Power System Reform Plan* in 2002. This study not only draws a holistic picture of power grid but also bears significance to policies and actions in urban regions.

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1. Introduction

China has experienced unprecedented urbanization since its reform and opening-up policy in the late 1970s. Millions of people flooded into cities, increasing China's urbanization rate dramatically from 17.92% in 1978 to 56.10% in 2015 (NBS, 2016). The continuously growing urban population and economy lead to a sharp rise in urban energy consumption and carbon emissions (Mi et al., 2015, 2016, 2017). The Intergovernmental Panel on Climate Change (IPCC) report shows that urban areas are responsible for more than two thirds of global energy cost and an even larger share of carbon emissions (IPCC, 2014). In China, carbon emissions in urban areas account for more than 90% of the national total (Song and Xu, 2011). As an important component of energy system and an inseparable part of modern urban activities, electricity is vital for every aspect such as commerce, industry and transportation, laying the foundation of prosperous urban economy and high quality of life (Liu, 2012, 2015). China's electricity consumption takes up 22.56% of total energy consumption in 2012, an increase from 9.53% in 1991. The carbon emissions from electricity generation account for 43% of China's total carbon emissions in 2013 (Chen et al., 2016).

* Corresponding author. Tel.: +86 027 87558598.
E-mail address: lijiashuo@hust.edu.cn (J.S. Li).
[1] These authors contributed equally to this work.

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Taking Beijing as an example, along with the booming urbanization, electricity consumption by urban areas also witnessed a striking 12.96 folds in the same period, increasing from 7.35E+00 TWh in 1978 to 9.53E+01 TWh in 2015 (BMBS, 2016). To satisfy the enormous electricity demand of urban areas, large scale power transmission grid mainly consisting of power stations and transmission lines were built in the same period (Wei et al., 2017). With the development of renewable energy generation, smart grids has been widely used in urban areas (Amini et al., 2013, 2015; Boroojeni et al., 2017). These evidence strongly indicate that urbanization, electrical power consumption and carbon emissions are closely interconnected (Lin and Du, 2015; Shahbaz et al., 2014; Wang et al., 2016; Yang et al., 2016). Under this circumstance, how to mitigate carbon emissions from urban electricity sector has become a compelling issue.

Carbon emissions from electricity sectors have two contributors: electricity generation and electricity transmission. It is found that most of the existing literature on electricity sector focuses on electricity generation (Burkhardt et al., 2013; Odeh and Cockerill, 2008; Rule et al., 2009; Sims et al., 2003; Turconi et al., 2013). On the contrary, similar studies on power transmission grid are still in scarce. Till now, only several recent studies highlight the environmental impact of electricity transmission and distribution networks.

Bumby et al. (2010) assesses the environmental impacts caused by the overhead and underground electricity distribution grid in the United States on the basis of life cycle assessment (LCA), showing that the dominant impact occurs during cable production. Jones and McManus (2010) performs LCA to analyze and compare the embodied impacts of three overhead lines and two underground cables in production and lifetime operation. They point out that operational conductor losses are the primary cause of impacts, which is in need of minimization. Harrison et al. (2010) also carries out LCA for carbon emissions of the transmission grid in Great Britain and finds out that the majority carbon emissions come from transmission loss. Similar efforts have also been made to estimate and characterize the environmental impacts of the Norwegian transmission grid (Jorge and Hertwich, 2013), the grid infrastructure in Europe (Jorge and Hertwich, 2014) and electricity generation and supply in Portugal (Garcia et al., 2014).

Notably, the aforementioned studies are performed in light of life cycle assessment (LCA). These LCA-based studies come to a conclusion that electricity transmission and distribution grid infrastructure has non-negligible environmental impacts. However, the LCA method cannot avoid the inherent truncation errors, which may provide incorrect information (Li et al., 2012; Meng et al., 2014). Input-output analysis (IOA) is another widely used approach for environmental emissions estimation (Li et al., 2014, 2015), which can provide the information on a unified and consistent base (Shao and Chen, 2013; Chen et al., 2017a). Therefore, IOA can avoid the disadvantages of LCA. However, IOA is not applicable for detailed process analysis as it used for macro-scale analysis (Li et al., 2016). Both of the methods' advantages and disadvantages, which have been extensively elaborated in the existing literature (Chen et al., 2017a,b; Li et al., 2017a, b). To make the best use of the advantages and bypass the disadvantages, the hybrid method, a combination of LCA and IOA, has been developed (Bullard et al., 1978; Feng et al., 2014; Wiedmann et al., 2011). There are numerous successful applications of the hybrid method in assessing different systems' embodied energy (Chen et al., 2011a, 2011b; Li et al., 2014; Wu et al., 2014), virtual water (Han et al., 2016), carbon emissions (Li and Chen, 2013; Li et al., 2012, 2013; Wu et al., 2016) and $PM_{2.5}$ emissions (Meng et al., 2015, 2016a, 2016b). Second, the electricity transmission grid in the previous studies come from a few developed countries, while their counterparts in China, with the biggest scale of electricity grid and the largest amount of carbon emissions have rarely been considered. Third, the impact of urban electricity power transmission, recognized as the key infrastructure for cities, is still unknown, which will hinder the low-carbon development of electricity sectors. Fourth, many papers have analyzed the causality and correlation between carbon emissions and influential factors, such as economic growth, energy consumption (Chang, 2010; Park and Hong, 2013; Muratori et al., 2017). As the largest contributor of China's carbon emissions (Chen et al., 2016), the influential factors of carbon emissions in power sector in China are also widely discussed (Cai et al., 2007; Liu et al., 2011), but few studies has conducted on the power transmission grids.

Environmental effect of power transmission grid has become one of the most important criteria for the whole power grid planning and construction on urban areas (Liu, 2012, 2015). Against the background of global climate change, the knowledge about carbon emissions from urban power transmission grid is of significance not only for understanding its impact on climate change, but also for facilitating low-carbon development strategies for urban power grid. Regarding this, this study aims to provide a holistic view of carbon emissions from one of the urban areas' most important infrastructure − electricity transmission and distribution grid in light of the hybrid method. We construct a most detailed inventory of the input items of typical 110 kV transformer substation and 110 kV transmission line project that contains over 200 input items. Carbon emissions from each input such as materials, equipment and even labors, can be accounted so that a clear understanding of urban power grids' impact on climate change will be achieved. After the Jing-Jin-Ji region joint development has risen to be China's national strategy, Jing-Jin-Ji region will experience rapid urbanization and expansive urban power grid construction. Therefore, this study selected the Jing-Jin-Ji Urban Agglomeration as the case area. This research for the first time takes depreciation life of urban power grids into consideration, which avoids the underestimation of the accumulated carbon emissions of urban power grid due to depreciation. The accumulated carbon emissions of urban power grid in Jing-Jin-Ji region from 1993 to 2020 are estimated under different conditions and scenarios. Moreover, the correlation between carbon emissions of urban power grid and important influential factors such as GDP and electricity consumption are also analyzed by using regression model, which may help to guide the construction of low carbon power grid.

The reminder of the study is organized as follows: Section 2 briefly overviews the economic development and the urban electricity transmission and distribution grid in Jing-Jin-Ji region. Materials and method used in this study are elaborated in Section 3. Section 4 presents the detailed results followed by the discussion in Section 5 and conclusions in Section 6.

2. Overview of urban grid in Jing-Jin-Ji region

The Jing-Jin-Ji region, referred to Beijing, Tianjin and Hebei, covers an area of about 2.16E+05 km^2 and hosts a population of more than 1.11E+08 residents (NBS, 2016). The Jing-Jin-Ji region is the economic center of North China and meanwhile, one of the most urbanized areas in China. Since the reform and opening up policy, the regional economy in Jing-Jin-Ji region has grown rapidly. From 1992 to 2015, the nominal GDP of Jing-Jin-Ji region has risen from 2.40E+03 CNY to 6.94E+04 CNY, with an average annual growth rate of 15.05%. Impelled by the collaborative development strategy, the integration of Beijing, Tianjin and Hebei will accelerate, which will also boom the regional economy and infrastructure. The unprecedented economic growth and urbanization also drives significant electricity consumption in Jing-Jin-Ji regions. The

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