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Sectoral energy-carbon nexus and low-carbon policy alternatives: A case study of Ningbo, China

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ABSTRACT

The intensive energy consumption in urban sectors is aggravating global warming, which triggers an in-depth thinking about energy-carbon nexus and low-carbon city actions. Hence, China has launched a pilot low-carbon city program to explore low-carbon pathways since 2010. This study employed a Long-range Energy Alternatives Planning System model (LEAP) to simulate six energy sectors-related GHG emissions in a pilot low-carbon Ningbo city, China. The LEAP-Ningbo model comprises three basic modules, i.e. energy supply, energy transformation and end-use energy demand in six urban sectors (i.e., household, service, agriculture, transport, industry, and transformation sectors), and resulting environmental impacts (CO_2 equivalents). The results identified by the business as usual (BAU) scenario indicate that total energy consumption is expected to reach 449.72 Mtce and results in emissions of 651.83 Mt CO_{2e} by 2050. In contrast, more aggressive policies and strategies involved in the integrated scenario (INT), which combines the energy structure optimization (ESO) scenario with the policy-oriented energy saving (PES) scenario, can lower energy demand by 14% and CO_{2e} emissions by 27%. A comparison among global cities and low-carbon plans helps identify the carbon emission level and define the actionable low-carbon policies. The high correlation between sectoral energy use and resulting GHG emissions implies energy-carbon reduction efforts, e.g., low-carbon energy substitution, intensive energy-saving policies, the improvement of energy efficiency, and industrial transformation. Achieving low-carbon city targets requires timeline-restricted actions and backgrounds-based measures in plans. The results of this study shed light on if and how cities can shape energy-carbon reduction trajectories and develop low-carbon pathways in China and beyond.

1. Introduction

1.1. Motivation

World-wide actions have been taken to curb global warming. The Intergovernmental Panel on Climate Change (IPCC) reported that it is more than 95% certain that global warming is mostly being caused by anthropogenic activities (IPCC, 2014). The climate models indicate that during the 21st century the global surface temperature is likely to rise a further 2.6 °C–4.8 °C for the IPCCs highest emissions scenario using stringent mitigation (IPCC, 2014). Subsequently, in 2015, after the tough political negotiations, 195 countries agreed by consensus at the Paris Climate Summit to set a goal of limiting the temperature increase to 1.5 °C. Prior to this, global warming caused by Greenhouse Gas (GHG) emissions has attracted academic interest for long period (Grimm et al., 2008; Wang et al., 2011; Yang et al., 2013; 2016a).

Among diverse anthropogenic activities, the energy consumption of urban sectors is the major contribution to GHG emissions, globally (Moomaw, 1996). Global energy-related carbon emissions accounted for 65% of the total GHG emissions in 2010, of which 55% were from industry (IEA, 2014), owing to rapid economic growth, urbanization and population expansion. The world is undergoing

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Nomenclatures

N1. Abbreviation
1) CO_2 equivalents, CO_{2e}
2) Gross Domestic Production, GDP, billion yuan
3) Greenhouse Gas, GHG, CO_2, N_2O, and CH_4 in this study
4) Intergovernmental Panel on Climate Change, IPCC
5) Long-range Energy Alternatives Planning System model, LEAP
6) Million ton coal equivalent, Mtce
7) Million ton CO_2 equivalents, Mt CO_{2e}

N2. Scenarios
8) Four scenarios in the LEAP-Ningbo model: Business As Usual scenario, BAU; Energy Structure Optimization, ESO; Policy-oriented Energy Saving, PES; Integrated scenario, INT
9) Six sub-scenarios in the LEAP-Ningbo model: Clean Energy Substitution, CES; Combined Heat and Power generation, CHP; Industry Energy Saving, IES; Power-Saving Appliance, PSA; Renewable and new Energy Utilization, REU; Transport Energy Saving, TES
10) Six energy-related sectors: Household, H; Transport, Tp; Industry, I; Agriculture, A; Service, S; Transformation, Tf

unprecedented rapid urbanization while consuming large amount of energy in many urban sectors. Urban areas, which occupy 2.4% of the global land surface, are estimated to consume 65% of the energy and produce up to 80% of the carbon dioxide (Grimm et al., 2008; Churkina, 2008). In 1900, a mere 10% of the global population was urban dwellers. Not surprisingly, that ratio will exceed 60% by 2030 (Grimm et al., 2008). In China, the urbanization rate reached a record 56.1% in 2015 from 17.9% of 1978 (NBS, 2016). In the next 15 years, the annual migration towards cities is expected to be approximately 20 million people from rural China. As a result of such urbanization, China accounted for 28% of global total CO_2 emissions in 2013 (IEA, 2014). Cities are critical because they concentrate socio-economic activities that produce climate change related emissions, and are therefore responsible for GHG mitigation. Hence, it is indispensable to trace the characteristics and estimate the trajectories of energy-related GHG emissions at the urban level, which can help form effective low-carbon strategies and ultimately achieve overall national targets.

Low-carbon actions and practices have prevailed along with aggravating global warming. In 2009, China committed to reducing the carbon intensity of its Gross Domestic Production (GDP) by 40–45% by 2020 compared to the 2005 baseline (Wang et al., 2011). In 2010 and 2012, the National Development and Reform Commission of China announced the selection of pilot provinces and cities to explore the low carbon development work. These pilot low carbon cases were selected based on geographic, social and economic diversity and representativeness, existing foundational and/or preparatory work in low carbon development and demonstrated interest by the local regions to be a pilot location (NDRC, 2010; Khanna et al., 2014).

This triggered some in-depth thinking about where a low-carbon city will fit specific targets. It is inevitable for us to help facilitate feasible city sector-related measures for seeking a low carbon future. Some studies have already discussed China's low-carbon city initiatives, e.g., the effectiveness of low-carbon city measures (Lin et al., 2010), low-carbon towns/city in China (Li et al., 2012; Yang and Li, 2013), Low-to-no carbon city (Lehmann, 2013), China's low-carbon city initiatives (Lo, 2014), and Low-carbon city logistics distribution network (Yang et al., 2016b), but most of them are only based on urban GHG emissions. Several studies have discussed the carbon-related issues in Ningbo (Wu et al., 2015; Mi et al., 2016). Meanwhile, low carbon actions combined with sectoral reduction strategies for energy-related GHG emissions need to be fully investigated for establishing model practices for Chinese cities.

1.2. Literature review

An increasing amount of literature has paid attention to the exploration of low-carbon development pathways and potential abatement strategies. One research stream focuses on tracing the intrinsic relationships between energy-related GHG emissions and their contributors. These previous studies include the Stochastic Impact by Regression on Population, Affluence, and Technology (STIRPAT) method (Wang et al., 2013), the Logarithmic Mean Divisia Index (LMDI) method (Cansino et al., 2015), the Impact = Population·Affluence·Technology (IPAT) method (Dietz and Rosa, 1997), the Kaya Index method (Mavromatidis et al., 2016), the input-output structural decomposition analysis (IO-SDA) method (Chen et al., 2016; Wei et al., 2016), etc. These methods attempt to seek solutions for decoupling economic growth and energy intensity, and explore the optimal means of reducing GHG emissions. However, a simple GHG emissions index conveys limited information of sectoral disparities and techno-economic connection on GHG emissions. Most studies have only analyzed the emissions driving forces at the national level; few studies have focused on city-level emissions (Kang et al., 2016; Yu et al., 2015).

The other research stream employs comprehensive energy-economic models (e.g., top-down, bottom-up and hybrid types) in quantifying the sectoral or regional energy-related GHG emissions, and simulating future dynamics. The top-down models, e.g., The Computable General Equilibrium (CGE) model (Naqvi and Peter, 1996), examines the relationships among energy activities and economic indices on a macro level, which does not depict technological details of energy production and consumption (Wen et al., 2014). The typical bottom-up models, e.g., the market allocation (MARKAL) model (Kannan, 2011), the model for evaluating regional and global effects of GHG reduction policies (MERGE) (Manne et al., 1995), the systems-engineering optimization MESSAGE model (Messner and Schrattenholzer, 2000), the computable general equilibrium and market allocation (CGE-MARKAL) model (Schäfer and Jacoby, 2006), the Long-range Energy Alternatives Planning system (LEAP) (Lin et al., 2010), and Asian-Pacific Integrated Model (AIM) (Wen et al., 2014), can describe production-related technologies and predict future trends by way of energy consumption and production. These models and their combination enable a macro evaluation of energy use-induced environmental effects.

Overall, evaluating energy-driven GHG emissions using systematic models is becoming the preferred method. However, some methods cannot be applied for the development of city-scale carbon emissions benchmarks and mitigation strategies with timelines and inventories. Recent years have shown that the LEAP model is widely adopted to extract energy policies at the city, national, and global scale (Emodi et al., 2017). The LEAP model was used to explore the energy, environmental and economic influences of consumption activities in the electricity sector (Özer et al., 2013; McPherson and Karney, 2014), transportation sector (Sadri et al., 2014; Shabbir and Ahmad, 2010), the iron and steel sector (Ates, 2015), energy sector (Huang et al., 2011) and policy interventions (Phdungsilp, 2010). Compared to top-down and other hybrid models, the bottom-up LEAP model has a flexible data structure which is not only easy to use, but also rich in technical and end-user details (Emodi et al., 2017). It can deliver energy scenario-based GHG emissions accounting combined with a set of carbon-reduction policies. However, the existing literature delivers very limited analysis of reducing GHG emissions and updating energy use structures for addressing the gap of low-carbon city targets, and facing Chinese cities seeking suitable low-carbon pathways.