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Carbon flow of urban system and its policy implications: The case of Nanjing

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ABSTRACT

China is now in the process of rapid urbanization. City's operating efficiency was directly determined by the scale and efficiency of energy consumption and flow. The pattern, scale and efficiency of urban carbon flow are not only important indicators that reflect urban efficiency and sustainable development, but also important references in the formulating low-carbon and sustainable energy polices for cities. Through establishing a theoretical framework and calculation method, this paper studied the carbon flows of Nanjing urban system in three different levels. It shows that urban production and transportation system, urban living system, rural production system and rural living systems are the major part of urban system in the carbon flow. The carbon flows between Nanjing and the external system, was much higher than the carbon flows among different internal subsystems. If the embodied carbon is taken into account, carbon flow from the urban to rural system of Nanjing was clearly greater than the flow in the opposite direction. With economic development and the implement of energy-saving and emission reduction policy, the carbon productivity and carbon flow efficiency in Nanjing has improved significantly since 2000. Fossil energy consumption, urbanization, agricultural activities, rural life demands and trade are key factors with major impact on urban carbon flows in Nanjing. Therefore, adjusting industrial structure, urban expansion control, and developing renewable energy are main measures to realize sustainable development of Najing city. Furthermore, the dual urban–rural structure in Nanjing brought large exchanges of products and embodied carbon between urban and rural areas, indicates that urban carbon flow and its efficiency was highly influenced by urban–rural structure, which will further aggravate carbon flow burden of urban systems.

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1. Introduction

Cities are the areas most profoundly influenced by human activity, for they are where human energy activity and carbon emissions concentrate. Arguably more than 80% of carbon emissions originate from urban areas [1], which occupy less than 2.4% of land mass globally [2]. As very open social-economic systems, there is huge carbon flows and exchange in urban systems as well as between those systems and the external system. Thus, the carbon cycle and circulation process of urban systems inevitably affect the regional and even global carbon cycle. Therefore, the study on urban carbon flow and its efficiency is very meaningful for comprehensively assessing the city's role in the regional carbon cycle, for establishing low-carbon urban energy and industrial strategies, and for raising energy efficiency of the urban system.

Urban carbon cycle simulation requires observations of both natural and anthropogenic carbon processes in urban system, as well as their interactions [1]. Since 2000, there appeared case studies on simulating carbon fluxes through the vegetation-soil component of an urban system [3–7]. In recent years, researchers have begun simulating social components of the carbon cycle in urban systems, such as studies on carbon effect of urbanization and land use [8–10], urban carbon budget [11,12], population, energy consumption and carbon emissions [13–16] and urban carbon flows [17,18]. Carbon cycle and carbon flows were simulated on different spatial scales: national [19], regional [20] or neighborhood level [21], which showed that the socio-ecological processes will highly impact the regional carbon budget [20]. The above studies greatly contribute to the modelling of carbon flow simulation in urban system. But the inner carbon flows among different urban sub-systems should be further studied, which is very important for the detailed designing of sustainable energy policies and city planning strategies.

Furthermore, there have been recent researches on urban metabolism simulation [17,22,23], which mainly focused on urban food carbon flow and metabolism [24,25], energy circulations [26] and carbon flux simulation [23,27]. Although metabolism method has been applied for metals, nutrients, and many other substances on various scales for decades, the systematic simulation of carbon flows by metabolism method on city or regional level just appeared in 2012 [20,23,27]. Generally, these studies of urban metabolism were mostly aimed at certain aspects of urban carbon processes. The direct and embodied carbon flows between urban and rural system and among different sub-systems were not fully discussed. It is quite different on individual carbon consuming habit, industrial and production structure and carbon flow characteristics between urban and rural systems. To explore effective strategies for urban energy and carbon management, systematic study of carbon flows in urban system should be strengthened. China is currently in a rapid urbanization process. The rapid economic growth led to more and more energy consumption [28]. China's urban areas contribute 75% of total primary energy demand, 85% of commercial primary energy demand, and 85% of the energy-related CO_2 emissions [29]. The intensity, scale and influences of urban carbon flows are increasing. But the systematic urban carbon flow study has not yet been appeared so far in China. Therefore, research on urban carbon flows and its efficiency not only helps to understand the mechanism of carbon processes, but also will be of great significance in the formulation of low-carbon energy policies for urban carbon management and carbon emission reduction in Chinese cities.

Nanjing, a rapidly developing city in eastern China, has a heavy chemical industry, so traditional energy consumption and the corresponding carbon emissions in Nanjing will increase rapidly. With rapid economic growth and urban expansion and high environmental pressure, Nanjing is representative of developing cities in China. Therefore, we selected Nanjing as a case study. Through carbon flow mechanism analysis and calculation method, we established a carbon flow map among different subsystems of Nanjing urban system, and evaluated carbon flow details and efficiency in Nanjing. This research can provide theoretical and practical guidance for urban energy management and low-carbon energy policies in different sectors of Nanjing city, and will helps to find a feasible way of sustainable development and emission reduction for Cities in China.

2. Carbon flow mechanism of the urban system

2.1. Definition of carbon flow in urban systems

The urban system is huge and complex, and includes natural, economic and social processes. Inside that system, and between the internal and external system, carbon in organic or inorganic form is continuously produced, decomposed, emitted, sequestered, transformed, circulated, input and output, which is called “urban carbon cycle”. The urban carbon cycle process is a “natural–social dualistic carbon cycle”, which includes carbon processes of natural ecosystems (such as carbon absorption by photosynthesis and carbon emission through respiration of vegetation or soils) and also carbon metabolism, input and output processes caused by human activities within urban social–economic systems (such as