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Ecological and economic analyses of the forest metabolism system: A case study of Guangdong Province, China

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ABSTRACT

Integrating forest resources into the socio-economic system correctly and reasonably is of vital importance to tackle the increasingly scarce forest resources. In this paper, forest resource input-output model and forest resource metabolism network model are established to provide new insights into the relationships among the systems, industries and sectors related to forest resources. A promising indicator named exploitation index is developed to reveal the weaker sectors in the ecological relations, which will further help to provide better corrective actions and integrated strategic measures. Guangdong is taken as an example to verify the availability of the model and solve the problem. The results show that the primary manufacturing consumes more direct timber, while advanced manufacturing and the service sector utilize timber indirectly. In addition, Guangdong forest metabolism system shows a negative correlation and the whole network does not achieve the mutualism state, leading to competition relationships between pairwise sectors that should not appear, such as Forestry sector and Papermaking and Paper Products sector. These results provide the corresponding reference for helping the decision makers to allocate forest resources and coordinate ecological and economic development.

1. Introduction

The forests act as a key role in the terrestrial ecosystem, which is important for ecology, economy and social development. Like energy, water and other ecological elements, forest resource is an important "nutrient element" for the urban sustainable development. In the natural ecological system, forests form a canopy cover and protect constituent species with their habitats. When flow into the urban ecological system, forests provide raw materials and products for some production sectors, promoting industrial development in the entire socio-economic system. To maximize the "nutrition" effect of forests, it is essential to understand and optimize the flow and utilization of forest resources in the complex urban ecological system.

Researchers have done a lot of research work in the field of forest resources and economy. Chen et al. (2015a,b) examined the current state of forest resource utilization in China from the angle of combining quantities and values based on input–output tables. Suh (2014) used input-output analysis technique to compare forest management programs in India and Philippines. Mattila et al. (2011) made use of an environmentally extended input-output analysis to quantify the overall vessel impact of forest industries in the Finnish economy in 2005. Liang et al. (2016) investigated how the consumption of nations drives Russian timber harvest. Through structural path analysis, individual supply chain paths were delineated to show linkages between Russian timber harvest and the final consumption of nations. Schaubroeck et al. (2012) took the forest economy as a case to quantify the total environmental impact of resource extraction and emissions during a product's life cycle. Shakur and Haque (2012). employed the input-output analysis of Bangladesh forestry to determine the depletion and degradation impact from forestry activities on GDP. Yang et al. (2016) measured the TFP of 135 key state-owned forestry enterprises in the northeast, southwest, and northwest regions of China in 2001–2011 through Malmquist-data envelopment analysis. On account of ecosystem coupling, Dong et al. (2013) inspected the extent of coupling between systems of forest ecology and forestry industry, and the economic benefit of the forestry industry was evaluated. Plch et al. (2015, 2016) applied the Life Cycle Assessment (LCA) to research the effect of the different Types of Felling on Carbon and Economic Balances. Jia et al. (2015) investigated the forest cover changes in the TNSFR during 1990–2005 based on a land cover dataset developed by the Chinese Academy of Science using remote sensing data and analyzed its relationship with meteorological change trends.

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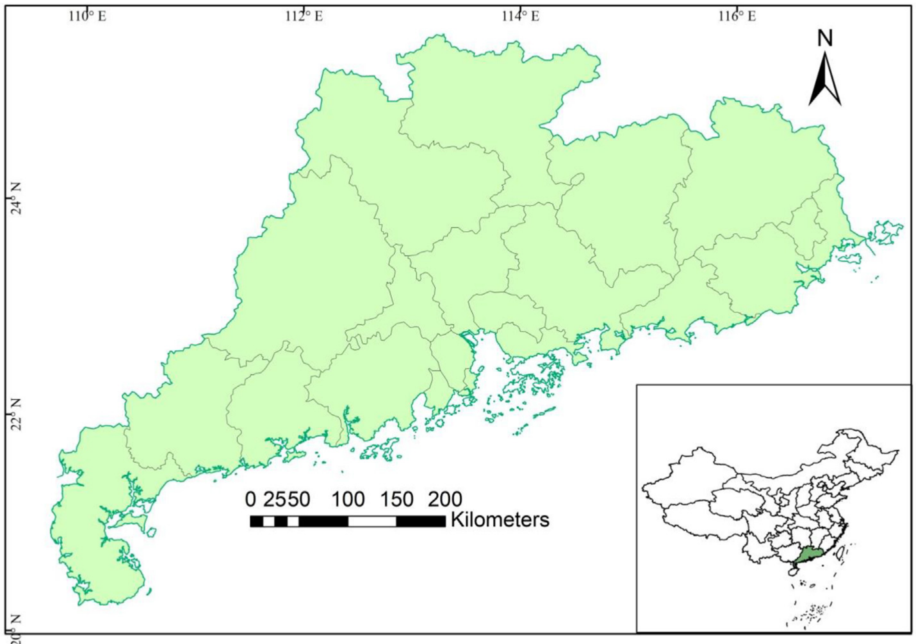

Fig. 1. The location and region of Guangdong province.

In the urban metabolism system, energy (Cai et al., 2009) and water (Li and Huang, 2009) are other two important "nutrient element". There are many previous studies that focused on energy systems planning (Huang and Cao, 2011) and water resources allocation and management (Li et al., 2009). Most of the previous studies adopted linear optimization model that considered the entire system as a whole, while neglected the internal interactive flows among various sectors (Zulueta et al., 2017; Liu et al., 2018). The environmental input-output analysis combined material flows with Input-output analysis (IOA) to better reflect the ecological elements flows in the urban metabolism system (Leontief, 1936, 1970). Now this model is widely used in international and interregional flows of products and services, accounting for energy consumption, and environmental pollution associated with inter-industry activities (Miller and Blair, 2009). In view of the computational framework of Leontief, Hannon (1973) founded the ecological network analysis (ENA). ENA aims to quantify the specific embodied ecological elements that are regulated by the activities within the regional's boundary (Chen S and Chen B, 2015). After the amelioration of Finn (1976, 1979), Patten (1982), Suh (2005) and other scholars, ENA has been widely applied to the study of natural ecosystems (Christian et al., 2009; Zhai et al., 2018) and socio-economic systems (Zhang Y et al., 2012, 2013).

IOA and ENA provide information about the flow characteristics of ecological elements from different aspects, which will facilitate the analysis of the "nutrition" effect of ecological elements in urban metabolism system. Dai et al. (2014) presented an extended exergy (EE) accounting to foster an in-depth understanding of the conflict between high-speed development and the available resources in China. Li et al. (2015) studied mercury emissions from fossil energy consumption in Beijing based on environmentally extended input-output analysis to control mercury emissions through the preparation of urban mercury emission inventory. Acquaye et al. (2017) estimated the ecological elements such as sulfur dioxide through the establishment of a multi-regional input-output (MRIO) modeling framework in specific countries as well as part of the Global Value Chain. Singh and Bakshi (2013) incorporated the biogeochemical cycle of nitrogen into the 2002 input-output model of the U.S. economy. Chen. Z M and Chen G Q (2013) analyzed the global virtual water economy and trade on account of the multi-regional input-output model, as well as brought to light the virtual trade relationship of the major trading partners. Chen. S and Chen. B (2012) assessed the interaction and control of urban ecosystems in Vienna and evaluated the systematic nature of urban carbon metabolism based on network environment analysis (NEA). Chen Z M and Chen G Q (2011) calculated and compared the embodied carbon dioxide emission intensity of G7, BRIC, and the rest of the world (ROW) and flexible abatement policies as well as equity on per capita entitlement were discussed. Zhang et al. (2014a,b) figured out the contribution of CH_4 emissions to different regions of China according to multi-regional input-output analysis.

However, some previous studies focused on the economic impact of forest resources on the forestry sector, while the impacts on other sectors were ignored. There are some studies that took the forest resources inputs of all industrial sectors into consideration, while the unidirectional analysis did not reflect the interactive flows among various sectors. In addition, the former study area is too large and the situations in different regions vary significantly. Thus, the previous research results cannot provide scientific basis to support the policy-making in other regions. Therefore, a systemic model for analyzing the metabolic among industrial sectors to detect the "disease area" in forest metabolism system is desired.

In this study, the Input-Output Model of forest resources and Forest resource metabolism network model will be conducted to implement multilevel analysis of timber resources by combining IOA and ENA. Guangdong, China is chosen as a case study to illustrate the applicability of the models. In detail, input-output analysis will be conducted to maximize the input and output benefits of timber. Analysis of industrial structure of timber metabolic in ecological network can stabilize the industrial structure. Study of ecological relationship between sectors can reveal the weakness sector and develop appropriate measures to increase the ratio of mutualism in the vulnerable sectors. Based on the analysis, the relationships among the system, industries and sectors about the forest resources are discussed in order to provide scientific basis for helping rational allocate timber resources, optimize the industrial structure and improve mutualism relationship among sectors.