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Water-energy control relationship in socio-economic system

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Abstract

The water and energy are two essential and fundamental supporting resources for urban rapid development, and the interaction between these two resources are complex. This research uses the concepts of virtual water and embodied energy to interpret the water and energy flow networks in socio-economic system. Ecological network analysis is used to manifest the relationships between energy and water resources in socio-economic network with a case study of Beijing. The results show that the embodied energy flows show stronger control influence in the socio-economic system than the one of virtual water flows. Among 30 economic sectors, only 6 sectors, mainly primary and secondary industrial sectors, have virtual water dominated control influences, while the rest of sectors have embodied energy dominated control influences.

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Keywords: Water-energy nexus, urban socio-economic network, ecological network, control analysis

1. Introduction

The urban rapid development needs resources inputs to provide fundamental motivation, especially water and energy resources. The water is important for energy production, for example cooling water for electricity generation, while energy is vital for water resources utilization, including pumping, distribution, irrigation and purification treatment. Therefore, several researches focus on water-energy nexus issue from concrete technological process perspective, such as electricity generation [1, 2] and water treatment process [3, 4]. Although these researches explore the interaction between water and energy resources by tracing the detail flow pathway, the water-energy nexus issue in socio-economic system is hard to detect using the tradition methods[5].

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The concepts of virtual water and embodied energy, which stand for the resources consumption during the production process, provide important concepts to explore the water and energy resources transaction in a socio-economic system [6, 7]. The researches about the virtual water or embodied energy in the socio-economic network have be manifested via systematic methods, such as input-output analysis and ecological network analysis [8, 9]. However, the interaction between virtual water and embodied energy in socio-economic network still needs further exploration.

Ecological network analysis (ENA), which is initially used for ecological food webs, has been successfully introduced in socio-economic issues to manifest the network structure and function from integrated perspective covering both direct and indirect influences [10]. One of the merits for ENA is that it can observe the control and dependence relationships between pairwise sectors and detect the nodes or pathways with strong control property. This research try to modify the tradition control analysis of ENA to explore the control relations between two kinds of material flows in the network.

Nomenclature

Abbreviation

ENA	Ecological Network Analysis
VWN	Virtual Water Network
EEN	Embodied Energy Network
NCA	Network Control Analysis

Symbols

T_i	Total throughflow of sector i
f_{ij}	Flows from sectors j to sector i
y_i	Boundary outputs
z_i	Boundary inputs
G	Direct flow intensity matrix
N	Integral flow intensity matrix
η_{ij}	Respective fractional transfer coefficient
cd_{ij}	Control difference
sc_j	System control vector

Subscript

i, j	Economic sector

2. MATERIAL AND METHODS

2.1. Ecological network analysis (ENA)

The virtual water network (VWN) and the embodied energy network (EEN) are established based on the traditional economic input-output model framework via incorporating with statistical data about water and energy consumption of each sectors. The VWN and EEN reflect the virtual water and embodied energy trade hidden in the production processing in the socio-economic system. Both the VWN and EEN are steady-state systems, i.e., total inputs equal to total outputs:

$$T_j = \sum_{i=1}^{n} f_{ij} + y_j = \sum_{i=1}^{n} f_{ij} + z_j \tag{1}$$

The direct flow intensity (g_{ij}) is a measure of the flow normalized by the total throughflow: