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Emergy-based comparative analysis of urban metabolic efficiency and sustainability in the case of big and data scarce medium-sized cities: A case study for Jing-Jin-Ji region (China)

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ABSTRACT

Emergy-based Urban Sustainability Assessment Framework (EmUSAF) is an effective and widely advocated method to evaluate the general condition at city-scale. However, applying this framework to medium-sized cities has encountered obstacles owing to the data scarcity and inconsistency problem. One the one hand, a range of data such as detailed import-export goods data are only compiled at provincial level therefore for prefectural cities the lack of data is very common. On the other hand, the original environmental data provided by local government is usually not uniform and well-formatted, meaning that the data inventory disclosed by the environmental data compilation administration in different cities are not identical, leading to the difficulty of comparison. Meanwhile, for a given year, not all elements needed in the emergy synthesis inventory are available due to the difference compilation and disclosure timelines of different statistics reports. These facts hinder both city-specific research at local scale and regional research. To address this lingering issue, we developed a methodology for deriving substitute data from extant available data of upper-level administration division and for integrating them into the EUSAF. With a case study on Jing-Jin-Ji region, covering 11 medium-sized prefecture cities, we conducted an emergy analysis of the whole region and examined the methodology discussing its uncertainties and limitations.

This study contributes to emergy synthesis in four aspects: (1) Provide a solution to the enduring data scarcity and inconsistency problem of emergy-based urban sustainability assessment; (2) Establish the deduction method which can deduce data at larger scale to smaller scale when lacking physical data at smaller scale instead of using monetary estimates, and also the accuracy of the deduced data can be identified by using uncertainty analysis; (3) Investigate the strategically essential Jing-Jin-Ji region as a case, applying the new approach to get the data for prefectural cities and carrying out an emergy analysis. We found that the indicators, reflecting the specific development traits of each city, are well confirmed by the status quo in the region. This fact proves that our new method framework is affordable and could be extended in the future study of medium-sized cities suffering from data scarcity. (4) Demonstrate the significant gap between using money value and physical amount to calculate emergy of imported goods, proving the importance of physical amount data in the Emergy-based comparative analysis of urban metabolic efficiency and sustainability.

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Nomenclature

EBS	Energy Balance Sheet
ELR	Environmental Load Ratio
emergy/$	Emergy Money Ratio
EP	Emergy Used Per Capita
ESI	Environmental Sustainability Index
F	Imported Fuels
G	Imported Goods
GACPRC	General Administration of Customs of the People Republic of China
GDP	Gross Domestic Product
GIS	Geographic Information System
HS	Harmonised System
IEGT	Import-Export Goods Table
IOAS	Input and Output Accounting System
IOSs	Input-Output sheets
Jing-Jin-Ji	Metropolitan Region or Jing-Jin-Ji (JJJ) Beijing-Tianjin-Hebei
MPI	Money Paid for Imports N Local Non-renewable Resource
NBSC	National Bureau of Statistics of China
NEAD	National Environmental Accounting Database
NEAS	National Economy Accounting System
PR	Population Report
R	Local Renewable Resource
SF	Service Flow
TF	Tourism Flow
TR	Total Receipt
U	The Total Emergy Used
UEVs	Unit Emergy Values
WRR	Water Resource Report

1. Introduction

The ability of statistical authorities to organize environmental and social economic surveys at urban level is the key to providing reliable and stable estimates of the urban metabolic efficiency and sustainability in China and elsewhere in the world. Obviously, it is not an easy task in the case of such a huge and economically diverse country as China. However, without establishing a reliable country-wide monitoring system, it does not make sense to calculate any urban measures of sustainability. China still has a long way to go in building a data collection system, ensuring quality and data consistency and constructing relatively long time-series of environmental and social economic data for big and middle size cities. So far, the developments in official statistics can be summarized as a mix of good intentions with slow-paced improvements and a lack of transparency (Plekhanov, 2016).

The "fog" surrounding official statistics has started to disperse recently, albeit rather slowly. Recently, the 19th conference of Chinese Communist Party, held in Beijing in October 2017, gave high priority to *Ecological Civilization*, *i.e.* the sustainable interaction between economy and ecosystem. This topic showed that the central government is now paying more attention to environmental and social economic stability issues. Sustainability as a policy concept is about solving the tension between the aspirations of mankind towards a better life and the limitations imposed by nature (Kulman and Farrington, 2010). Effective and comprehensive environmental management over the country is crucial in the pursuit of *Ecological Civilization*. Consequently, monitoring developments in related areas are getting more important than ever. To achieve this goal, an institution for management and supervision of natural resources and ecosystem is going to be established. Based on the available data of the whole nation, this institution should be able to plan and implement policies from a comprehensive perspective, thereby boosting the overall environmental management efficiency. Apart from the optimization of the data-based official management process, integration of some cutting-edge technology can also contribute to the realization of sustainability. For example, Amini et al. (2018) introduced smart cities as a prominent example of sustainable interdependent networks that could collaborate together to achieve sustainability in terms of upgrading the infrastructures to more intelligent and efficient systems. Mohammadi et al. (2018) presented a decentralized decision-making algorithm for collaborative operation of electricity transmission system operators (TSOs) and distribution system operators (DSOs) optimal power flow (OPF) implementation that could improve the economy and reliability of the entire power system.

However, analysis of government data has always posed a challenge for China urban watchers. The existing key problem lies in the process of acquiring correct and detailed urban data. Due to the limitation of current statistics compilation system, data scarcity and inconsistency is common for medium-sized or small-size cities, which hinders urban ecosystem research. The administrative division of China consists of five levels: provincial; prefecture; county; township; village. Until 2017, national statistics were collected from each division and compiled at different administrative scales. International trade statistics, provided by the General Administration of Customs of the People Republic of China (GACPRC), are collected by each province and for several important port cities, such as Dalian and Qingdao. Comprehensive information is recorded from a provincial perspective, while, at prefecture level, public import and export data are usually given as total amounts in yearbooks. The Energy Balance Sheet (EBS), compiled at the provincial level, reflects the condition of energy production, sale, storage and consumption, incorporating the primary data collected by each department. Corresponding management departments or industry associations are in charge of energy and electricity consumptions accounting of four transportation sectors (i.e.: railway, airway, roadway and water way). Among other included items, manufacturing, wholesale and retail industries are assigned to the provincial affiliation of National Bureau of Statistics of China (NBSC). The provincial-level EBSs are published monthly and annually through provincial statistics report, China Energy Statistics Annual Report and also via the official website of NBSC. National Economy Accounting System (NEAS) defines the Input and Output Accounting System (IOAS), which also includes Gross Domestic Production (GDP) accounting. Unlike EBS, other reports are compiled every five years and published two years later than the accounted year. Every basic input and output sheet is compiled in 2nd and 7th year of each decade, while the extended sheet is compiled in 0th and 5th year of each decade (which results in the inconsistency of the statistics). IOAS reports three kinds of sheet: the input and output sheet; the supply sheet; the utilization sheet. Specifically, the input and output sheet displays the input resources and the output destinations in a matrix form, illustrating the flows of resources among different economic sectors and revealing how they interact each other.

Urban general information statistics accounting system is applied in China only for higher-level cities. It covers a wide range of socio-economic aspects. In particular, they include: the administrative division, land area, water resources; population and labor