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Urban water-energy nexus: a review on the perspective of accounting and methodologies

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ABSTRACT

Urban water-energy nexus is regarded to be highly important for the sustainable development of cities and the effective management of resources. Research methods on urban water-energy nexus are emerging, and a summary of these methods can help to determine the appropriate tool to manage urban water and energy. The accounting of energy and water in existing nexus research is not consistent, so the results and evaluation are also different. From supply to end-use, account the water and energy consumed in each stage, and the factors that affect the consumption of both in each process are analyzed. Review the latest development of research methods and models in urban water-energy nexus, and propose their advantages and limitations. For systematic models, the determination of parameters and the upgradation are still a huge challenge. In the future, more attention should be paid to the coupling and combination of various methods to understand urban water-energy nexus from a multi-scale perspective. In addition, future research directions should also pay more attention to the internal mechanisms and driving factors of urban water- energy nexus, and how to deal with the nexus under climate change, the interaction with other resources such as food, and the change of urban water and energy under policy control.

Keywords: urban water and energy, nexus, accounting, methods and models

NONMENCLATURE

Abbreviations	
IOA	*Input-output analysis*
ENA	*Ecological network analysis*
LCA	*Life cycle assessment*
ANN	*Artificial neural network*
SD	*System dynamics models*
DMM	*Dynamic metabolism model*

1. INTRODUCTION

In almost all forms of energy extraction, treatment ,and conversion, a large amount of water are directly and indirectly required, and a large amount of energy is also consumed in the production, distribution, and treatment of water. The water industry can benefit from universal energy access. If energy development does not consider water demand and water pollution, energy access will have a negative impact on water resources and limit the water security of other industries. Similarly, water shortage also threaten the feasibility of long-term energy projects. This complex interdependence makes energy and water a complex system. If the water-energy nexus is considered in the decision of a water conservancy project, significant energy savings and higher energy efficiency can be achieved (Shrestha E, et al., 2012). Therefore, the coupling of water and energy is essential for establishing a resilient and sustainable energy system and water resource system.

The high degree of openness and complexity of the city and the spatial coupling between the city and the region make the city a key hub that affects the safety of resources and the environment. Urban areas account for 75% of global energy consumption (UNDESA,2018). World energy consumption rises by nearly 50% between 2018 and 2050 (IEA2019). Urban is the main carrier where matter and energy flows. The supplies and demands of water and energy resources in the urban are more complex than those in the countryside. Globally, more people live in urban areas than in rural areas, with 55 % of the world's population residing in urban areas in 2018. In 1950, 30 % of the world's population was urban, and by 2050, 68 % of the world's population is projected to be urban(UN,2018). With the increase of urbanization process, the water-energy nexus of urban system has attracted more and more attention over the world recently(Ding et al.,2020).

At present, there are many studies on the urban water-energy nexus, and the accounting of the energy demanded for water and the water required for energy are different in each study. Therefore, the research results of the urban water-energy nexus and the final evaluation of this nexus will be different. At the same time, research methods and models for the urban water-energy nexus are emerging. Understanding the research progress of these existing methods and models is helpful to clarify their advantages and disadvantages, and then find out the focus and direction of further improvement. This paper attempts to summarize the urban water-energy nexus from the perspective of accounting and methodologies. It has four main parts: 1) summary of the research on urban water-energy nexus; accounting the water and energy in the city from the aspects of the energy required for water and the water required for energy; 3) reviews of urban water-energy nexus research methods and models; 4)suggestions for the future research direction of urban water-energy nexus. Finally, the conclusions were drawn.

2. CLASSIFICATION OF URBAN WATER-ENERGY NEXUS RESEARCH

At present, the research on urban water-energy nexus is divided into two categories(Fig1). The first category is the study from the perspective of the macro scale, that is, the whole city as a whole, calculating the energy required by the city during the entire water cycle and the water required for energy.

The other category is the micro scale of urban water-energy nexus studies, including research on part of the water cycle,sector, facility, and technology. Research on one part of the water cycle has focused on water supply and consumption. Facility nexus research focuses on the energy and water consumption of specific facilities, such as urban residential buildings (Wanjiru E& Xia X. 2017). Sector nexus research is more common in the industrial and economic sectors(Lu Y & Chen B. 2016; Ding T, 2020;Fang D,et al.,2017). Technology nexus research is an analysis of the water use of different energy-saving technologies and the energy consumption of water-saving technologies (Wang CY, et al., 2017; Erik Porse, et al, 2020; Aymerich I, et al., 2015).

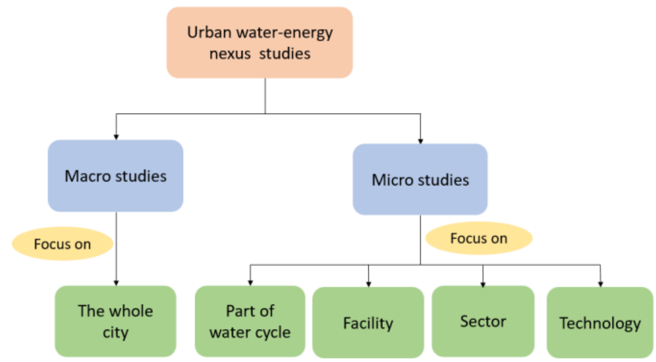

Fig 1 The classification of urban water-energy nexus studies based on research scale.

3. WATER AND ENERGY ACCOUNTING

3.1 Energy for water

Based on the water supply, distribution, end-use, heating and cooling, and wastewater treatment stages in the water system, analyze the energy required for the construction, operation, and maintenance stages (Table 1).

3.2 Water for energy

The water required for energy includes direct water and indirect water. Direct water refers to the water directly used for energy production, and indirect water refers to the water required to produce energy products (Okadera et al., 2015). The common method for calculating the water for energy is energy production multiplied by the water use coefficient of each energy technology (Spang et al., 2014). Every stage of the energy supply chain requires water (Ansorge L, Zeman M, 2016; Tidwell V, Moreland B, 2016). For example, energy production and power generation require large amounts of water. To accurately obtain the total water consumption for the city's energy supply requires an extensive and in-depth analysis of the energy supply chain and data on water use in all parts of the chain(Table 1).

Table 1 Accounting of energy for water and water for energy.

	Stage	Process	Influence factor
Energy for water	Water supply	● Water Supply&conveyance ● Water treatment/ purification	● Types of water supply sources ● Water treatment technology
	Water distribution	● Water distribution	● Transportation distance ● Topology ● Topography and landform
	Water end-use	● Residential end-use ● Non-residential end-use	● Utility type ● Appliance efficiency ● Water use behavior ● Water use sector
	Wastewater treatment	● Wastewater collection ● Wastewater treatment ● Recycled water treatment	● Region ● Treatment process ● Standards after wastewater treatment
Water for energy	Water withdrawal	● Extraction ● Processing ● Conversion	● Fuel type ● Cooling technology
	Water consumption	● Evapotranspiration ● Degradation	● Usage ● Water-saving awareness
	Water discharge	Water discharge	● Discharge system ● Discharge standard

4. METHODS AND MODELS

The study of the urban water-energy nexus was originally the flow and change of two resources. With the global attention for water and energy security, research has gradually expanded to the internal interaction between water and energy in cities and the environmental impact of their nexus (Babkir A, 2018). Research methods are continuously improved, such as input-output analysis, life cycle assessment, and ecological network analysis. More complex system models are used in the study of urban water-energy nexus (Table 2).

5. FUTURE DIRECTIONS

The future research focus of urban water-energy nexus should be innovative integration of methods and models, analysis of internal mechanisms, joint analysis with other resources, and formulation of corresponding policies(Fig2).

6. CONCLUSIONS

Both water and energy are important resources. Studying the water-energy nexus is of great significance for the sustainable development of both resources. With the development of global urbanization, cities have become the main carrier of human activities. The urban water-energy nexus has attracted more and more attention. Research on the urban water-energy nexus

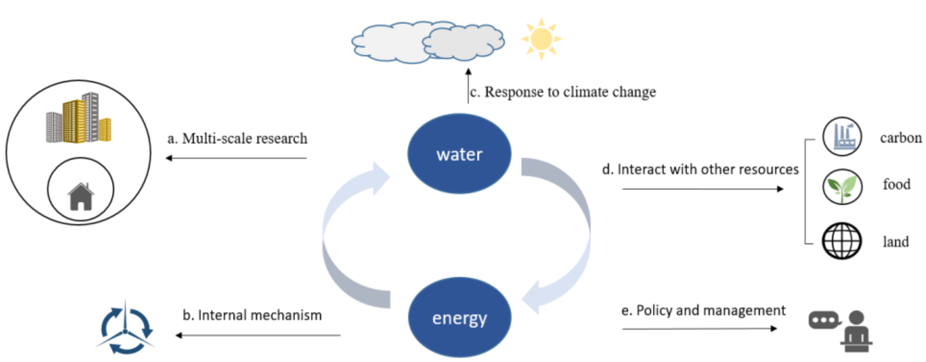

Fig 2 Future urban water-energy nexus research directions.

includes macro and micro research. In the study of the macro urban water-energy nexus, there are more studies based on urban metabolism. This is an important step towards practical urban sustainability. The research on the water supply side is relatively extensive concerning urban water-energy nexus.

Among the different research scales, the research scale for analyzing the nexus from the perspective of centralized and decentralized systems needs to be expanded. The accounting of the water required for energy and the energy required for water has been involved in many studies, but the content is not completely consistent. From supply to consumption, the water and energy consumption of each stage is accounted for, and the reasons for the differences in each stage are different. Understanding the source of

Table 2 Comparison of the main urban water-energy nexus methods and models.

Method		Advantage	Limitation	Reference
Input-output analysis(IOA)		It can be applied to reveal the relationships between water and energy at different scales and sectors.	It relies on regional input-output tables.	Duan CC and Chen B,2017; Tang et al., 2016; Sun et al., 2017;Liu et al., 2017; Zhang F, et al, 2018
Ecological network analysis(ENA)		Through the simulation of water and energy among components, the system structure and function can be analyzed.	The network structure and the division of sectors require additional analysis. In addition, such analyses require large quantities of data.	Dai J, et al, 2018; Zhang Y, et al, 2017; Zheng SS , et al, 2016; Xia LL, et al, 2018; He C,et al.,2020
Life cycle assessment(LCA)		It can be used to evaluate the environmental impact of water and energy activities.	Large amounts of data are required, so it is difficult o apply in data-scarce regions.In addition,it can not predict future trends.	Lundie et al., 2004; Lam KL., et al, 2017; Stang S, et al, 2018; Salmoral G, et al.,2018; Hellweg S, et al.,2014
Optimization model	Graph theory-based approach	Able to identify and remove excess water and energy consumption in the nexus which is critical for designing an effective system.	The economics of retrofitting a nexus is not take into account.	Tsolas SD. et al.,2018
	Artificial neural network(ANN)	Forecast the future trend of water and energy consumption.	Tend to overfitting and mislead the final judgment.	Yin Z,et al,2018; Song J.,et al.,2020
	Driving force-Pressure-State-Impact-Response model(DPSIR)	It can study urban water-energy nexus and its impact on aquatic ecology and human systems.	The reliability of data and indicators in the model is a huge challenge for some regions.	Gabriela da Costa Silva，2013；Jago-On, KA,et al.,2009
	System dynamics models(SD)	Capture dynamic changes and feedback related to urban water and energy from a system perspective.	Political policies and social factors are difficult to be structured in the model.	Zhou et al., 2013;Chhipi-Shrestha G,et al.,2017
	Dynamic metabolism model(DMM)	Analyze the metabolic flow of water and energy and environmental impact from a holistic systemic perspective.	The accuracy and general suitability need to be improved.	Venkatesh et al., 2014; G Venkatesh a ,et al.,2014
	the Long-range Energy Alternatives Planning System and Water Evaluation and Planning tools(LEAP-WEAP)	It has powerful computing capabilities and flexible the framework which can be adjusted according to the data.	There are currently few applications on the city scale.	Khan et al., 2017; Lin et al., 2018; Lin J.,et al.,2019

these differences can improve resource utilization efficiency. The research methods of urban water-energy relations are constantly improving, especially various models that have been tried to be developed and applied. Each method and model has its advantages and limitations, and the appropriate method can be selected according to the purpose and focus of the research on the nexus between urban water and energy. For systematic models, the determination of parameters and the further upgrading and optimization of the models are still a big challenge.

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