Energy Water Nexus and Its Implications in Urban Sectors

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Abstract
Rapid industrial development and urbanization have raised serious concerns. Energy and water resources both are considered main factors influencing sustainable urban growth and hence resource accounting and tracing are drawing increase attention. In the current study, we proposed an energy-water nexus accounting framework for Shanghai (referred to year 2010) based on environmentally extended multi-regional input output (EE-MRIO) analysis. The energy and water flows were traced from source to destination from a production-based and consumption-based perspective. Electricity, Others and Transport are the largest sectors which consumes about 89.40% of production based energy flows whereas Electricity, Services and Construction consumes about 79.16% of consumption-based energy flows of the total flow. In the case of water, Electricity, Agriculture and Construction are the largest sectors and consumes about 96.62% of production based water flows whereas Electricity, Construction and Services consumes about 78.78% of consumption based water flows of the total flow. Urban sectoral energy water nexus can offer discrete ways to tackle growing environmental challenges. This research can present a reference to decision makers in identifying specific sectors that requires policy interventions in easing environmental stress to accomplish sustainability and balance the tradeoff. Additionally, collaboration and regulation of urban industrial structure is needed.

Keywords: MRIO, nexus, production, consumption

1. Introduction
Urban centers contribute to more than 60% of energy consumption worldwide and 75% of pollutant releases (IEA, 2012; Seto et al., 2014). China is undergoing serious urban development with a growth rate of about 52.57% since 2012 (Yang et al., 2018; Guan et al., 2018). This rapid shift is raising alarms due to growing demand for energy and water as both are main indicators to sustainable urban development (Cai et al., 2018). Thus mega cities, particularly the four municipalities in China (i.e. Beijing, Tianjin, Shanghai and Chongqing) are consuming huge amount of energy and water resources together with pollutant emissions and hence experiencing grave environmental pressure (Bai et al., 2018; Meng et al., 2018). In this respect, the nexus concept has emerged an imperative field of research for sustainable development. This is evident from the fact that even IEA's World Energy Outlook 2012, assigned a chapter to the energy water nexus (IEA, 2012). Since then, numerous research investigations have been conducted on this topic from a systematic and macro-level perspective. For instance, interaction mechanism of energy water or quantitative effects of energy production and transportation on water resources, and by energy utilization during water treatment and supply.

A growing number of studies is now focusing on micro level perspective of energy water research broadening its scope. Lee et al. (2017) selected urban water cycle and studied 20 regions and 4 countries in the world. It disclosed that high water risk regions are linked with increase energy usage and GHG emissions associated with water supply systems. It also presented the consistency between water scarcity problems with energy consumption. Other studies investigate the content of existing energy water research in specific sectors. Marsh et al. (2008) studied the mechanism of the physical connection between power and water based on detailed discussion on water use in power
production and consumption, and power consumption in water usage in Australia. To analyze nexus, new tools and methods have been developed. Current practices are not restricted to qualitative description. Mo et al. (2010) applied IO-LCA model to study energy consumption in water supply system from life cycle perspective. Hu et al. (2013) used Sankey diagram to show economic and energy flows over time and used this method in industrial processes to explain runoff of water resources in production and treatment in China.

In this paper, we aimed to construct an urban nexus accounting framework based on Multi-Regional Input Output (MRIO) model for Shanghai referred to year 2010 using MRIO analysis. The urban economic structure is analyzed to identify specific sectors with potential for resource efficiency improvements, as these are related to national and global policy goals.

2. Case study

As a special case, Shanghai functions as a main financial, trade and shipping center in China and consumes huge amount of resources mainly imported from other regions due to its mature urbanization. In year 2014, city electricity production was about 792.3 TWh, whereas domestic electricity use stretched up to 1369.03 TWh. A huge amount of crude oil (22.42 million tons) and natural gas (72.43 billion CBM) was consumed accounting for 99.7 percent and 97.1 percent of imported fuel respectively. The per capita water consumption touched about 437.58 m3 (2014) which somehow revealed that the city largely relies on neighboring provinces for water (Zhang et al., 2018; Yang et al., 2018; Wang et al., 2018). Thus, due to increasing energy water trade links and distinct development pattern of Shanghai, underlying economic structure needs to be studied more deeply and targeted analysis is essential. In turn, it may enable the city to make global difference in reducing resource use and maximize positive economic effect.

3. Method

3.1 Framework and EE-MRIO model

This study aims to construct an accounting framework based on environmentally extended multi-regional input output model (EE-MRIO) to assess energy and water flows in the economic system and depict energy-water nexus. The EE-MRIO model was employed to conduct energy and water flow embodied in the goods and services produced or consumed in city both from production and consumption perspective. And the basic principle is linking the imports and export in MRIOT of China to the World Input-Output Table (WIOT), based on the World Input-Output Database (WIOD). Of which, the MRIOT of China was compiled by Liu et al. (2014), widely used in several researches (Feng et al., 2013).

In the EE-MRIO model, the world is divided into 8 domestic regions in China including Shanghai and 6 international regions including the RoW region. The detailed equation is below.

\[
T_{ij}^{ps} = \sum_{s} T_{ij}^{Cs} \sum_{j} T_{ij}^{ps} 
\]

where, \( T_{ij}^{Cs} \), taken from the world MRIO table, describes the economic flow from sector \( i \) in mainland China to sector \( j \) of region \( s \).

The fundamental input-output balance principle can be presented as

\[
\begin{pmatrix}
  x^1 \\
  x^2 \\
  x^3 \\
  \vdots \\
  x^m
\end{pmatrix}
= 

\begin{pmatrix}
  A^{11} & A^{12} & A^{13} & \cdots & A^{1m} \\
  A^{21} & A^{22} & A^{23} & \cdots & A^{2m} \\
  A^{31} & A^{32} & A^{33} & \cdots & A^{3m} \\
  \vdots & \vdots & \vdots & \ddots & \vdots \\
  A^{m1} & A^{m2} & A^{m3} & \cdots & A^{mm}
\end{pmatrix}
\begin{pmatrix}
  x^1 \\
  x^2 \\
  x^3 \\
  \vdots \\
  x^m
\end{pmatrix} + 

\begin{pmatrix}
  \sum_j y_{i1} \\
  \sum_j y_{i2} \\
  \sum_j y_{i3} \\
  \vdots \\
  \sum_j y_{im}
\end{pmatrix}
\]

The embodied environmental impacts can be mathematically presented as follows:

\[
E = R_e(1 - A)^{-1}Y 
\]

\[
W = R_w(1 - A)^{-1}Y 
\]

where \( E \) and \( W \) represent the embodied energy and water matrix induced by the final demand of the whole economic system, respectively. \( R_e \) and \( R_w \) are the diagonal matrix representing the pressure coefficient of energy consumption and water consumption, respectively. \((I - A)^{-1}\) is the Leontief inverse matrix. \( Y \) is a diagonal matrix, while the diagonal element \( Y_i \) represents the final demands of products and services in sector \( j \).

For the industrial balance analysis, the formula can be calculated as follows:

\[
NET_{wi} = W_{iMI} - W_{EXi} 
\]

\[
NET_{EI} = E_{iMI} - E_{EXi} 
\]

where, the NET represents the net energy and water consumption embodied in trade for each sector, \( E_{iMI} \) and \( W_{iMI} \) refer to the energy and water consumption embodied in import in sector \( i \), respectively, \( E_{EXi} \) and \( W_{EXi} \) refer to the energy and water consumption embodied in export in sector \( i \).

### Sectors Coding

<table>
<thead>
<tr>
<th>Sector Name</th>
<th>Sector Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>S1</td>
</tr>
<tr>
<td>Food &amp; Tobacco</td>
<td>S2</td>
</tr>
<tr>
<td>Electricity, Gas &amp; Water</td>
<td>S3</td>
</tr>
<tr>
<td>Construction</td>
<td>S4</td>
</tr>
<tr>
<td>Transport</td>
<td>S5</td>
</tr>
<tr>
<td>Services</td>
<td>S6</td>
</tr>
</tbody>
</table>
4. Primary Results

4.1 Local intersectoral analysis for Energy

Here only the local intersectoral analysis was studied from production and consumption perspective. As can be seen in figure 1. Electricity (S3), Others (S7) and Transport (S5) are the key sectors and consumes about 53.26%, 21.64% and 14.49% of production based energy flows respectively occupying around 89.40% of total energy flow. Of which, including destination of energy flows in downstream supply chain, around 59.48% of energy flows is driven by S3 itself, similarly around 40.71% of energy flows of S7 is transferred to S4 and around 54.60% of energy flows is driven by S5 itself flows.

Whereas Electricity (S3), Services (S6) and Construction (S4) consumes about 33.10%, 24.31%, and 21.75% of consumption-based energy flows respectively occupying around 79.16% of total energy flow. Of which, including source of energy flows in upstream supply chain, around 95.71% of energy flows is driven by S3 itself, while around 41.55% of energy flows of S6 is transferred to S3 and around 40.50% of energy flows of S4 is transferred to S7.

4.2 Local intersectoral analysis for water

As can be seen in figure 2. Electricity (S3), Agriculture (S1) and Construction (S4) are the key sectors and consumes about 63.96%, 21.17%, and 11.48% of production based water flows respectively occupying around 96.62% of total water flow. Of which, including destination of water flow in downstream supply chain, around 59.26% of water flows is driven by S3 itself, similarly around 65.21% of water flows is driven by S1 itself and around 93.42% of water flows is driven by S4 itself.

Whereas Electricity (S3), Construction (S4) and Services (S6) consumes about 38.12%, 21.80%, and 18.86% of consumption based water flows respectively occupying around 78.78% of total water flows. Of which, including source of water flows in upstream supply chain, around 99.44% of water flows is driven by S3 itself, while around 49.20% of water flows is driven by S4 itself and about 64.87% of water flows of S6 is transferred to S3.

5. Concluding Remarks

Megacities are the crucial regions for nexus management. The preliminary result of this work concludes that energy-water flow nexus is more evident in Electricity sector and rest of sectors are mostly controlled by single resource. Additionally, in most of the sectors, the energy water nexus is common from consumption perspective, particularly for Electricity Services and Construction sector. Detailed study intended for spatial distribution (i.e. domestic and international regions) and energy-water nexus involving Shanghai and other mega cities (such as Beijing, Chongqing and Tianjin) will be figured out in future to test the sustainability of the cities more explicitly.

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Reference


