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The nexus of water-energy-food in China's tourism industry

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ABSTRACT

The tourism industry contributes significantly to the growth of the global economy and is considered to be strongly associated with a large amounts of water and energy consumption. In this study, the tourism water footprint (TWF) and the tourism energy footprint (TEF) of 138 sectors were investigated to examine the water-energy-food (W-E-F) nexus in the Chinese tourism industry from 2012 to 2017 by developing the water- and energy-based environmentally extended input-output analysis with the tourism satellite account. This study revealed that the W-E-F supply groups consumed total 15,556 million m^3 of water and 4,964 million tce of energy to support the Chinese tourism industry. The largest contributor to the total TWF is the indirect water use from the food supply group (65%), while the largest proportion of total TEF is contributed by the direct energy use from 11 tourism direct sectors (63%), most especially the air transport sector. A much larger growth of the tourism industry was observed in 2017 compared to that of 2012. The structure decomposition analysis revealed that the growth of the overall water and energy consumption of China tourism is mainly driven by the growth of the total tourism expenditure, i.e. the scale effect. It is the same case for the food supply group associated with the Chinese tourism industry. In contrast, the contribution of the changes to the tourism expenditure composition is relatively low. Furthermore, the growth in water and energy consumption can be offset effectively by reducing the water and energy use coefficient and adjusting the economic production structure of tourism and its associated food supply group. In sum, the food supply and air transport sectors play a crucial role in the water-energy-food nexus of the tourism industry. Therefore, in the future, focus should be placed on improving the water and energy use efficiency of these sectors as well as enhancing their production structures.

1. Introduction

The versatile culture and beautiful scenery of China attracts a large number of domestic and inbound tourists. Activities in the tourism industry contributed to 11% of the total gross domestic product of China in 2018 (WB, 2019). The tourism industry not only provides a significant contribution to the national economy, but also is critical to the global tourism development (NBSC, 2019; PIE, 2019). Tourists generally seek a more comfortable life where they consume more food, energy and water. It has been reported that the water footprint per tourist is about two or three times than that of local residents (Gössling et al., 2012). Therefore, a better understanding of the relationship amongst food, water and energy related to tourism plays a crucial role in the sustainable development of tourism industry.

Due to the rapid growth in economy and global population, there is rising demand for water-energy-food (W-E-F) resources. At the global scale, approximately 70% of fresh water resources are consumed by agriculture, with the other 30% of the energy being spent for food production and supply (UN, 2019). It presents a significant challenge to the sustainable development of tourism industry by providing sufficient W-E-F resources to accommodate the fast-growing demand. In particular, the current COVID-19 pandemic may seriously disrupt the global food supply chain due to the related containment measures that make food more unsecure than before for many low-income countries (FAO, 2020). The negative impacts of swift consumptions of W-E-F has been examined in a number of studies (Berger et al., 2012; Chapagain and Hoekstra, 2007; Chen and Chen, 2013; Chen et al., 2012; Jeswani and Azapagic, 2011).

The W-E-F nexus was first appeared in World Economic Forum on 2011 and termed as the connections between W-E-F resources, together with the synergies, conflicts and trade-offs among each other (WEF, 2011). Since then, W-E-F nexus has been widely adopted in policy making and research communities (Zhang et al., 2019). To better understand the W-E-F nexus for sustainable development, some studies were undertaken to cover theoretical, methodological and empirical aspects in various fields such as science, technology and policy

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(Liu et al., 2018; Heard et al., 2017; NRD, 2018; Simpson and Jewitt, 2019; Zhang et al., 2018). It is widely recognized in these studies that data collection presents as one of most significant challenges. This has impeded the practical implementations of the W-E-F nexus to assist in poverty reduction, and improvement in human well-being and sustainable development. It is crucial to identify new data sources or proxies to advance W-E-F nexus research and sustainability (D'Odorico, 2018). Furthermore, there is no single method that can be applied to all disciplines related to W-E-F nexus. Majority of existing studies focused on a macro scale of specific regions or certain types of energy and food of the W-E-F nexus based on various methods. For example, Feng et al. (2019) developed a physical input-output model to represent urban W-E-F nexus in the Detroit Metropolitan Area. D'Odorico et al. (2018) collected water footprint data required for the production of certain types of energy and food to investigate the global W-E-F nexus. White et al. (2018) used transnational interregional input-output table to investigate regional water, energy, and food consumption which was applied for China, South Korea, and Japan. Yang et al. (2019) adopted a betweenness-based method and principal components analysis to investigate the W-E-F pressure transmission center sectors for Shanghai. Li et al. (2019) adopted a multi-objective non-linear programming model to study the only agricultural W-E-F nexus in the Heihe River basin, China. Niva et al. (2020) assessed water demand for the food and energy sectors which included coal, gas, biofuel, and nuclear sources for electricity production in China. After reviewing 245 journal articles and book chapters related to W-E-F nexus, Albrecht et al. (2018) reveals that integrate social and political aspects of water, energy, and food by using mixed-methods and trans-disciplinary approaches are essential for scientists and stakeholders. Also, Endo et al. (2017) reviewed 37 related nexus projects and found the importance of developing a unified framework which can be shared not only among scientists, but also among stakeholders in society for understanding the complexities of W-E-F systems. There is lack of understanding on the sophisticated sectorial supply and consumption of W-E-F nexus in a specific industry, especially for the tourism industry.

The footprint methods are widely used to assess the efficiency of W-E-F system (Zhang et al., 2019). The indicator of footprint is used to express the consumption amount of the targeted resources. For example, the indicator of water footprint (WF) is a measurement of water consumption amount with three components, i.e. blue, green, and gray water (Hadjikakou et al., 2015; Hoekstra et al., 2011; Hoekstra and Mekonnen, 2012). WF can express the amount of direct water use during the production of a product or service as well as the indirect water use in the supply chains of products or services. The WF of a product or a service is amount of water required to cover the entire supply chain for the completion of a product or a service (Hoekstra, 2009). The similar approach can be applied to the energy consumption as energy footprint (EF). For tourism, the indicator of footprint is often applied to describe the impact of tourism activities on resources and environment. The direct tourism WF (TWF) or tourism EF (TEF) refers to the water or energy use that is directly generated by the tourists for their necessary tourism actions such as transportation, accommodation, dining, drinking, and entertainment (Bennasar, 2014; Sun and Hsu, 2018). In contrast, the indirect TWF or TEF is the water or energy used by the sectors that are the supply chain of the tourism industry such as agriculture, power, and fuel (Lenzen et al., 2018; Sun and Hsu, 2018). Most of footprint related studies focused on water or carbon related to energy. In contrast, very few studies have attempted to examine the food footprint associated with tourism. A potential challenge is that food is a product and not a natural resource like water and energy. A number of studies have found that the water footprint of tourism is closely related to the agriculture related sector (Cazcarro et al., 2014; Hadjikakou et al., 2013).

Thus, the main task of this study is to employ relatively mature concepts of the water footprint and the energy footprint to analyze the W-E-F nexus in tourism to ensure its sustainable development. For this task, it is imperative to review the TWF and TEF related studies. Currently, both top-down and bottom-up methods are widely used to evaluate the TWF and TEF (Wang et al., 2017). Top-down methods adopt the input-output (IO) analysis principle to assess the TWF or TEF for a country or inter-country. Since the IO table are available to the public, top-down method has been ordinarily adopted to assess the TEF (Cadarso et al., 2015; Dwyer et al., 2010; Lenzen et al., 2018; Munday et al., 2013; Perch et al., 2010; Sun, 2014) and TWF (Cazcarro et al., 2014; Sun and Hsu, 2018). Meanwhile, bottom-up method generally adopts a stepwise life cycle assessment (LCA) principle to investigate the TWF or TEF of a tourism product or service (De, 2012; Zhang et al., 2017). However, it is difficult to include all required information when studying the entire tourism industry via bottom-up method, which may result in a poor accuracy (Kuo and Chen, 2009; Zhou et al., 2015).

Therefore, a top-down approach is employed in this study to investigate the W-E-F nexus in the Chinese tourism industry by undertaking the environmentally extended input-output (EEIO) analysis with the tourism satellite account (TSA) data. In this study, the EEIO table includes 138 sectors. These sectors are further classified into: 11 tourism direct sectors, 1 water supply sector, 6 energy supply sectors, 18 food supply sectors and 112 others sectors for detailed analysis. The linkage analysis between direct and indirect TWF and TEF are also conducted in this study to evaluate the W-E-F nexus. This helps to present an intuitional visualization of interaction between water and energy consumption in the tourism industry.

Moreover, the structural decomposition analysis (SDA) is employed to analyze the impact of driving forces to the changes in TEF and TWF of W-E-F supply groups that support the Chinese tourism industry between 2012 and 2017. In China, this period is termed as the "new normal" that witnessed the paradigm shift of economic growth from quantity-oriented to quality-oriented, i.e. towards sustainable growth (Zheng et al., 2019). The SDA model is a method that has been widely used to identify a set of key parameters in an IO table. It is a useful tool to quantify the contributions of various driving forces to the targeted change over time that has been used to investigate the environmental pollution and resource consumption growth (Rose and Casler, 1996; De Haan, 2001; Koller and Stehrer, 2010; Su and Ang, 2012).

Existing studies have employed various methods to quantify the W-E-F nexus in specific production sectors via the assessment of single resource, such as water consumption for the energy and food production sectors (D'Odorico et al., 2018 and Niva et al., 2020). However, there is lack of W-E-F nexus research in the tourism industry. Production industries are located in the upstream of the supply chain. By contrast, the tourism is a service industry that is coordinated by the consumption of tourists. This study fills this critical knowledge gap by incorporating the two highly interconnected resource (water and energy) used flow into the three-dimensional system of W-E-F nexus from the perspective of resource provision in the Chinese tourism industry. To our best knowledge, this is the first study to investigate W-E-F nexus focusing on the downstream industry that is consumption-oriented. In addition, we advance the existing body of knowledge by: (1) comparing average daily water and energy footprint per capita between domestic and international inbound tourist, (2) analyzing indirect water and energy usage derived from each tourism direct sector, (3) evaluating the tourism water and energy footprint demand of each sector in food, energy and water supply groups, (4) investigating the impact of drivers on the TWF and TEF changed with a focus on W-E-F supply groups from 2012 to 2017. Thus, the specific objective of our study is to identify the key economic sectors and driving factors behind the interactions amongst the W-E-F resource provision. Findings will assist policy makers to define co-benefit opportunities of tourism W-E-F nexus to advocate synergies and tradeoff.

2. Methods and data

In this study, a water and energy based EEIO model with TSA framework was developed to examine TWF and TEF of five groups (i.e., water supply, energy supply, food supply, tourism direct and others sectors) that are either directly or indirectly related to the China tourism industry. Hence, W-E-F nexus of W-E-F supply groups can be revealed. We also identified the critical supply chain path flows of indirect TWF and TEF derived from tourism direct sectors. In addition to estimating the annual water and energy consumption in the tourism industry, and our study applied the SDA technique to investigate the contribution of four driving forces including direct water (energy) use coefficient, economic production structure, tourism expenditure composition, and total tourism expenditure to the change of TWF and TEF for aforementioned W-E-F supply groups in 2012–2017.

2.1. Construction of water/energy based EEIO table

To assess TWF and TEF of the tourism industry, the national IO table, tourism expenditure data (i.e., TSA), and water/energy use coefficients were collected in this study to construct a water/energy based EEIO table.

The typical matrix balance equation (Eq. (1)) and Leontief inverse square matrix (Eq. (2)) are required in the IO table analysis for the top-down approach, and are given as follows (Leontief, 1970):

$$X = AX + Y \tag{1}$$

$$X = (I - A)^{-1}Y \tag{2}$$

Where X is the column vector of the total output. Y is a column vector of the final demand. A is a n x n direct consumption coefficient matrix. I is a n x n identity matrix. $(I\text{-}A)^{-1}$ is a n x n Leontief inverse square matrix. n is the sector's total number of IO table.

The direct water and energy use coefficients of each sector i are calculated as below:

$$DW_i = \frac{W_i}{X_i} \tag{3}$$

$$DE_i = \frac{E_i}{X_i} \tag{4}$$

Where DW_i is direct water coefficient of sector i. DE_i is direct energy use coefficient of sector i. W_i is the water use (m^3) of sector i, E_i is the energy use (tce) of sector i, and X_i is the total output (US $) of sector i obtained from IO table.

The original China's 2017 IO table with 149-sectors and 2012 IO table with 139-sectors were obtained from National Bureau of Statistics of China (NBSC, 2019) to reveal the inter-sectors connection between the demand side and supply side. To better compare the TWF and TEF of 2012 and 2017, the original 2012 and 2017 IO tables were modified and integrated into a unified 138-sector IO table for both 2012 and 2017. To reveal the nexus of W-E-F of tourism, the 138 sectors were divided into five groups i.e., water supply (1 sector), energy supply (6 sectors), food supply (18 sectors), tourism direct (11 sectors) and others (102 sectors) (see **Table 1**). This classification is essential to analyze their relationship with each other.

The water use data were mainly derived from China Economic Census Yearbook (CECY, 2008) and National Bureau of Statistics of China (NBSC, 2019). Likewise, the energy use data were mainly derived from National Bureau of Statistics of China (NBSC, 2019). The details please see the Supplementary Method.

The TWF and TEF of sectors can be calculated as:

$$TWF = DW(I - A)^{-1}Y_T \tag{5}$$

$$TEF = DE(I - A)^{-1}Y_T \tag{6}$$

Where DW and DE are 138 × 1 direct water and energy use coefficient (m^3/US$ and tce/US$) vectors. Y_T is 138 × 1 tourism expenditure (US$) vector. These serve as the final demand by using TSA data for the identified tourism direct sectors and 0 for the rest sectors in IO table (Lenzen et al., 2018).

In this study, China's 2012 and 2017 TSA data (Y_T) and other tourism related data (i.e. the number, visiting days and expenditures of domestic and inbound tourists) were obtained from the Ministry of Culture and Tourism of the People's Republic of China (CTS, 2013, 2018). The determined 11 tourism direct sectors used in this study are given in **Table SI-1**.

Table 1
Complete sector name of various groups in IO table and their corresponding brief sector name.

Group	Complete sector name (IO table)	Brief sector name (This study)
Tourism direct	Wholesale and retail	Wholesale
	The railway transport	Railway transport
	Road transport	Road transport
	Water transport	Water transport
	Air transport	Air transport
	Accommodation	Accommodation
	Food and beverage	Food service
	Telecommunications services	Telecommunications
	Other services	Other services
	Culture and art	Culture
	Entertainment	Entertainment
Water supply	Water production and supply	Water supply
Energy supply	Coal mining products	Coal
	Oil and gas production products	Oil
	Refined petroleum and nuclear fuel processing products	Refined petroleum
	Coking products	Coking
	Electricity and heat production and supply	Electricity
	Gas production and supply	Gas
Food supply	Agriculture	Agriculture
	Forestry	Forestry
	Animal husbandry	Animal
	fishery	Fishery
	Agricultural, forestry, animal husbandry and fishery services	Agricultural services
	Grain mill products	Grain
	Fodder processed product	Fodder
	Vegetable oil products	Vegetable oil
	Sugar and sugar products	Sugar
	Slaughter and meat processing products	Slaughter
	Aquatic products	Aquatic
	Vegetables, fruits, nuts and other processed agricultural foods	Vegetables
	Instant foods	Instant foods
	Dairy products	Dairy
	Condiments, fermented products	Condiments
	Other food	Other food
	Alcohol and wine	Alcohol
	Beverages and refined tea products	Beverages

2.2. Structural decomposition analysis (SDA)

SDA is a commonly utilized to examine the contribution of underlying driving forces to the changes of the observed indicator in an IO table (Dietzenbacker and Los, 1998; Hoekstra and van der Bergh, 2002; Xu et al., 2011). In this study, we applied SDA to understand the impact of four driving forces (i.e. the direct water or energy use coefficient (*DW* or *DE*), economic production structure (*PS*), tourism expenditure composition (*EC*) and total tourism expenditure (*ET*) on the change of TWF and TEF in 2012–2017. The average of all possible first order decompositions SDA equation (Xu et al., 2011; Zheng et al., 2019) is adopted in this study as follows:

$$
\begin{aligned}
\Delta \mathrm{TWF} &= \mathrm{TWF}_{(t)} - \mathrm{TWF}_{(t-1)} \\
&= DW_{(t)}PS_{(t)}EC_{(t)}ET_{(t)} - DW_{(t-1)}PS_{(t-1)}EC_{(t-1)}ET_{(t-1)} \\
&= (\Delta DW)PS_{(t)}EC_{(t)}ET_{(t)} + DW_{(t-1)}(\Delta PS)EC_{(t)}ET_{(t)}+ \\
&\quad DW_{(t-1)}PS_{(t-1)}(\Delta EC)ET_{(t)} + DW_{(t-1)}PS_{(t-1)}EC_{(t-1)}(\Delta ET)
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
\Delta \mathrm{TEF} &+ \mathrm{TEF}_{(t)} - \mathrm{TEF}_{(t-1)} \\
&= DE_{(t)}PS_{(t)}EC_{(t)}ET_{(t)} - DE_{(t-1)}PS_{(t-1)}EC_{(t-1)}ET_{(t-1)} \\
&= (\Delta DE)PS_{(t)}EC_{(t)}ET_{(t)} + DE_{(t-1)}(\Delta PS)EC_{(t)}ET_{(t)}+ \\
&\quad DE_{(t-1)}PS_{(t-1)}(\Delta EC)ET_{(t)} + DE_{(t-1)}PS_{(t-1)}EC_{(t-1)}(\Delta ET)
\end{aligned} \tag{8}
$$

Where t and t-1 represents the year of 2017 and 2012 respectively. The symbol Δ means the 2017 value minus 2012 value. Four terms in the Eq. (7) and (8) represent the impact of four driving forces on the change TWF and TEF between 2012 and 2017. The first, second, third and fourth term represents the individual effect of direct water or energy use coefficient, economic production structure, tourism expenditure composition and total tourism expenditure, respectively, when other driving forces remain constant.

In Eq. (7) and (8), the *PS* term represents the Leontief inverse square matrix of $(\text{I-A})^{-1}$ of IO table. The original *PS* is 138×138 matrix with 138 sector in supply side and 138 sectors in demand side. Meanwhile, *EC* term in Eq. (7) and (8) is a 138×1 vector with 11 values for corresponding tourism direct sectors and 0 value for other sectors. After the calculation, each term in Eq. (7) and (8) have 138 sectors in supply side and 11 tourism direct sectors in demand side. Thus, the *PS* effect is mainly derived from the structural adjustment of 11 tourism direct sectors from demand side.

3. Results and discussion

3.1. Component analysis of the water and energy footprint of tourism (TWF and TEF)

The TWF component analysis was conducted for tourism direct sectors, W-E-F supply groups and other 102 sectors in 2017 (see Fig. 1). Fig. 1**(a)** demonstrates that the food supply group is the largest water consumer, which accounted for 66% (12,653 million m^3) of total TWF. Agriculture accounts for the largest share (38%) of the food supply system, followed by fisheries (12%). In contrast, the TWF derived from tourism direct group accounted for 12% of total TWF. Among the tourism direct sectors, more than half of the TWF is generated by accommodation. The TEF component analysis of various groups are illustrated in Fig. 1**(b)**. It can be observed that 68% (267 million tce) of the total TEF were generated by tourism direct sectors. Among these tourism direct sectors, air transport accounted for the largest proportion (33%), followed by accommodation (11%). This indicates that the tourism direct sectors are the major energy consumers, especially the air transport sector. The food supply group contributed to around only 2% of the total TEF. The energy consumption of the food supply group is lower than that of other groups (Fig. 1**(b)**). Fig. 1 also exposes that the energy supply group contributed to 15% and 11% of TWF and TEF, respectively. In addition, both TWF and TEF generated by water supply group is less than 1%.

In sum, for the tourism direct sectors, the largest TWF and TEF were produced by accommodation and air transport sectors, respectively. For the W-E-F supply sectors, the food supply group is the main indirect water consumer in the tourism industry. The energy supply sector consumes more water and energy than the water supply sector.

3.2. The TWF and TEF of domestic and inbound tourists in China

The domestic and inbound TWF and TEF of 2017 in China are presented in Fig. 2. Fig. 2**(a)** demonstrated that the total domestic and international inbound TWF is 16,141 million m^3 and 3,054 million m^3, respectively. The total TWF of 19,195 million m^3 accounts for approximately 3.7% of the total water consumption (504,000 million m^3) in China in 2017. The total domestic and international inbound TEF is 330 million tce and 62 million tce, respectively. The total TEF of 392 million tce accounts for approximately 9.9% of the total energy consumption (3,909 million tce) in China in 2017. The total domestic TWF and TEF are around 5 times larger than that of the international inbound tourists.

For the average daily TWF per domestic tourist, the TWF is 1,616 (L/tourist/day) and the TEF is 33 (kgce/tourist/day). For the international inbound tourists, the average daily TWF is 6,346 (L/tourist/day) and the TEF is 129 (kgce/tourist/day) (see Fig. 2**(b)**). Although the annual amount of international inbound TWF and TEF are 5 times lesser than domestic tourists, the average daily TWF and TEF per inbound tourist are around 4 times higher than those of the domestic tourists. This results mainly attributed to the larger average daily expenditure by international inbound tourists and implied that inbound tourist consumed higher-intensity water and energy activities than the domestic tourists in China.

3.3. The linkage between direct and indirect TWF and TEF derived from tourism direct sectors

To further analyze the relationship amongst sectors, the indirect TWF and TEF derived from each tourism direct sector of the Chinese tourism industry in 2017 are illustrated in Fig. 3(a) and (b). Fig. 3(a) illustrates that 11 tourism direct sectors generated direct TWF of 2,065 million m^3, and produced indirect TWF of 12,653 (food supply), 2,846 (energy supply), 57 (water supply) and 1,574 (other 112 sectors) million m^3. The overall indirect TWF is around 6 times higher than the

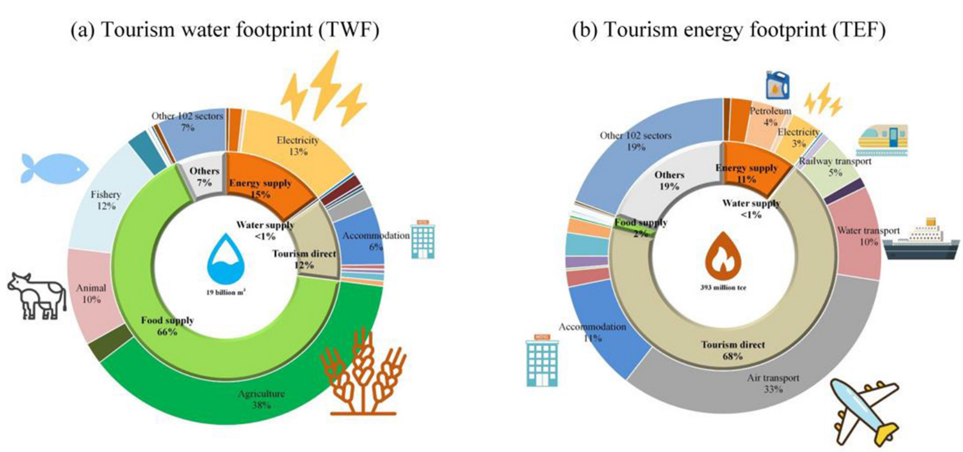

Fig. 1. Component analysis of the Chinese tourism industry of (a) TWF and (b) TEF in 2017. .

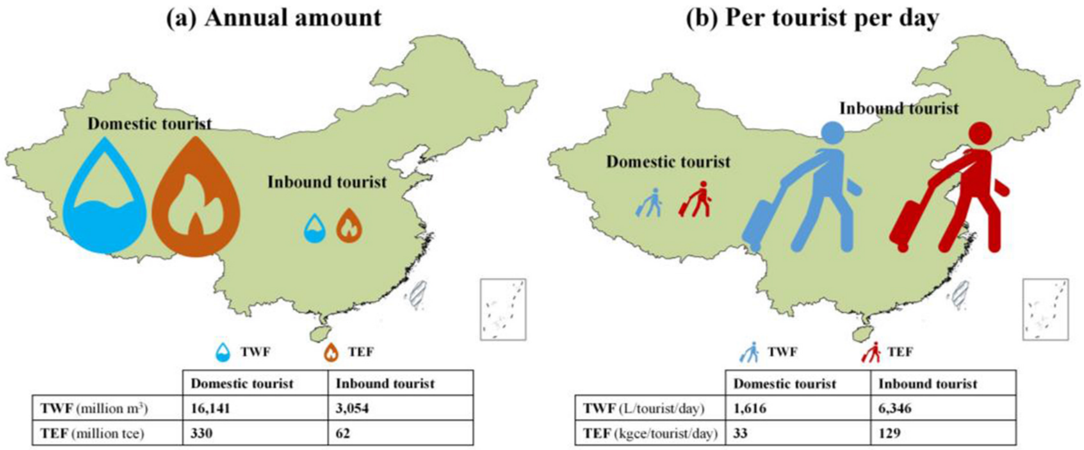

Fig. 2. The 2017 TWF and TEF of (a) annual amount and (b) generation per tourist per day of inbound and domestic tourists in China.

direct TWF. The largest linkage flow is between food service and food supply group. Although the direct water footprint of the food service sector is relatively small, the indirect water footprint of the food supply sector has exaggerated its impacts.

Fig. 3(b) exposes that 11 tourism direct sectors generated direct TEF of 25,120 ten thousand tce, and produced indirect TEF of 690 (food supply group), 4,190 (energy supply group), 84 (water supply group) and 9,193 (other 112 sectors) ten thousand tce. Dislike TWF, the direct TEF is around 2 times larger than indirect TEF. Thus, most of the energy consumed by the tourism industry is caused by tourism direct sectors themselves rather than their supply chains. The air transport sector not only produces the greatest direct TEF, but also derives a vast amount of indirect TEF from energy supply group and other sectors. The results of linkage analysis further confirmed the importance of food supply sectors and air transport sector in reducing the water footprint of tourism industry.

3.4. Analysis of the water-energy-food nexus in tourism

To further analyze the W-E-F system, we evaluated the relative value of TWF and TEF demand of each sector in water, energy and food supply group. These sectors are divided into four quadrants according to the relative water footprint and energy footprint.

In the food supply group, only the agriculture sector appeared in quadrant I, which means agriculture sector needs a large quantity of water. At the same time, the energy consumption of agriculture is close to the middle level in the food supply group. The beverage, alcohol, fisher sectors appeared in quadrant II. This indicates these sectors needs more energy than the other food supply sectors.

In the energy and water supply group, the electricity sector appeared in quadrant I. This reflects that the electricity sector consumes the most energy and water resources among these energy and water supply sectors. The refined petroleum and oil sectors appeared in quadrant II, which reveals that the two sectors need more energy than the others in the energy and water supply group.

However, most of sectors in W-E-F supply groups are in the quadrant III, which means they need relatively small energy and water. It is interesting to note that no sector appeared in the quadrant IV. According to the quadrant classification, such sector consumes larger water but less energy in the quadrant IV. In other words, except for agriculture and electricity sectors, the disparity of water consumption in these W-E-F supply sectors is relatively smaller than that of energy consumption. As shown in Fig. 4**,** most sectors are vertically distributed along the y-axis.

Consequently, the W-E-F nexus in term of TWF and TEF for China tourism industry can be illustrated in Fig. 5. It reveals that the water supply group provided 12,653 million m^3 TWF and the energy supply group offers 690 million tce TEF to the food supply group for the production to support tourism. Furthermore, the water supply group provided 2,846 million m^3 TWF to the energy supply group and 57

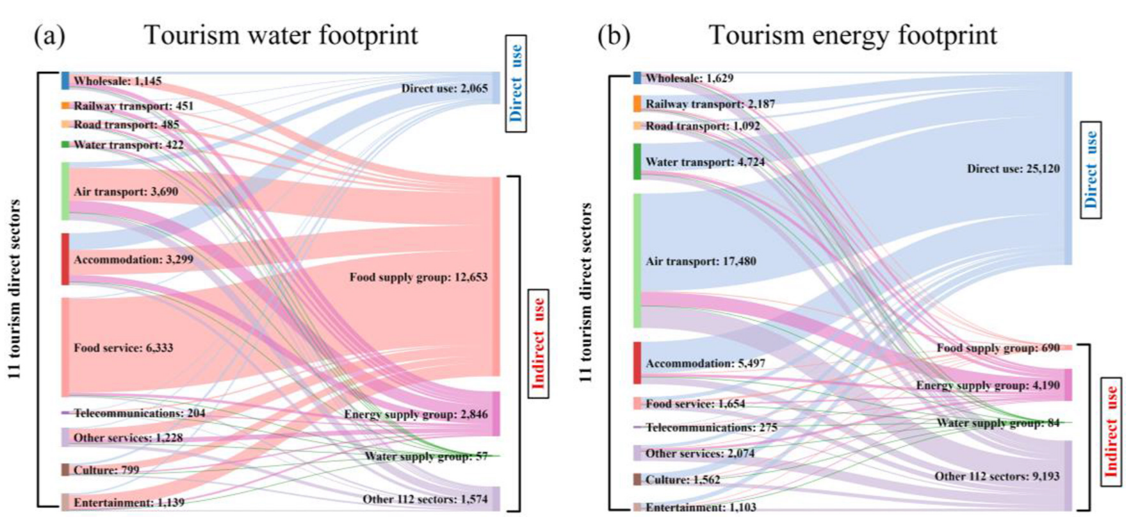

Fig. 3. Indirect water and energy resources usage derived from each tourism direct sector on 2017, (a) TWF (unit: million m^3); (b) TEF (unit: ten thousand tce). The amount presented in W-E-F supply groups and other 112 sectors belong to the indirect water/energy usage.

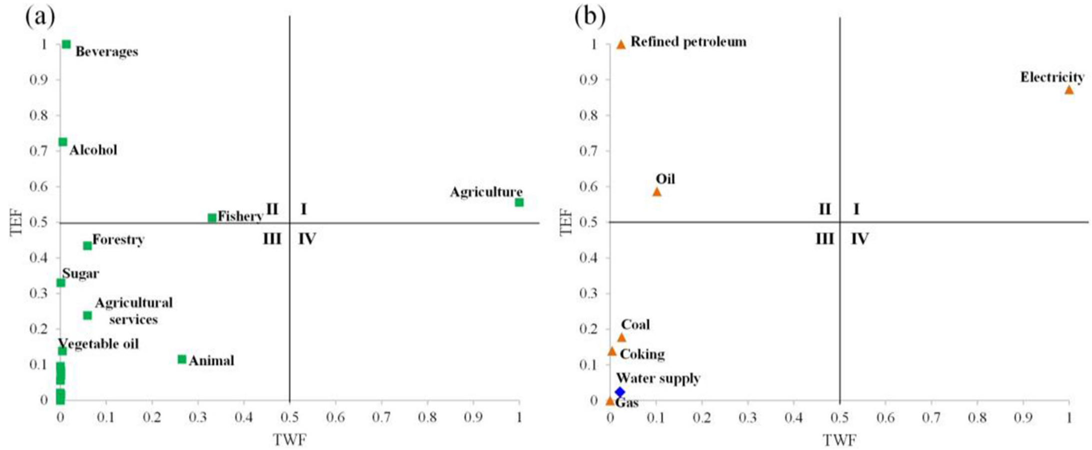

Fig. 4. TWF and TEF nexus of (a) food supply group, (b) energy and water supply groups of 2017. The non-dimension ratio of X and Y axis are calculated by (each sector's TWF (TEF)−minimum TWF (TEF) of each group)/ (maximum TWF (TEF) of each group−minimum TWF (TEF) of each group).

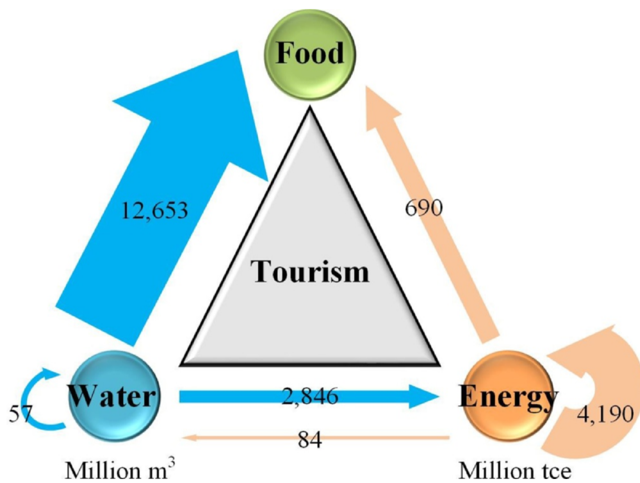

Fig. 5. W-E-F nexus in TWF and TEF for 2017 Chinese tourism industry.

million m^3 TWF to itself to ensure adequate energy and water to support China tourism industry. Vice versa, the energy supply group provided 84 million tce TEF for the water supply group to produce enough water for tourism activities. Also, energy supply group provided 4,190 million tce TEF to itself for supporting the supply of electricity, gasoline and other energy to tourism. Totally the W-E-F supply groups need to consume 15,556 million m^3 water and 4,964 million tce energy resources to support the development of tourism industry in China.

Results of component analysis, linkage between direct and indirect, and W-E-F nexus of TWF and TEF are similar between 2012 and 2017. The relevant charts for 2012 are shown in **Fig. SI-1, SI-2** and **SI-3**, respectively.

3.5. The changes of water-energy-food supply group in 2017 compared to 2012

Despite similar pattern, the total TWF and TEF increased 4,834 million m^3 and 142 million tce from 2012 to 2017, respectively. Fig. 6 illustrated the changes in TEF and TWF of various W-E-F supply sectors in 2017 compared to 2012. It reveals that most of the tourism W-E-F supply sectors have an increase in both TEF and TWF. The aquatic sector has a largest TWF (140%) increase and the agriculture service sector has a largest TEF increase (150%). Both these two sectors belong to the food supply group. 7 out of 18 food supply sectors have a TWF decrease and 1 sector has a TEF decrease. In contrast, 2 out of 6 energy supply sectors have a TWF decrease and 1 sector has a TEF decrease. It indicates that the reduction of energy may be more difficult than the reduction of water for those W-E-F supply sectors. It is even more difficult to reduce the energy and water use at same time as no such sector can be found in Fig. 6.

3.6. Structural decomposition analysis of TWF and TEF

In order to further explore the driving force that the tourism water and energy footprint in 2017 are larger than that in 2012, we applied the method of SDA to understand the impact of four driving forces of *DW* (direct water use coefficient) or *DE* (direct energy use coefficient), *PS* (economic production structure), *EC* (tourism expenditure composition) and *ET* (total tourism expenditure) on the TWF and TEF changes. *DW* and *DE* can be regarded as intensity effect, *PS* and *EC* as structural effect, *ET* as scale effect. The overall SDA results are shown in Fig. 7.

Within 6 years period there are a total of 34% and 58% increase for TWF and TEF, respectively. The significant increases for both TWF and TEF were mainly contributed by the driving force of total tourism expenditure with an amount of 108%. The tourism expenditure composition resulted in a small increase of 5% for TWF and 4% for TEF. These two kinds of driving forces contributed to the increase of both TWF and TEF. In contrast, the direct water use coefficient reduced 48% of TWF and direct energy use coefficient cut down 33% of TEF. The economic production structure also caused 31% reduction of TWF and 21% reduction of TEF. These results indicate that the total tourism expenditure is the main factor leading to the growth of water and energy consumption of the Chinese tourism industry. By contrast, the major factor of slowing down water and energy consumption is the direct water and energy use coefficient, followed by economic production structure. The direct use coefficient reflects the technological innovation level. The SDA results indicated that the improvement of water- and energy-saving technologies is the most crucial driving force to slow down the consumption of water and energy in the tourism industry. Similar to other SDA related studies (Sun and Hsu, 2018; Zheng et al., 2019), the consumption of resources is derived from the scale effect of economy, while the technologies plays a crucial role in mitigating these effects.

Meanwhile, it is worth noting that the economic production structure also slowed down the consumption of resources, second only to the technological innovation. To further investigate the impact of drivers focus on W-E-F supply groups, **Table 2** and **Table 3** presents the SDA results of TWF and TEF changes for W-E-F supply groups, respectively.

Compared with 2012, the economic production structure for the energy supply group in 2017 played an important role in slowing down the increase of both TWF and TEF. The contribution of economic production structure even exceeds that of direct use coefficient for energy supply group, with an offset amount of 66% for TWF and 91% for TEF.

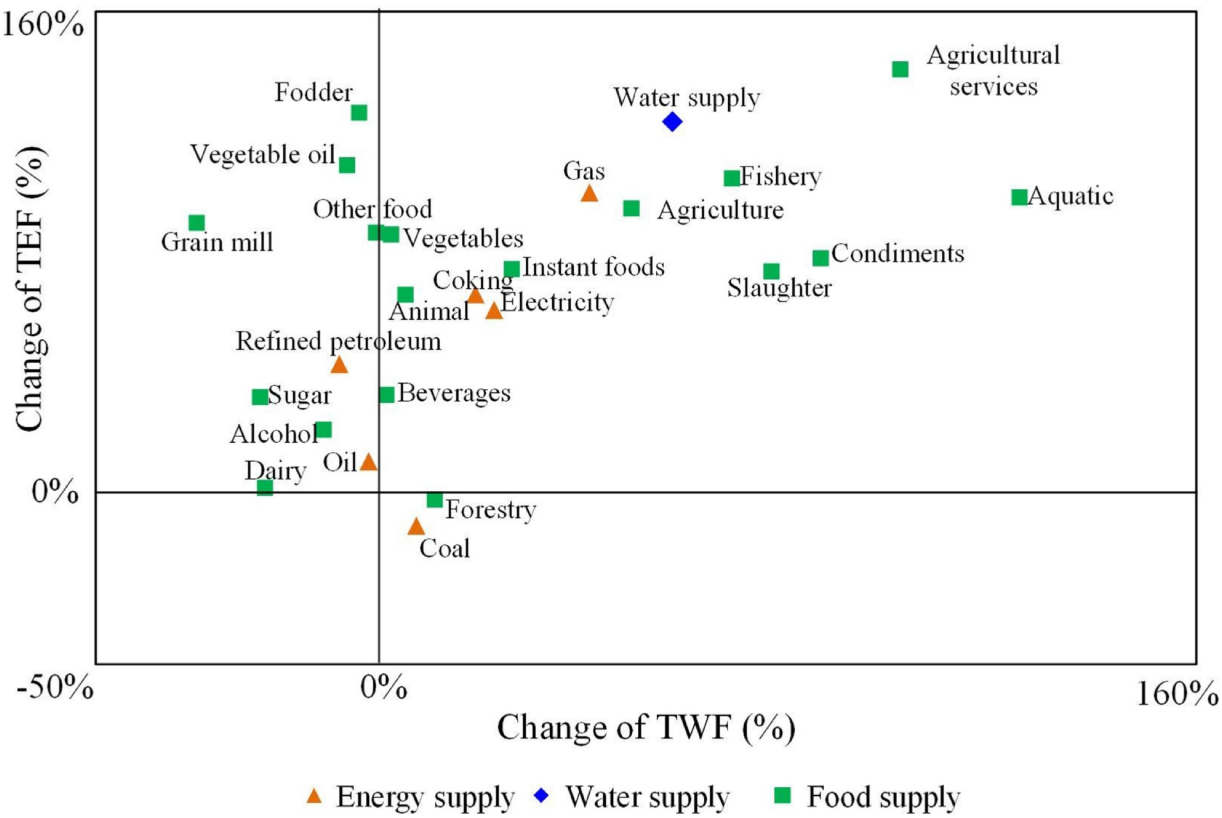

Fig. 6. The change percentage of TEF versus TWF for China tourism's W-E-F supply sectors in 2012–2017.

The economic production structure is the intermediate input structure (i.e., Leontief inverse square matrix of $(I\text{-}A)^{-1}$). This indicator showed a large negative value, which means that 11 tourism direct sectors have shifted toward an energy intermediate input-saving structure.

As for food supply group, the contribution of structural effect (i.e. economic production structure) and intensity effect (i.e. direct water use efficiency) demonstrated similar results as that of the whole tourism industry. However, for the water supply group, the economic production structure drove the even more increased of water and energy consumption in tourism. This result led a 43% increase in TEF and TWF. This is because more high-intensity water consumption facilities are installed such as five-star hotels that are equipped with spa and swimming pool. By contrast, the intensity effect mainly mitigated the growth of TWF (93%) for water supply group.

4. Conclusions

This paper examined the relationship amongst water, energy and food provision for the tourism industry. Results reflected that the greatest component of TWF (about 64%) is contributed by the indirect water use from food supply sectors while the largest component of TEF (about 62%) is from tourism direct sectors. In the food supply sectors, agriculture plays the most important role for water footprint. In the tourism direct sectors, air transport leads to a largest consumption of direct energy footprint. In the tourism industry, the water-energy-food nexus is highlighted as an important linkage between food supply sectors and water resources. However, the energy supply sectors are not closely related to water supply sectors. The water supply sectors require less water and energy than food supply and energy supply sectors.

Compared with 2012, although the composition structure of direct

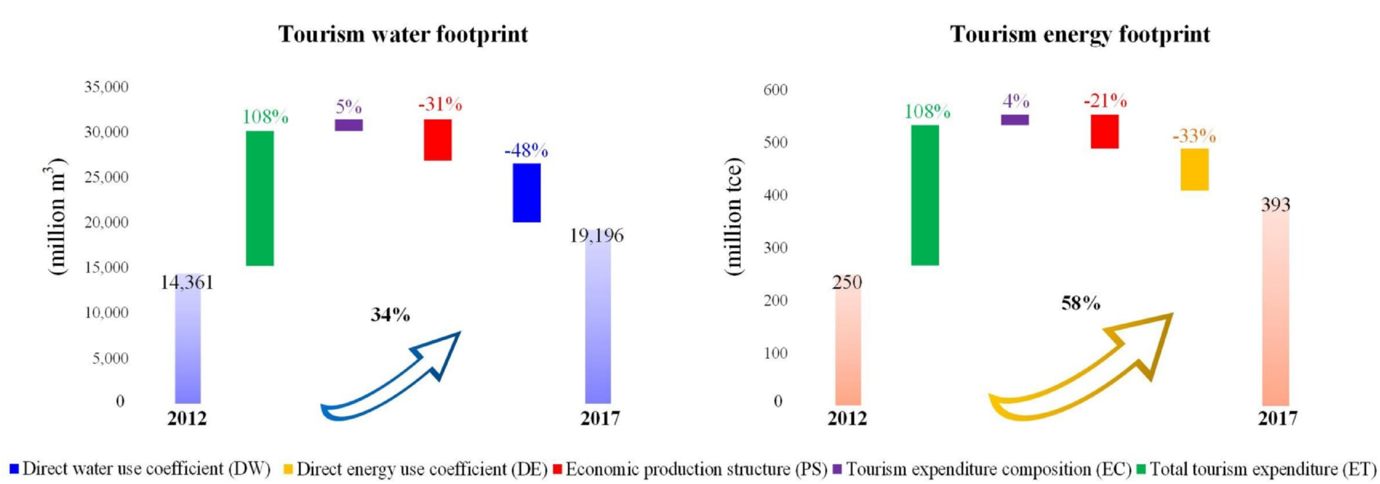

Fig. 7. The overall SDA of the change of (a) TWF (b) TEF in 2012–2017 for China tourism industry. .

Table 2
SDA of TWF change of W-E-F supply groups in 2012–2017 for the Chinese tourism industry.

Group \ Driving force	Direct water use coefficient	Economic production structure	Tourism expenditure composition	Total tourism expenditure
Food supply	-41%	-30%	8%	108%
Energy supply	-25%	-66%	4%	108%
Water supply	-93%	43%	4%	108%

and indirect TWF and TEF does not change significantly, the total quantity of TWF and TEF has increased by 34% and 58% in 2017, respectively. Based on SDA method, the increase of TWF and TEF can be largely offset by driving forces such as intensity effect (i.e. direct water or energy use coefficient) and structural effect (i.e. economic production structure) which ranged from 20 to 50%. It indicated these two driving forces of tourism direct sectors are in favor of mitigating TWF and TEF for the Chinese tourism industry. In general, the intensity effect is more significant than the structural effect. However, for the energy supply sectors, the structural effect is more significant than the intensity effect due to the reduction of intermediate requirement from tourism direct sectors. The economic production structure shows a large ramification of offset, which means that the economy has shifted toward a resource-saving mode among the intermediate inputs between the demanders and suppliers.

In summary, due to the characteristic of water-energy-food nexus in tourism, the key interlinkage of the tourism industry is the connection between food and water. According to the results of this paper, more than 12 billion m^3 of indirect water consumption from the food supply sectors to support tourism activities in China. For the development of tourism in water-deficient areas, the import of agricultural products should be increased to reduce the consumption of local water resources. Therefore, it is crucial to design a specific policy to improve the water-use efficiency in the upstream agricultural production. More efforts are needed to adopt advanced technologies on water and energy saving such as eliminating backward facilities, implementing clean energy technologies, application of unconventional water source.

The limitation of this paper belongs to the lack of more detailed input data on food, water and energy. For example, only the blue water footprint was studied due to data availability. Future studies can apply the methods proposed in this study to explore the green and gray water footprint, and even recycle or seawater.

5. Policy implications

The governance of each sector is highly complex and often comes to a discrepancy decision-making from the perspective of society, economy and environment disparities. However, the W-E-F nexus of large-scale tourism industry (such as China), can only be conducted through the systematic assessment of inter-disciplinary integration between parties and regions with a consideration of constraints such as finance, resource and time.

To develop an effective water and energy conservation plan for the sustainable tourism development in China, the first policy implication is that reducing tourists' energy use in the transportation sectors (from the perspective of tourism) will significantly reduce the energy output from the energy supply sectors. This also leads to the reduction in water demand for energy production (cooling water, etc.). Furthermore, the water saving by the reduction of energy use in the transportation sectors (from the perspective of water supply sector) can be shifted to those regions with higher water-use efficiency in the agricultural sector for irrigation activities (from the perspective of food supply sectors). As a result, a close-linked and sustainable regional tourism-food supply chain can be formed. This will mitigate both tourism water and energy footprint through the W-E-F inter-disciplinary collaboration. It is worth noting that importing food from other regions leads to an additional energy consumption. However, with the considerable reduction of indirect water use from the food supply, there will be significant decline of energy demand (electricity, etc.) for the water supply (from the perspective of energy supply sectors), especially in drought regions.

Since tourism is an end-consumption industry, the main water and energy conservation policy should focus on improving the utilization efficiency of water-energy-food resources on the consumer side. The second policy implication is that tourism sectors should be certified for implementing effective water and energy saving practices, such as hotels. Meanwhile, policies such as incentives and publicity should be implemented to encourage tourist to stay in these certified hotels.

Last but not least, water is required for each stage of energy production, and energy is essential for the provision and transport of water. Due to the interdependency between water and energy, the water conservation practices save energy while the energy conservation measurements save water. From the perspective of governments, the tourism industry should coordinate the water and energy saving initiatives by encouraging the installation of water- and energy-saving equipment such as water-saving flower sprinkling and energy saving lamps with Light Emitting Diodes (LED). In addition, the local governments are suggested to apply the price leverage (in both water and electricity supply) to stimulate the application of advanced water- and energy-saving technologies in tourism industries, especially in hotels and air transportation sectors. From the perspective of guests, consumption of water and energy are suggesting separately accounted and conducted in the room prices when people checking out, which may stimulate water and energy saving behavior.

Author statement

Lien-Chieh Lee: Writing- Original draft preparation, Data curation, Visualization, Investigation. **Yuan Wang:** Methodology, Investigation, Writing- Reviewing and Editing. **Jian Zuo:** Conceptualization, Investigation, Writing- Reviewing and Editing

Table 3
SDA of TEF change of W-E-F supply groups in 2012–2017 for the Chinese tourism industry. .

Group \ Driving force	Direct energy use coefficient	Economic production structure	Tourism expenditure composition	Total tourism expenditure
Food supply	-15%	-29%	2%	108%
Energy supply	16%	-91%	5%	108%
Water supply	-21%	43%	4%	108%

Declaration of Competing Interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105157.

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