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Quantifying the water-energy-food nexus in Guangdong, Hong Kong, and Macao regions

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ABSTRACT

Water, energy, and food are indispensable resources for regional social and economic development. The cross-regional resource transfer can increase the complexity in the coordinated management of water, energy, and food in Guangdong, Hong Kong, and Macao regions. This study proposed a footprint accounting framework for cross-regional water, energy, and food nexus, which incorporates direct flows within territory and nexus flows embodied in final consumption. An environmentally extended multi-regional input-output model was established to quantify water, energy, food, water-related energy, food-related energy, energy-related water, and food-related water footprints in Guangdong, Hong Kong, and Macao regions. The results indicated that direct energy footprint was 5.3 times of food-related and water-related energy footprints, and energy-related and food-related water footprints were 3.8 times of direct water footprint. Inter-regional trade plays an important role in the management of the water, energy, and food nexus in three regions. Hong Kong and Macao outsource huge water, energy, and food nexus footprints by importing freshwater, electricity, and food from Guangdong to satisfy local demand. The proposed footprint framework could serve as indicators or tools for measuring sustainable development goals, and the results could provide the basis for the coordinated resources management of Guangdong, Hong Kong, and Macao regions.

1. Introduction

Water, energy, and food (WEF) are three essential resources driven by population growth, urban expansion, and climate change. Global demand for WEF resources will increase by over 50% by 2050, compared to the 2015 level, and pose massive pressure on existing urban WEF systems (de Amorim et al., 2018; Yang et al., 2012). Urban WEF systems are dynamic and complex. Changes in certain factors, such as climate, energy price, technologies, and population, impact the balance of supply and demand in a city. Moreover, urban energy production and supply are often water-intensive (such as coal mining and power generation). The extraction, distribution, and treatment of water are associated with massive energy consumption. Food cultivation, storage, and manufacturing also require extensive water and energy (Chaudhary et al., 2018; Zhang et al., 2019b). These complicated linkages posed significant challenges to local decision-makers and government managers dealing with WEF-related issues. To meet this challenge, the United Nations (UN) introduced the WEF nexus as a conceptual framework to investigate mutual dependency linkages and conversion-process-coupling mechanisms (Albrecht et al., 2018; Jeswani et al., 2015). The framework can help reduce unexpected sectoral trade-offs and promote sustainable development in urban WEF systems.

Urban activities (e.g., building, lighting, and cooking) consume vast amounts of WEF resources. Sustainable utilization of WEF resources is important for cities' regular operation and future development (Martín and Grossmann, 2015; Zhang et al., 2018). In 2015, the UN introduced 17 sustainable development goals (SDGs). SDGs 2 (zero hunger), 6 (clean water and sanitation), and 7 (affordable and clean energy) directly link to urban food, water, and energy systems, respectively (Fig. 1). These are closely related to the complex linkages of urban WEF systems. For example, urban energy access (SDG 7) is a critical driver in wastewater treatment, which is vital to water availability and the urban water cycle (SDG 6).

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Nomenclature

D	Direct/physical water, energy, and food consumption
ND	nexus-oriented consumption - E-water, F-water, W-energy, and F-energy consumption
HD	hybrid consumption - the sum of direct and nexus-oriented consumption
GD	Guangdong
HK	Hong Kong
MA	Macao
PI	primary industry
SI	secondary industry
TI	tertiary industry
H-water	hybrid water - the sum of water, E-water, and F-water consumption
H-energy	hybrid energy - the sum of energy, W-energy, and F-energy consumption
H-food	hybrid food - food consumption
E-water	energy-related water - the water consumption in energy production, transportation, and consumption
F-water	food-related water - the water consumption of food irrigation, manufacturing, storage, and edible
W-energy	water-related energy - the energy consumption of water withdrawal, supply, usage, and treatment
F-energy	food-related energy - the energy consumption of food irrigation, manufacturing, storage, and edible
IO	input-output
MRIO	multi-regional input-output
EE-IOA	the environmentally extended input-output analysis
EE-MRIO	the environmentally extended multi-regional input-output model
a	direct flows (e.g., direct water, energy, and food flows)
b	nexus-oriented flows (e.g., E-water, F-water, F-energy, and W-energy)
c	hybrid flows (e.g., hybrid water, energy, and food flows)
m	corresponding consumption coefficient of nexus-oriented flows
n	material types (e.g., surface water, gasoline, and grains)
IT	total inter-regional trade flow
EX	total monetary export of region r
IM	total monetary import of region s
d	geographic distance between the region r and region s
θ_1	weight index of flow mass for the original
θ_2	weight index of flow mass for the destination
θ_3	distance weight
TC	inter-regional trade coefficient
SC	self-regional trade coefficient
T	total monetary output flow
s	intermediate flow of MRIO table
f	final consumption of MRIO table
μ	intensity of material flow
L	Leontief inverse matrix
I	an identity matrix
A	coefficient submatrix of MRIO table
IF	the intra- and inter- regional embodied flow matrix
TF	total embodied flow
TEA	per capita territorial footprints
TEAI	intensity of TEA based on value-added
VA	value-added in MRIO table
CBF	consumption-based footprints
CBFI	intensity of CBF based on final consumption
FC	final consumption

The harvesting, processing, and transportation of food (SDG 2) consumes a significant amount of energy (SDG 7), and crops (SDG 2) require water (SDG 6) to grow (Bieber et al., 2018). Furthermore, the WEF systems also indirectly affect SDGs 11 (sustainable cities and communities), 12 (responsible consumption and production), and 13 (climate action) through SDGs 2, 6, and 7. A secure and stable energy supply (SDG 7) guarantees a more reliable and cleaner water and food supply (SDG 12). Meeting this demand with fossil fuel-fired power generation instead of renewable energy (e.g., hydropower) will release more greenhouse gasses that exacerbate climate change (SDG 13). This could accelerate the evaporation of surface water, increase electricity demand and reduce food production to threaten the security of the WEF supply (SDGs 2, 6, and 7). Increasing electrification could result in massive local and community power outages (SDG 11) (Fang and Chen, 2017; White et al., 2018). The above examples show that a city's sustainable development is strongly related to WEF systems and, therefore, quantifying the WEF nexus is imperative.

In 2019, the Chinese government officially released the Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area. This area will eventually face tremendous pressure and challenges from international competition. It puts forward a higher demand and poses significant challenges in the sustainable utilization of WEF resources in the Greater Bay Area (Deng et al., 2020; Xiao et al., 2019; Zhou et al., 2018). However, the regional characteristics of the Greater Bay Area increase the complexity of WEF systems. First, the WEF resources of Guangdong, Hong Kong, and Macao are scarce. Local water resources per person in Guangdong only constitute a quarter of the world. The self-sufficiency rates of energy and food are only 13% and 23% in Hong Kong and Macao, respectively (Owen et al., 2018; Wang and Chen, 2016). Second, Hong Kong and Macao have long relied on Guangdong to supply WEF resources. Cross-regional resource allocation makes coordinated management of WEF resources difficult. Third, the differ-

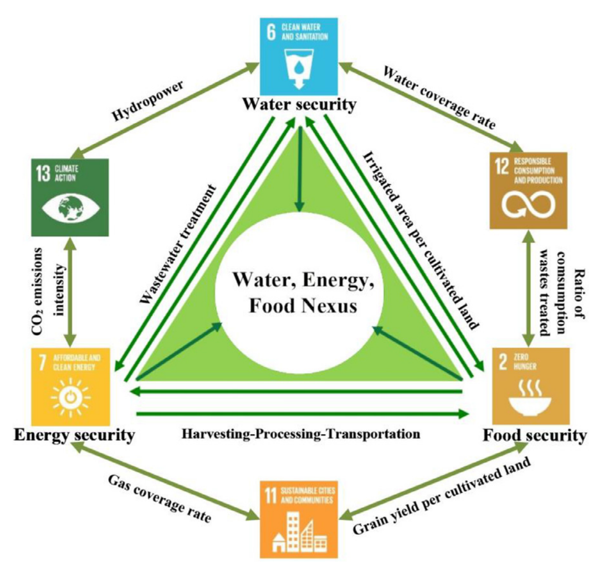

Fig. 1. The complex linkage of water-energy-food nexus and sustainable development goals.

ent social-political systems in the three regions make it challenging to implement WEF-related policies. Therefore, taking the study area of Guangdong, Hong Kong, and Macao regions, this study aims to quantify the WEF nexus and reveal the complex interactions. Results could support cross-regional joint management of WEF resources and WEF-related SDGs in Guangdong, Hong Kong, and Macao regions.

2. Literature review

Many studies have attempted to capture a holistic view of the WEF nexus system to support SDGs in recent years (Chen et al., 2018; Walker et al., 2014; Zheng et al., 2019). For example, Rasul (2016) proposed a policy framework for cross-sectoral coordination and managing nexus challenges. The study found that greater policy coherence among the three sectors was critical for decoupling increased food production from water and energy intensity and moving to sustainable and efficient resources. Olawuyi (2020) examined the legal, policy, and governance aspects of integrating and implementing the WEF nexus to achieve the SDGs. These studies underscored the importance of understanding the complex relationships between WEF-related policy and the achievement of SDGs. It is critical to developing a sustainable and secure WEF nexus (Chen et al., 2019; Xiao et al., 2019; Zhang et al., 2016). However, the above studies are mainly in qualitative analysis from a policy perspective, and lack quantitative analysis to describe the relationship between WEF and SDGs.

To further clarify the linkages of the WEF nexus to support the SDGs, an environmentally extended input-output analysis (EE-IOA) was introduced to evaluate the total environmental footprint embodied in a product or activity of WEF systems (Liu et al., 2018; Malago et al., 2021). It can link physical WEF with inter-sectoral trade based on monetary flows, further revealing the WEF nexus characteristics (Chen et al., 2017, 2020; Wang et al., 2020). For example, Zhai et al. (2019) developed an ecological network model based on an EE-IOA for an energy metabolism system. It aimed to quantify the urban metabolic processes and energy metabolism levels within the urban system and illustrate the influence of energy classification differences on the metabolism system. Zhang et al. (2019a) developed a water ecological network model based on the EE-IOA of Guangdong, aimed to analyze the water consumption structure and interaction control relationships among different sectors within an urban ecosystem. EE-IOA is an effective measure for quantifying the WEF nexus, but it highly relies on the input-output (IO) table. There is no regional IO table of Guangdong-Hong Kong-Macao, which makes it challenging to capture region's cross-regional WEF nexus characteristics (Biggs et al., 2015; Vanham et al., 2019).

Due to the lack of multi-regional IO table of Guangdong-Hong Kong-Macao, some studies have focused on the WEF systems in individual regions of Guangdong, Hong Kong, and Macao. For example, Li et al. (2014) performed a comprehensive assessment of the energy embodied in Macao's external trade based on the most recent trade statistics and embodied energy intensity databases. Chen and Li (2015) assessed a water system based on the latest water intensity databases. There is complex inter-regional coordinated allocation of WEF resources among the three regions, which will bring about embodied WEF nexus flows. To characterize the inter-regional WEF footprints of the regions, this study constructed an environmentally extended multi-regional input-output (EE-MRIO) model to analyze cross-regional linkages in the WEF nexus system. The EE-MRIO model was constructed based on multi-regional input-output (MRIO) tables of Guangdong-Hong Kong-Macao compiled in this study (Chen et al., 2018). It can quantify the inter-regional linkages and is conducive to the coordinated management of WEF systems to promote sustainable development of Guangdong, Hong Kong, and Macao regions. The accounting framework of the WEF nexus system can provide the basis for other regions at home and abroad, such as the Jing-Jin-Ji region of China and the European Union.

3. Methods

3.1. Study area

The Guangdong-Hong Kong-Macao Greater Bay Area is located in South China. It is China's economic pilot demonstration zone and external window. The area covers 0.5% of the land area, and contributes 12% to the national gross domestic product (GDP) with only 5% of the total population in 2019 (Fang and Chen, 2017; White et al., 2018). The growing population and economic activities have increased the demand for WEF resources. Hong Kong and Macao are extremely poor in WEF resources. They are typical heterotrophic cities, relying heavily on WEF resources from Guangdong Province. High resource dependency also puts great pressure on Guangdong's WEF resource systems. The detailed information of WEF nexus characteristics in this region is listed in Table 1. This study proposes a WEF nexus accounting framework based on the EE-MRIO model to reveal the three regions' WEF resource consumption and cross-regional characteristics. This framework mainly includes direct and nexus-oriented WEF consumption accounting and inter-regional WEF nexus flow evaluation. The framework is expected to provide insights into the sustainable development of the WEF system in the Greater Bay Area.

3.2. Direct and nexus-oriented water-energy-food consumption accounting

This accounting provides primary environmental account data for compiling the EE-MRIO. Direct water refers to the total physical consumption of surface water, groundwater, and purified seawater for irrigation, power generation, breeding, shipping, and other purposes. Direct energy is the sum of various physical energy consumption types (i.e., gasoline, kerosene, diesel, petroleum gas, coal, electricity, and natural gas) (Bai et al., 2018; Clough et al., 2016). Direct food refers to the physical consumption of grains, edible oils, legumes, meat, eggs, dairy, and aquatic products (see Eq. (1)) (Xin et al., 2015). The nexus-oriented consumption (e.g., energy-related water, food-related water, food-related energy, and water-related energy) is measured using the direct WEF and the corresponding consumption coefficient obtained by Liu et al. (2020). Energy-related water (E-water) mainly refers to water consumption in energy production, transportation, and consumption. Food-related water (F-water) and energy (F-energy) are water and energy consumption of food irrigation, manufacturing, storage, and edible. Water-related energy (W-energy) is the energy consumption of water withdrawal, supply, usage, and treatment, as shown in Eq. (2). Due to the lack of the corresponding consumption coefficient, water-related (W-food) and energy-related food (E-food) are not considered (Mannan et al., 2018). Meanwhile, we combine the direct and nexus-oriented consumption to form the hybrid WEF (H-water, H-energy, and H-food), as shown in Eq. (3).

$$\mathbf{D^a_{r,i}} = \sum_1^{\mathbf{n}} \mathbf{a^n_{r,i}} \tag{1}$$

$$\mathbf{ND^b_{r,i}} = \sum_1^{\mathbf{n}} \mathbf{b^n_{r,i}} \times \mathbf{m^b_{r,i}} \tag{2}$$

$$\mathbf{HD^c_{r,i}} = \mathbf{D^a_{r,i}} + \mathbf{ND^b_{r,i}} \tag{3}$$

Table 1
The water-energy-food nexus characteristics of the case area.

Study area	Guangdong	Hong Kong	Macao
Area (km^2)	179,725	1107	33
Population (10^4 person)	10,724	724	62
GDP (millions $)	1,155,882	299,679	45,415
Water-energy-food nexus characteristics	1. Guangdong supplied 57% freshwater, 25% electricity (e.g., nuclear power), and 20% food (e.g., chicken, pork, and eggs) for Hong Kong; 2. Guangdong supplied 96% freshwater, 25% electricity (e.g., coal, natural gas), and 30% food (e.g., fish, drinks, and fabrics) for Macao.		

where **a**, **b**, and **c** represent the direct, nexus-oriented, and hybrid consumption for **n**th type, respectively. **m** represents the nexus-oriented flow corresponding to the consumption coefficient. **D**, **ND**, and **HD** refer to direct, nexus-oriented, and hybrid consumption, respectively. **r** represents the region, **i** represents the sector, and **n** represents the material type.

3.3. Inter-regional flows evaluation of water, energy, and food nexus

EE-MRIO model can further track the interval flows based on the WEF consumption. The steps of constructing the EE-MRIO model are as follows. We first compiled the MRIO table of Guangdong-Hong Kong-Macao, which is the basis of EE-MRIO (Fig. A1). Due to limited statistics data of Hong Kong and Macao, the original IO table was grouped into three industries: primary industry (PI), secondary industry (SI), and tertiary industry (TI) for sector consistency (Tables A1-A3). The gravity model was adopted to modify the interactions of economic flows at the sectoral level based on bilateral trade statistics analysis. The formula for the classical gravity model is

$$\mathbf{IT_i^{r,s}} = \mathbf{e}^{\theta_0}\frac{\left(\mathbf{EX_i^r}\right)^{\theta_1}\left(\mathbf{IM_i^s}\right)^{\theta_2}}{\left(\mathbf{d^{r,s}}\right)^{\theta_3}} \tag{4}$$

where $\mathbf{IT_i^{r,s}}$ is the total inter-regional trade flows of sector **i** between region **r** and region **s**, $\mathbf{e}^{\theta_0}$ is the constant of proportionality, $\mathbf{d^{r,s}}$ is the geographic distance between the central cities of the two provinces in this study, $\mathbf{EX_i^r}$ is the total outflow, and $\mathbf{IM_i^s}$ is the total inflow. θ_1, θ_2, θ_3 are the critical parameters in which θ_1 and θ_2 are the weight indices of the flow mass for the original and destination, respectively and θ_3 represents the distance weight.

The estimation of the model parameters is key to the implementation of the gravity model. The parameters are estimated using the ordinary least squares (OLS) method. The system boundary mainly focused on inter-regional trade (e.g., import, export, and re-export) in Guangdong, Hong Kong, and Macao. Trade between the three regions and the rest of the world is excluded. The equation of the standard gravity model is as follow (Viorică, 2012).

$$\mathbf{lnF_{ij}} = \theta_0 + \theta_1\mathbf{lnGDP_i} + \theta_2\mathbf{lnGDP_j} - \theta_3\mathbf{lnD_{ij}} \tag{5}$$

where $\mathbf{F_{ij}}$ represents the bilateral trade flows between country **i** and country **j**; $\mathbf{GDP_i}$ is the gross domestic product for country **i**; $\mathbf{GDP_j}$ is the gross domestic product for country **j**; $\mathbf{D_{ij}}$ is the distance between the capitals of the two partner countries.

The inter-regional trade coefficient is then calculated, which is crucial for calculating the initial matrix of the intermediate flow and final consumption. The trade coefficient includes the inter-regional trade coefficient and self-sufficiency coefficient, as shown in Eqs. (6) and (7), respectively.

$$\mathbf{TC_i^{r,s}} = \frac{\mathbf{IT_i^{r,s}}}{\mathbf{T_i^s} + \mathbf{IM_i^s}} \tag{6}$$

$$\mathbf{SC_i^{s,s}} = \frac{\mathbf{T_i^s}}{\mathbf{T_i^s} + \mathbf{IM_i^s}} \tag{7}$$

where $\mathbf{TC_i^{r,s}}$ is inter-regional trade coefficient in region **r** and **s**, $\mathbf{IT_i^{r,s}}$ is total inter-regional trade flows, $\mathbf{T_i^s}$ is total input, $\mathbf{IM_i^s}$ is the import foreign and domestic. $\mathbf{SC_i^{s,s}}$ is self-sufficiency coefficient, indicating the percentage of self-consumption in the total input of sector **i**.

The initial regional intermediate flows and final consumption can be calculated using the diagonal matrix of the self-sufficiency coefficient and inter-regional trade coefficient, as shown in Eqs. (8)-(11):

$$\left[\mathbf{s_{i,j}^{r,s}}\right]_{\mathbf{n\times n}} = \mathbf{diag}\left[\mathbf{TC_i^{r,s}}\right]_{\mathbf{n\times n}} \times \left[\mathbf{s_{i,j}^{s}}\right]_{\mathbf{n\times n}} \tag{8}$$

$$\left[\mathbf{f_{i,j}^{r,s}}\right]_{\mathbf{n\times m}} = \mathbf{diag}\left[\mathbf{TC_i^{r,s}}\right]_{\mathbf{n\times n}} \times \left[\mathbf{f_{i,j}^{s}}\right]_{\mathbf{n\times m}} \tag{9}$$

$$\left[\mathbf{s_{i,j}^{s,s}}\right]_{\mathbf{n\times n}} = \mathbf{diag}\left[\mathbf{SC_i^{s,s}}\right]_{\mathbf{n\times n}} \times \left[\mathbf{s_{i,j}^{s}}\right]_{\mathbf{n\times n}} \tag{10}$$

$$\left[\mathbf{f_{i,j}^{s,s}}\right]_{\mathbf{n\times m}} = \mathbf{diag}\left[\mathbf{SC_i^{s,s}}\right]_{\mathbf{n\times n}} \times \left[\mathbf{f_{i,j}^{s}}\right]_{\mathbf{n\times m}} \tag{11}$$

where $[\mathbf{s_{i,j}^{r,s}}]_{\mathbf{n\times n}}$ and $[\mathbf{s_{i,j}^{s,s}}]_{\mathbf{n\times n}}$ are intermediate flow matrices of the EE-MRIO table, $[\mathbf{f_{i,j}^{r,s}}]_{\mathbf{n\times m}}$ and $[\mathbf{f_{i,j}^{s,s}}]_{\mathbf{n\times m}}$ are final consumption matrix of the EE-MRIO table, and $\mathbf{diag}[\mathbf{TC_i^{r,s}}]_{\mathbf{n\times n}}$ and $\mathbf{diag}[\mathbf{SC_i^{s,s}}]_{\mathbf{n\times n}}$ are the diagonal matrices of the inter-regional trade coefficient and self-sufficiency coefficient, respectively. $[\mathbf{s_{i,j}^{s}}]_{\mathbf{n\times n}}$ and $[\mathbf{f_{i,j}^{s}}]_{\mathbf{n\times m}}$ are intermediate flow matrix and final consumption matrix of the single-regional IO table, respectively.

The initial matrix of the intermediate flow and final consumption can be acquired as described above. Since the multi-regional generalized bi-proportional matrix balancing technique updating (GRAS) model is now a widely used bi-proportional technique for updating or balancing IO tables and can maintain the initial matrix structure to enable it to reach a new balanced state (Umed et al., 2019). The GRAS model is adopted to balance the initial multi-regional table.

The EE-MRIO can be constructed based on the direct and nexus-oriented WEF consumption accounting and MRIO table. We can account for the embodied WEF nexus flows based on the EE-MRIO. Here, the Leontief matrix quantifies the embodied flows triggered by final consumption. The formula is given by Eqs. (12)-(15):

$$\mu_{\mathbf{r,i}}^{\mathbf{t}} = \frac{\mathbf{D_{r,i}^t}}{\mathbf{T_i^r}} \tag{12}$$

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1},\ \mathbf{A} = \left[\frac{\mathbf{s_{i,j}^{r,s}}}{\mathbf{T_j^s}}\right]_{\mathbf{n\times n}} \tag{13}$$

$$\begin{aligned}\mathbf{IF^t} &= \begin{pmatrix}\mathbf{IF_{r,r}^t} & \mathbf{IF_{r,s}^t}\\ \mathbf{IF_{s,r}^t} & \mathbf{IF_{s,s}^t}\end{pmatrix} = \mathbf{diag}\left[\mu_{\mathbf{r,i}}^{\mathbf{t}}\right] \times \mathbf{L} \times \mathbf{F}\\ &= \begin{pmatrix}\mu_{\mathbf{r,i}}^{\mathbf{t}} & 0\\ 0 & \mu_{\mathbf{s,i}}^{\mathbf{t}}\end{pmatrix}\begin{pmatrix}\mathbf{L_{r,r}} & \mathbf{L_{r,s}}\\ \mathbf{L_{s,r}} & \mathbf{L_{s,s}}\end{pmatrix}\begin{pmatrix}\mathbf{f_{r,r}} & \mathbf{f_{r,s}}\\ \mathbf{f_{s,r}} & \mathbf{f_{s,s}}\end{pmatrix}\end{aligned} \tag{14}$$

$$\mathbf{TF_i^t} = \sum_{\mathbf{j=1}}\mathbf{IF_{r(j)\to s(i)}^t} + \sum_{\mathbf{j=1}}\mathbf{IF_{s(i)\to r(j)}^t} \tag{15}$$

Table 2
Specification of collected data.

Data	Time	Category	Source of data	Illustration
Direct consumption	All parameters measured on 2015	Water	Guangdong Province Water Resources Department (2015), Hong Kong Water Supplies Department (2015), and Macao Statistics and Census Service (2015)	Surface water, groundwater, and purified seawater
		Energy	Guangdong Province Statistics Bureau (2015b), Hong Kong Census and Statistics Department (2015b), and Macao Direct Services of Protect Ambiental (2015)	Gasoline, kerosene, diesel, petroleum gas, coal, electricity, and natural gas
		Food	Guangdong Province Natural Resources Department (2015), Hong Kong Census and Statistics Department (2015a), and Macao Cartography and Cadastre Bureau (2015)	Grains, edible oils, legumes, meat, eggs, dairy and aquatic products
Consumption coefficients		Nexus-oriented WEF nexus	Liu et al. (2020)	Energy-related water, food-related water, food-related energy, water-related energy
Single-regional input-output table		Guangdong	Guangdong Province Statistics Bureau (2015a)	The database of Guangdong Provincial Bureau of Statistics
		Hong Kong	Organization for Economic Co-operation and Development (2015)	The database of OECD
		Macao	Eora Global Value Supply Chain database (2015)	The database of Eora
Actual trade volume		Guangdong	Guangdong Province Statistics Bureau (2015b)	The total interregional import-export trade monetary volume and GDP of Guangdong-Hong Kong, Guangdong-Macao, and Hong Kong-Macao
		Hong Kong	Hong Kong Census and Statistics Department (2015a)	
		Macao	Macao Statistics and Census Service (2015)	

where t is the material flow type (i.e., water, energy, food, and nexus-oriented flows), $\mu^t_{r,i}$ is the intensity of the flow of t type of sector i in region r, $D^t_{r,i}$ is the direct consumption, T^r_i is the total monetary output flow of sector i in region r in the MRIO table. L is the Leontief inverse matrix which refers to all sectors direct and nexus-oriented requirement coefficients; I is an $n \times n$ identity matrix; A is a coefficient submatrix that represents the direct requirement of the MRIO table, and it can be acquired by the inter-regional and inter-sectoral monetary flows ($s^{r,s}_{i,j}$) divided by sector j in region s total output monetary flow (T^s_j). IF^t refers to the intra- and inter-regional embodied flows triggered by the final consumption (F), which includes the expenditure of households, expenditure of the general government, and gross capital formation. TF^t_i represents the total embodied flow between regions r and s of t type of sector i, in which $IF^t_{r(j)\to s(i)}$ refers to the flow from region r to region s and $IF^t_{s(i)\to r(j)}$ to the flow from region s to region r.

3.4. Footprints evaluation of water, energy, and food nexus

The per capita territorial accounting (TEA) and consumption-based footprints (CBF) were applied to quantify the footprint of the WEF nexus. The TEA refers to the direct and nexus-oriented WEF consumption footprints occurring within a region. CBF is the total embodied WEF flow driven by final consumption related to inter-regional trade (Chen et al., 2019). The ecological footprints of the WEF can be expressed by TEA and CBF intensities by the value-added and final consumption in the MRIO table, as shown in Eqs. (16)-(19):

$$TEA^t_{r,i} = \frac{D^t_{r,i}}{RP_r} \tag{16}$$

$$CBF^t_{r,i} = \frac{TF^t_{r,i}}{RP_r} \tag{17}$$

$$TEAI^t_{r,i} = \frac{TEA^t_{r,i}}{VA^t_{r,i}} \tag{18}$$

$$CBFI^t_{r,i} = \frac{CBF^t_{r,i}}{FC^t_{r,i}} \tag{19}$$

where RP_r is the resident population in region r, $TEA^t_{r,i}$ is the direct consumption footprint, $D^t_{r,i}$ is the direct consumption, and $CBF^t_{r,i}$ is the embodied flows driven by the final consumption; $TF^t_{r,i}$ represents the total embodied flows; $TEAI^t_{r,i}$ and $CBFI^t_{r,i}$ are the intensities of TEA and CBF, $VA^t_{r,i}$ and $FC^t_{r,i}$ are the value-added and final consumption.

3.5. Data sources

As shown in Table 2, the data on direct consumption of WEF was collected from the annual reports of water resources, the environment, and energy in Guangdong, Hong Kong, and Macao. Nexus-oriented consumption is measured based on direct WEF and the corresponding consumption coefficient obtained by Liu et al. (2020). The Guangdong-Hong Kong-Macao MRIO table was compiled based on the single-regional IO table of the three regions (in 2015) from the Statistics Bureau of Guangdong Province, the Organization for Economic Co-operation and Development (OECD), and the Eora global value supply chain database (Eora), respectively, which have been widely used for multi-regional IO analysis (Giljum et al., 2019). The Eora is currently the only database globally that can obtain the single IO table of Macao. The IO table types of Hong Kong and Macao in Eora are the SUT (supply-use table) and IIOT (industry-by-industry table), respectively, which are two different methods for compiling IO tables, and were developed based on the industrial sector process and product process assumptions. The IO table types of Hong Kong in OECD are the IIOT, and the OECD has no single IO table of Macao. The types of Guangdong IO table is also IIOT. To ensure the consistency of the types of the three IO tables, this study used Macao's IO table obtain from Eora database and Hong Kong's IO table obtained from the OECD database to build the MRIO. The data in gravity model, which mainly includes the amount of imports, exports, and GDP, is from the Guangdong Province Statistics Bureau, Hong Kong Census and Statistics Department, and Macao Statistics and Census Service in 2011–2016.

4. Results

4.1. Direct and nexus-oriented footprints of water-energy-food nexus

The direct and nexus-oriented consumption of the WEF is shown in Fig. 2. Dominant consumption varied in different types of WEF footprints. For water footprints, Guangdong, Hong Kong, and Macao had similar water consumption structures. Food-related water had one of the largest proportions of hybrid water, with an average of 78%. Direct water also played an important role in that it took up 21% of hybrid water. Compared to food-related and direct water footprints, the proportion of energy-related water was negligible (approximately 1%). The results confirmed previous research that food was the most important contributor to water consumption (de Amorim et al., 2018; White et al., 2018; Zhang et al., 2019a). The high water consumption rate of food is the main reason for this result. To further explore food-related water footprint characteristics, this study analyzed the main process of food consumption (i.e., irrigation, manufacturing, storage and transport, and edible). The edible process accounted for the largest proportion of food-related water consumption; especially for Hong Kong and Macao, the proportion was 98% and 99%, respectively. In Guangdong Province, this proportion was 66%, and the irrigation process took up 27%. This is mainly because 20% of the food in Guangdong Province is produced locally, while Hong Kong and Macao produce no food locally and import most of their food from foreign regions, indicating that the edible food process dominates food-related water footprints. Large imports of water-intensive food may increase local water stress, and reducing food waste would be an excellent choice to ease water stress. The irrigation process cannot be ignored in Guangdong, and efficient water-saving infrastructure is necessary. Extensive management of the food-related water footprint may directly affect the sustainable development of water resource systems in the three regions and indirectly affect the security of the food supply. Especially for Guangdong Province, the transfer of water pressure will directly affect the realization of SDGs 2 and 6.

For energy footprints, Guangdong, Hong Kong, and Macao had similar energy consumption structures, but the structure was different from water. Direct energy footprint dominated in hybrid energy, with an average proportion of 84%. The proportion of food-related and water-related energy was lower than direct energy; their proportions were 6% and 10%, respectively. These results indicated that the energy footprint was dominated by physical energy consumption. Although saving physical energy consumption is important, food-related and water-related energy footprints still play an important role in hybrid energy, especially for Hong Kong and Macao, their proportions had exceeded 10%. The fact that Hong Kong and Macao import a large amount of freshwater and food from Guangdong per year may be an important reason for this result. In food-related energy, the storage and transport (e.g., refrigeration, truck, train, and plane) and edible (e.g., cooking) processes were important in energy saving. In water-related energy, the most important process was water usage, such as shower, washing, heating, and greening. Besides, more attention should be paid to physical energy consumption, and some practical energy-saving facilities could be adopted, for instance, solar street lamp, reduce the use time of air conditioning, and green transformation of high energy consumption enterprises. Reducing physical energy consumption footprints can effectively reduce energy supply pressure and greenhouse gas emissions in the three regions, contributing to SDGs 7 and 13. Reducing the food-related and water-related energy footprints can serve as a complementary measure to enhance energy conservation; especially in Hong Kong and Macao, they should further strengthen imported freshwater and food management.

4.2. Inter-regional embodied footprints of water-energy-food nexus

Fig. 3 illustrates the inter-regional embodied WEF flows between Guangdong, Hong Kong, and Macao. We found the embodied resources transferred from Guangdong to Macao dominate in all types of WEF nexus flow networks. The biggest difference was in Guangdong's secondary industry, in which the transfer from Hong Kong and Macao to Guangdong was 90 times

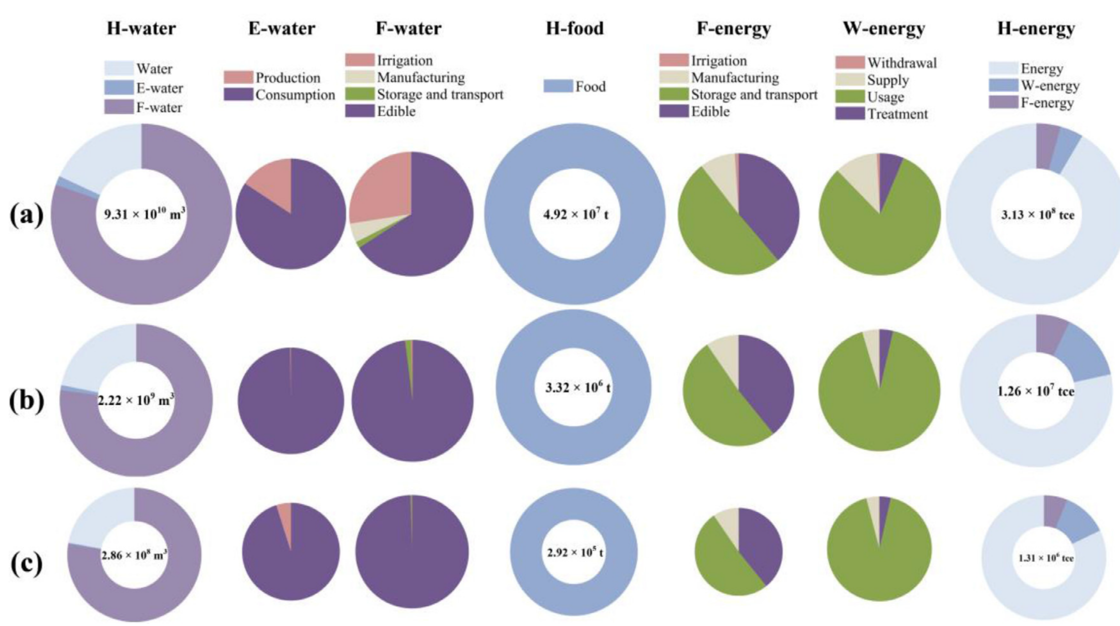

Fig. 2. The direct and nexus-oriented consumption of water, energy, and food. Note: (a): Guangdong; (b): Hong Kong; (c): Macao; H-water: hybrid water; E-water: energy-related water; F-water: food-related water; H-food: hybrid food; F-energy: food-related energy; W-energy: water-related energy; H-energy: hybrid energy. The size of circles is the relative value of water, energy, and food consumption, not the absolute value.

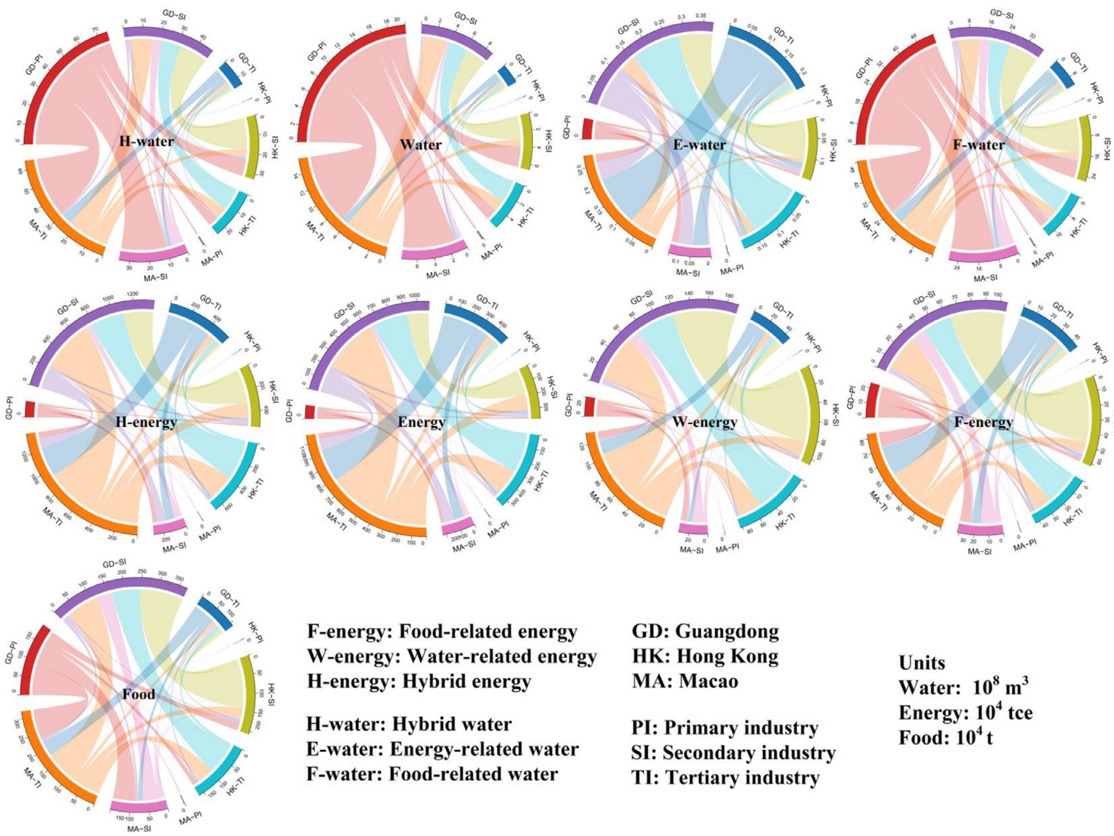

Fig. 3. Inter-regional sectoral water, energy, and food flows.

bigger than the opposite direction in the direct water network, while the smallest gap lay in the energy-related water network, which was 2 times bigger. Dominant exporting sectors vary in different types of WEF nexus flow networks.

Hong Kong and Macao were highly influenced by Guangdong's primary industry in all types of WEF networks. Especially in water-related networks, secondary and tertiary industries in Macao were the largest importing sector, which took up approximately 80%. Plenty of agricultural products are sold to Macao for reprocessing to meet the final consumption demand of local. This is mainly caused by the lack of primary agricultural products in Macao. Hong Kong was relatively less dependent than Macao in all types of WEF nexus flow networks. Guangdong's secondary industry had a dominant impact on Hong Kong and Macao. The import of embodied water was 90 times that of export. Hong Kong and Macao outsource huge products to Guangdong, originated from advanced manufacturing-related activities of latter. Although this transfer can effectively promote the economic development of the three regions, it may put more pressure on Guangdong's WEF resource systems. The flow distribution of embodied WEF resources was relatively dispersive in terms of Guangdong's tertiary industry, where manufacturing and services sectors are all important in characterizing their embodied flows. The exports had a higher proportion than imports in hybrid energy, direct energy, energy-related water, and food-related water networks. In contrast, service products export dominated in all types of WEF nexus flow networks of Hong Kong and Macao's tertiary industry. The above results indicated that the three regions were highly shared WEF resource communities. The primary industry in Guangdong was almost entirely a net export of WEF resources to Hong Kong and Macao. This will further increase the burden on the former. Similarly, embodied WEF resources transfer from Hong Kong and Macao to Guangdong's secondary industry may also negatively impact. Developing local agriculture and manufacturing in Hong Kong and Macao may be a good way to achieve sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12).

4.3. Inter-regional water-energy-food nexus footprints driven by final consumption

Fig. 4 shows the inter-regional WEF nexus footprints driven by various final consumption categories. Dominated WEF footprints embodied in final consumption varied in Guangdong, Hong Kong, and Macao. For example, embodied footprints in gross capital formation were highest in Guangdong Province, with an average proportion of 53%; Hong Kong's embodied footprints were mainly focused on the expenditure of households (56%); the proportion of embodied footprints in gross capital formation and expenditure of households in Macao were equal, approximately 43%. These results are closely related to the industrial structure of the three regions. Hong Kong and Macao are consumer-type regions, and both residents and tourists contribute huge consumption. Their embodied footprints in the expenditure of households were significantly higher than Guangdong (39%). Guangdong has relatively complete production chains within its territory, including resources extraction, manufacturing, and processing industries, and has invested heavily in buildings and equipment to keep the whole industry chain running. In contrast, Hong Kong and Macao's products are primarily outsourced to other regions, and Guangdong is an important partner. Thus Hong Kong (29%) and Macao (43%) have a lower investment in buildings and equipment than Guangdong.

Fig. 5 shows the per capita territorial-based accounting (TEA) and consumption-based (CBF) footprints of Guangdong, Hong Kong, and Macao. Guangdong and Hong Kong had a larger TEA than CBF regarding all types of metabolic flow. The impact of four energy-related flows (i.e., physical, water-related, food-related, and

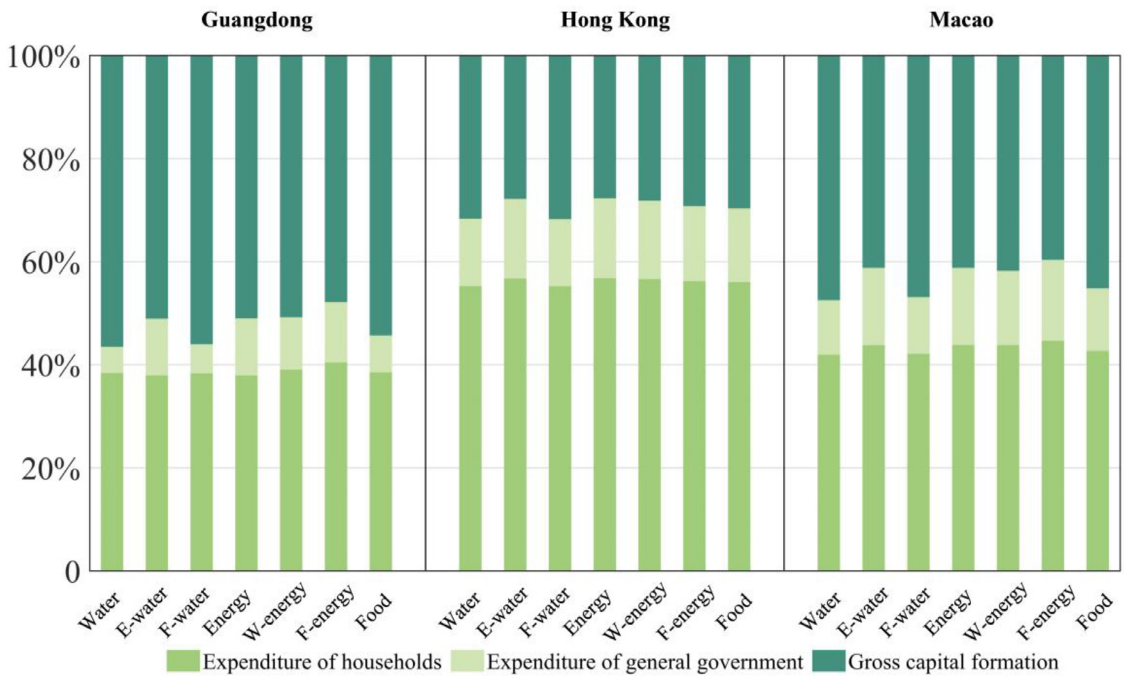

Fig. 4. The contribution of water, energy, and food driven by final consumption. Note: H-water: hybrid water; E-water: energy-related water; F-water: food-related water; H-food: hybrid food; F-energy: food-related energy; W-energy: water-related energy; H-energy: hybrid energy.

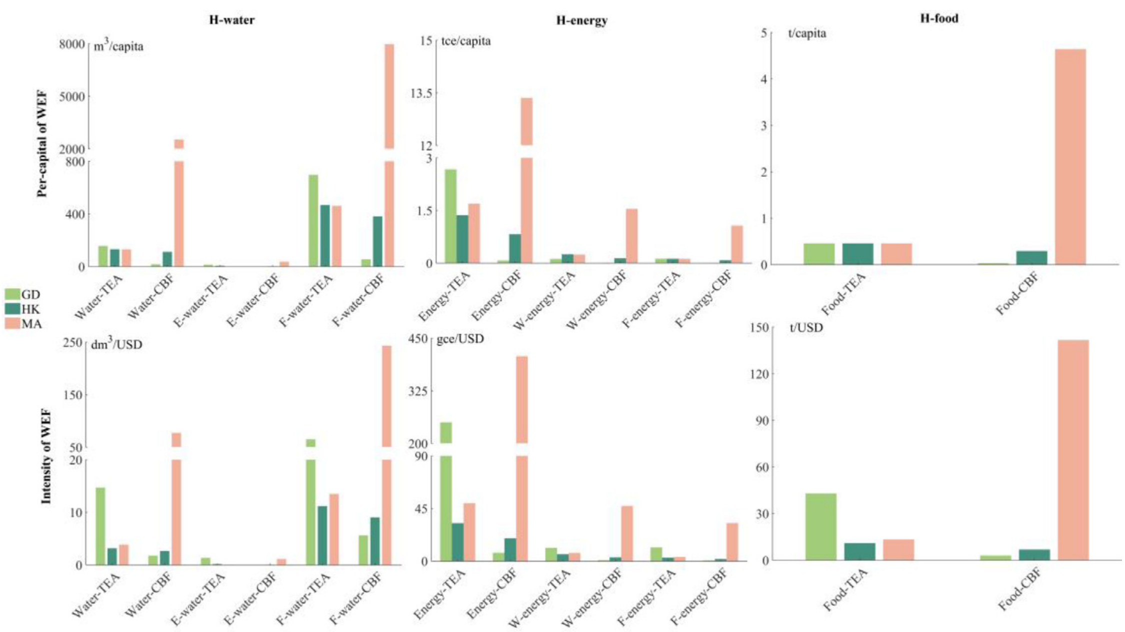

Fig. 5. Water-energy-food territorial-based and consumption-based footprints. Note: GD: Guangdong, HK: Hong Kong, MA: Macao, TEA: territorial-based accounting, CBF: consumption-based footprints, H-water: hybrid water; E-water: energy-related water; F-water: food-related water; H-food: hybrid food; F-energy: food-related energy; W-energy: water-related energy; H-energy: hybrid energy.

hybrid energy) was higher from a consumption-based perspective in Guangdong and Hong Kong, while the difference between TEA and CBF was small in terms of four water-related flows (i.e., physical, energy-related, food-related, and hybrid water). For instance, the energy TEA in Guangdong was 37 times that of CBF, while the value in water flow was 8.8. These results indicated that export production was the significant driver of Guangdong and Hong Kong's energy system pressure, which often includes energy-intensive and high-carbon industries. On the contrary, Macao had notably higher WEF footprints from a consumption-based perspective, among which the difference in energy-related water was largest; the CBF was 22 times higher than its TEA. The environmental impact of Macao's economy is mainly induced by the high consumption by its urban citizens. The CBF intensities of WEF footprints in Macao were significantly higher than TEA and all types of metabolic flow in Guangdong and Hong Kong. The intensity of CBF in energy-related water was 23 times higher than TEA. The high CBF in Macao is mainly due to the consumption associated with services sectors such as wholesale, retail trade, repairs, hotels, and restaurants. The above results showed that Guangdong, Hong Kong, and Macao were all consumption-oriented regions, especially in food-related water, physical water, and energy consumption footprints. Relatively, there are shortcomings in infrastructure and policy-making. The mismatch between excessive consumption and lack of savings measures can adversely affect the realization of all WEF-related SDGs (i.e., SDGs 2, 6, 7, 11, 12, and 13).

5. Discussions

5.1. Increasing utilization efficiency and local water, energy, and food supply

To reduce the impact of nexus footprints outsourcing on the local WEF systems in Guangdong, the government should accelerate the structural upgrading of the WEF-related industries. Traditional water and energy-intensive industries should be phased out and upgraded on priority in Guangdong, for instance, agriculture, food processing factory and electricity, stem, heat supply, and production. Hong Kong and Macao should strengthen publicity and education focusing on food conservation and develop advanced water and energy-saving techniques. Fossil fuel subsidies for the production and supply of electricity, heat, gas, and water should be reduced or eliminated. The government encourages related industries to develop renewable energy (e.g., wind, nuclear and solar power) by strengthening subsidies and technical support. Renewable and other clean energy will result in a general net positive effect for the Energy SDG (SDG 7) and also for the water and food SDGs. As the access to clean and affordable energy increases to meet this goal, careful attention to synergies with water and food goals will need to be pursued to increase the potential for positive synergies and improvements over traditional energy sources.

Furthermore, Hong Kong and Macao are very rich in coastal resources. Abundant seawater resources would be a good choice, and Hong Kong has shown an excellent example of flushing toilets with seawater. At present, sea-rice technology has been put into practice, and the regions can make great efforts to promote sea rice. Hong Kong and Macao have the advantage of being a vibrant region and sufficient money to guarantee the implementation of these technologies. Offshore wind and tidal power could also provide more electricity for Hong Kong and Macao. Offshore wind power generation is a globally recognized renewable energy generation technology and has been widely used. Although tidal power is an expensive technology for generating electricity, it plays an increasingly important role in relieving global energy shortage problems. Many countries/regions have built tidal power stations, such as France, England, the United States, Canada, and China. It is helpful to develop tidal power for promoting energy structure transformation and achieving sustainable energy supply in Hong Kong and Macao. The authorities can propose policies of financial subsidies and tax exemptions to support the development of renewable energy. The above technologies are beneficial for the sustainable utilization of WEF resources in the two regions, especially in achieving SDGs 2 (zero hunger), 6 (clean water and sanitation), and 7 (affordable and clean energy).

5.2. Strengthen inter-regional cooperation

The critical trade-offs and synergies of the WEF nexus play significant roles in achieving the SDGs. The externalization of water-related footprints is prominent in Hong Kong and Macao, posting a big challenge for promoting water sustainability within its boundary. The influence of upstream production efficiencies on water and food footprint would cause uncertainty on measuring sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12) of the regions. It is necessary to establish the organizations (i.e., United Nations and European Union) that are dedicated to the across-regional coordinated management of WEF resources. A budgetary allocation system could be constructed for the management of WEF resources. By balancing many factors (e.g., interests, regime, law, standard, and public opinion), the maximum benefits can be achieved to effectively open up the production and consumption of resource products in the three regions. Based on economic means such as taxation and finance, the organizations can reduce the consumption footprints by conducting targeted demand management for those products embodied with high water and energy footprints and appropriately adjust the price of related products. The complementarity of economic structure and consumption pattern between regions can create opportunities to address environmental burdens and social inequality.

5.3. From incompact to delicacy management on food-related water consumption footprints

The research of nexus has been accelerating, but there is still debate over whether equal attention should be paid to all types of nexus. Our results showed that the energy-related nexus footprints were only a small proportion of the total WEF footprints, either territorial or consumption-based. However, the food-related water footprint took up most of the total water footprints, and the specific consumption of nexus flows turns out much more intensive than generic energy and water consumption, especially for food-related water footprint. The direct intensities of food-related water are significantly higher than total water intensities. Such intensity gap is even more prominent in embodied flow intensities for Hong Kong and Macao regions. This intensity gap implies our management of nexus flows is more incompact than what has been done on generic energy and water flows. For example, when considering the technology of pumping water from Hong Kong and Macao to Guangdong, water resource volume and water quality usually dominate the decision-making process, while little attention has been paid to energy consumption. Also, not enough thought has been given to conserving water resources when using water in food processing. The low efficiencies of nexus flow increase water footprints faster than the regional economy on average. Especially for Hong Kong and Macao, as global consumer markets, this inefficient management of the WEF nexus may cause even bigger problems due to the amplified energy and water consumption and indirectly transmit the risk to Guangdong. A shift from incompact to delicacy management on food-related water consumption footprints could positively affect SDG 12.

5.4. Limitations

There are some limitations to the analysis and the data used. First, due to the data availability, the WEF nexus analysis was only made from three industries. Rough classification makes it difficult to obtain more detailed sectoral WEF consumption inventories. Some sectors in the secondary industry with large WEF consumption footprints cannot be conducted in-depth analysis (e.g., electricity, steam, heat supply, electrical equipment, and construction). Second, the IO tables of Guangdong, Hong Kong, and Macao come from three databases. Uncertainties were artificially introduced when compiling the MRIO, which has an impact on the results of interregional flows and footprint accounting. For example, the individual databases selected for this study are officially recognized and widely used in many studies, it is difficult to fully verify the consistency of the IO table since the way IOs are compiled. Third, water-related food (W-food) mainly refers to water quality decline caused by food residues entering the water body. Energy-related food (E-food) mainly refers to biofuels, such as biogas and biomass alcohol. As the corresponding consumption coefficient is difficult to obtain, water-related food and energy-related food were not considered in the WEF-related studies. The corresponding consumption coefficient could be obtained by field survey in future research through the actual survey.

6. Conclusions

This study quantified the WEF nexus in Guangdong, Hong Kong, and Macao by constructing an environmentally extended multi-regional input-output model and realized the direct and nexus-oriented consumption, as well as the quantification of inter-regional flows and WEF nexus footprints. Based on the results, three main conclusions have been indicated by this paper.

First, the dominant consumption in Guangdong, Hong Kong, and Macao varied in all types of WEF footprints within their territories. The delicacy management of food-related water and direct energy footprints may be key nodes to solve the WEF resources constraint conflicts, especially for consumption-oriented regions (i.e., Hong Kong and Macao). More strict management measures of WEF resources should be formulated to avoid excessive waste.

Second, Guangdong, Hong Kong, and Macao are highly shared WEF resource communities. Hong Kong and Macao outsource huge WEF nexus footprints by importing freshwater, electricity, and food from Guangdong to satisfy the demand of local service industries. Therefore, a cooperative framework for managing these footprints across boundaries is required, and tertiary industry of Hong Kong and Macao and secondary industry of Guangdong Province should share the responsibility of reducing the WEF nexus footprints.

Third, the vast gap in direct and nexus intensities implies that Guangdong, Hong Kong, and Macao should make more efforts to manage nexus footprints. Developing water and energy conservation infrastructure, promoting food saving promotion, developing sea-rice technology, flushing toilets with seawater, and developing renewable energy are options to reduce the impact of nexus footprints intensities gap in Hong Kong and Macao.

This study could provide the following lessons for further research in other regions (e.g., China, Asia, and European Union). First, promoting coherence and coordination in WEF resources and implementing SDGs 2, 6, and 7 requires a clear, comprehensive, and integrative accounting framework that explores the WEF nexus. Our research can provide the basis for other areas based on direct and nexus-oriented WEF footprints. Second, the resource consumption embodied in inter-regional trade is important for managing the WEF resource. The EE-MRIO could reveal this complex relationship and provide support for multi-regional cooperation. Third, footprint accounting is an important index for measuring the consumption level of WEF resources in a region. TEA and CBF footprints can be used as vital parameters to reveal the relationship between WEF utilization and SDGs in other regions.

Declaration of Competing Interest

The authors declare no competing interests.

CRediT authorship contribution statement

Pan Zhang: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Yanpeng Cai:** Conceptualization, Validation, Writing – review & editing, Supervision. **Ya Zhou:** Conceptualization, Validation, Writing – review & editing, Supervision. **Qian Tan:** Writing – review & editing. **Bowen Li:** Data curation, Investigation. **Bo Li:** Data curation, Investigation. **Qunpo Jia:** Data curation, Investigation. **Zhifeng Yang:** Writing – review & editing.

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Appendix A

Fig. A1, Table A1, Table A2, Table A3

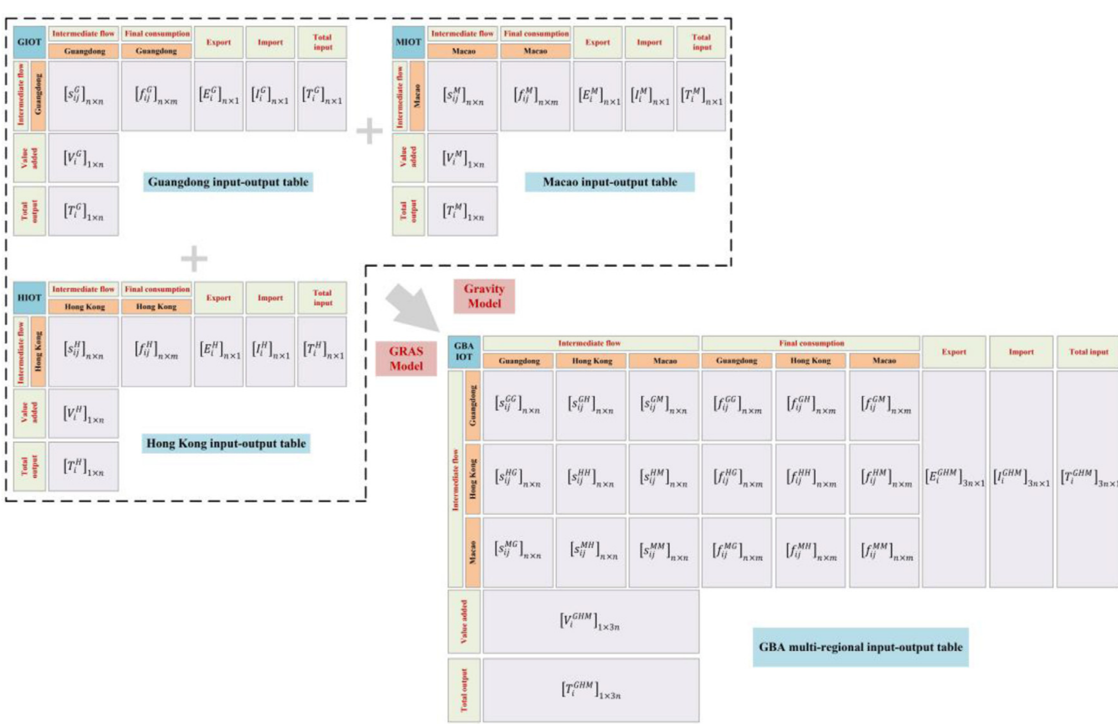

Fig. A1. The framework process of the multi-regional input-output table. Note: G: Guangdong, H: Hong Kong, M: Macao, s: sector, f: final consumption, E: export, I: import, T: total input/output.

Table A1
Aggregated original sectors of the input-output table for Guangdong.

Aggregated sectors	Original sectors in Guangdong	Original sectors number
Primary Industry (PI)	Agriculture, forestry, animal husbandry and fishery	G1
Secondary Industry (SI)	Coal mining and dressing	G2
	Petroleum and natural gas extraction	G3
	Metal ore mining	G4
	Non-metal minerals mining	G5
	Manufacture of food products and tobacco processing	G6
	Textiles	G7
	Wearing apparel, leather, fur, down and related products	G8
	Sawmills and furniture	G9
	Paper and products, printing and record medium reproduction	G10
	Petroleum processing, coking and nuclear fuel processing	G11
	Chemical industry	G12
	Nonmetallic mineral products	G13
	Metal smelting and pressing	G14
	Metal products	G15
	General purpose machinery	G16
	Special purpose machinery	G17
	Transport equipment	G18
	Electric equipment and machinery	G19
	Electronic and telecommunication equipment	G20
	Instruments, meters, cultural and office machinery	G21
	Art ware and other manufacturing products	G22
	Scrap and waste	G23
	Metal products, machinery and equipment repair services	G24
	Electricity, stem and hot water production and supply	G25
	Gas production and supply	G26
	Water production and supply	G27
	Construction	G28
Tertiary Industry (TI)	Wholesale and retail trade services	G29
	Transport, storage and post services	G30
	Accommodation and food serving services	G31
	Telecommunication, computer services and software	G32
	Finance and insurance	G33
	Real estate	G34
	Rental and business services	G35
	Scientific research	G36
	Water resources, environment and public facilities management	G37
	Residential services and other social services	G38
	Educational services	G39
	Health, social security and welfare	G40
	Cultural, sporting and recreational services	G41
	Public management and social organization	G42

Table A2
Aggregated original sectors of the input-output table for Hong Kong.

Aggregated sectors	Original sectors in Hong Kong	Original sectors number
Primary Industry (PI)	Agriculture, forestry and fishing	H1
Secondary Industry (SI)	Mining and extraction of energy producing products	H2
	Mining and quarrying of non-energy producing products	H3
	Mining support service activities	H4
	Food products, beverages and tobacco	H5
	Textiles, wearing apparel, leather and related products	H6
	Wood and of products of wood and cork (except furniture)	H7
	Paper products and printing	H8
	Coke and refined petroleum products	H9
	Chemicals and pharmaceutical products	H10
	Rubber and plastics products	H11
	Other non-metallic mineral products	H12
	Manufacture of basic metals	H13
	Fabricated metal products, except machinery and equipment	H14
	Computer, electronic and optical products	H15
	Electrical equipment	H16
	Machinery and equipment N.E.C.	H17
	Motor vehicles, trailers and semi-trailers	H18
	Other transport equipment	H19
	Other manufacturing; repair and installation of machinery and equipment	H20
	Electricity, gas, water supply, sewerage, waste and remediation services	H21
	Construction	H22
Tertiary Industry (TI)	Wholesale and retail trade; repair of motor vehicles	H23
	Transportation and storage	H24
	Accommodation and food services	H25
	Publishing, audiovisual and broadcasting activities	H26
	Telecommunications	H27
	IT and other information services	H28
	Financial and insurance activities	H29
	Real estate activities	H30
	Other business sector services	H31
	Public administration and defense; compulsory social security	H32
	Education	H33
	Human health and social work	H34
	Arts, entertainment, recreation and other service activities	H35
	Private households with employed persons	H36

Table A3
Aggregated original sectors of the input-output table for Macao.

Aggregated sectors	Original sectors in Macao	Original sectors number
Primary Industry (PI)	Agriculture	M1
	Fishing	M2
Secondary Industry (SI)	Mining and quarrying	M3
	Food & beverages	M4
	Textiles and wearing apparel	M5
	Wood and paper	M6
	Petroleum, chemical and non-metallic mineral products	M7
	Metal products	M8
	Electrical and machinery	M9
	Transport equipment	M10
	Other manufacturing	M11
	Recycling	M12
	Electricity, gas and water	M13
	Construction	M14
Tertiary Industry (TI)	Maintenance and repair	M15
	Wholesale trade	M16
	Retail trade	M17
	Hotels and restaurants	M18
	Transport	M19
	Post and telecommunications	M20
	Financial intermediation and business activities	M21
	Public administration	M22
	Education, health and other services	M23
	Private households	M24
	Others	M25
	Re-export & re-import	M26

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