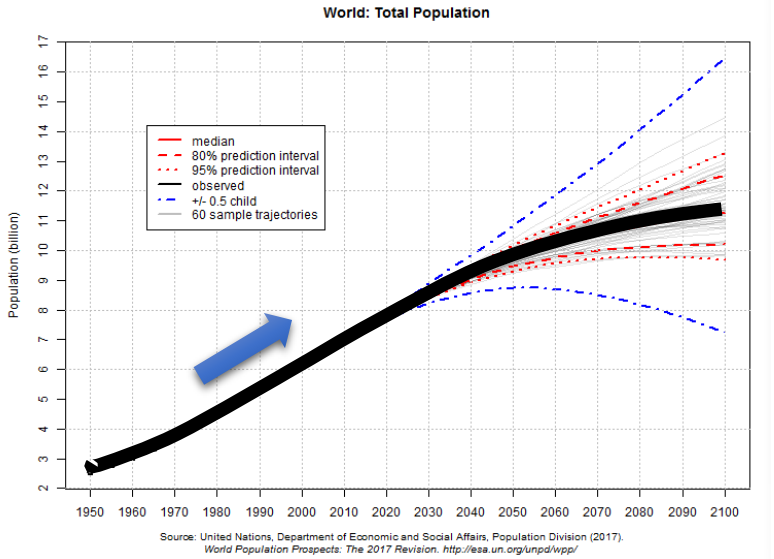
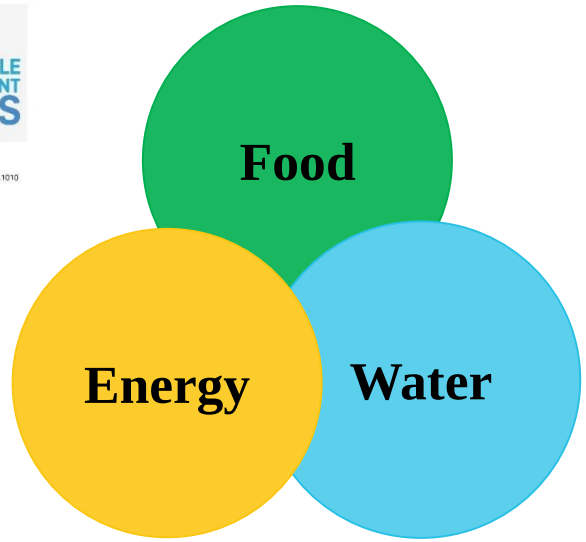
Food-Energy-Water Resources in Circular Economy and Their Nexus

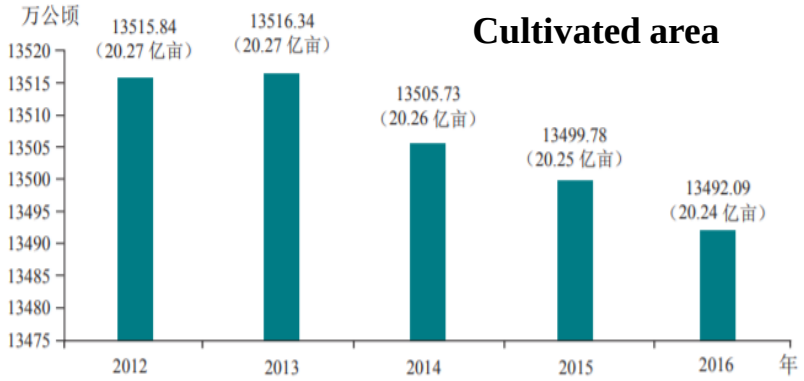
Sai Liang, Ph.D.

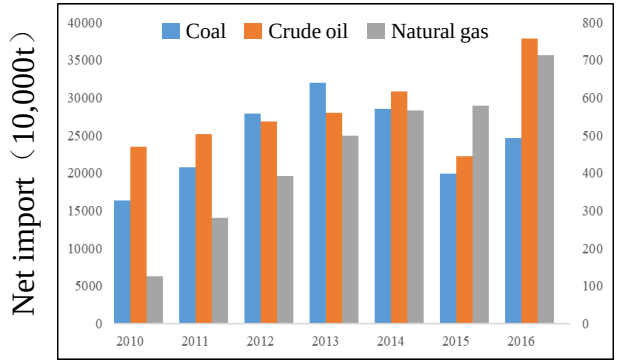
Selected case studies in the manual

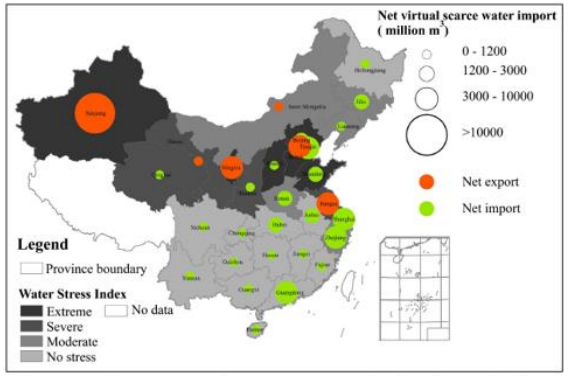
Food-Energy-Water and Sustainability







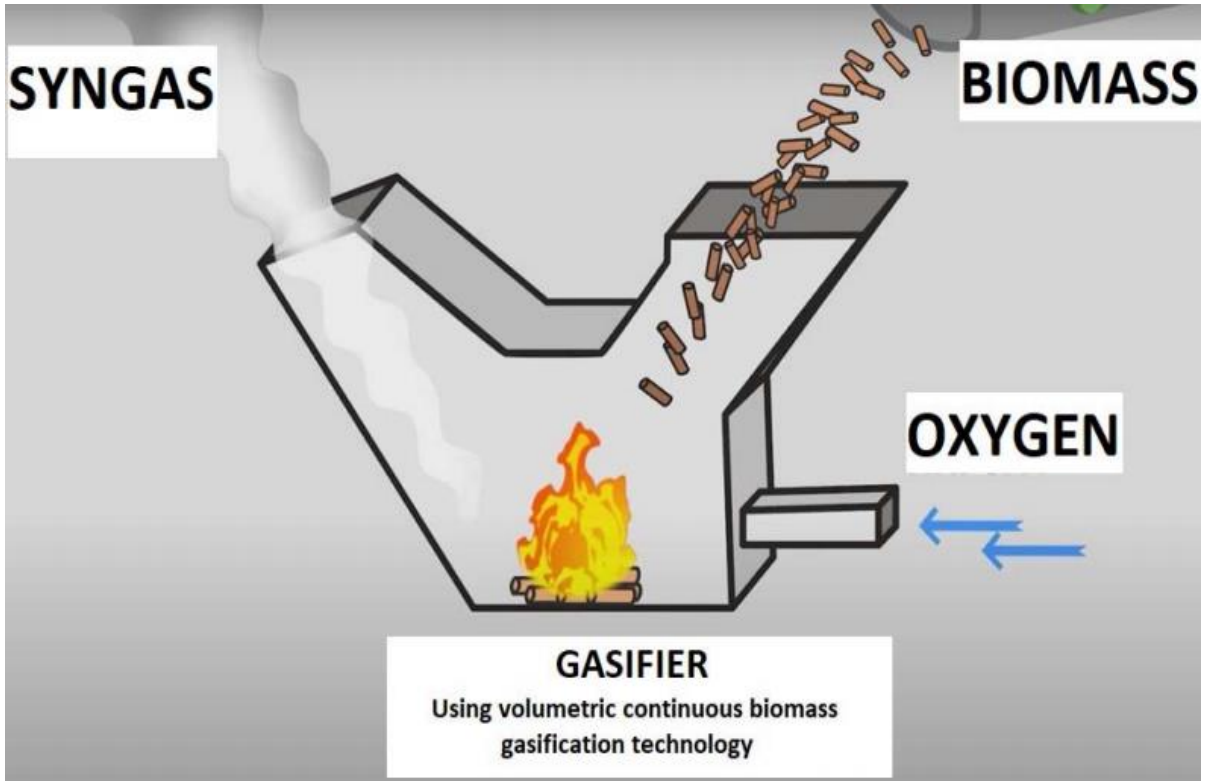




Zhao X., et al. 2018. Measuring scarce water saving from interregional virtual water flows in China. Environ. Res. Lett. 13.

Case study in Energy sector of the manual

- Biomass gasification technology for local communities



The biomass gasification project by Oxfam

Case study in Energy sector of the manual

- Smart home technologies for greater energy-efficiency

Xiaomi smart home integrated appliances

Case study in Water and Food sector of the manual

- Agricultural irrigation technology – safer and more efficient irrigation

A Precision Mobile drip irrigation (PMDI) system

Case study in Water and Food sector of the manual

- Vertical and indoor farming

Aeroponics, AeroFarms

Case study in Food sector of the manual

- Technology for food waste reduction

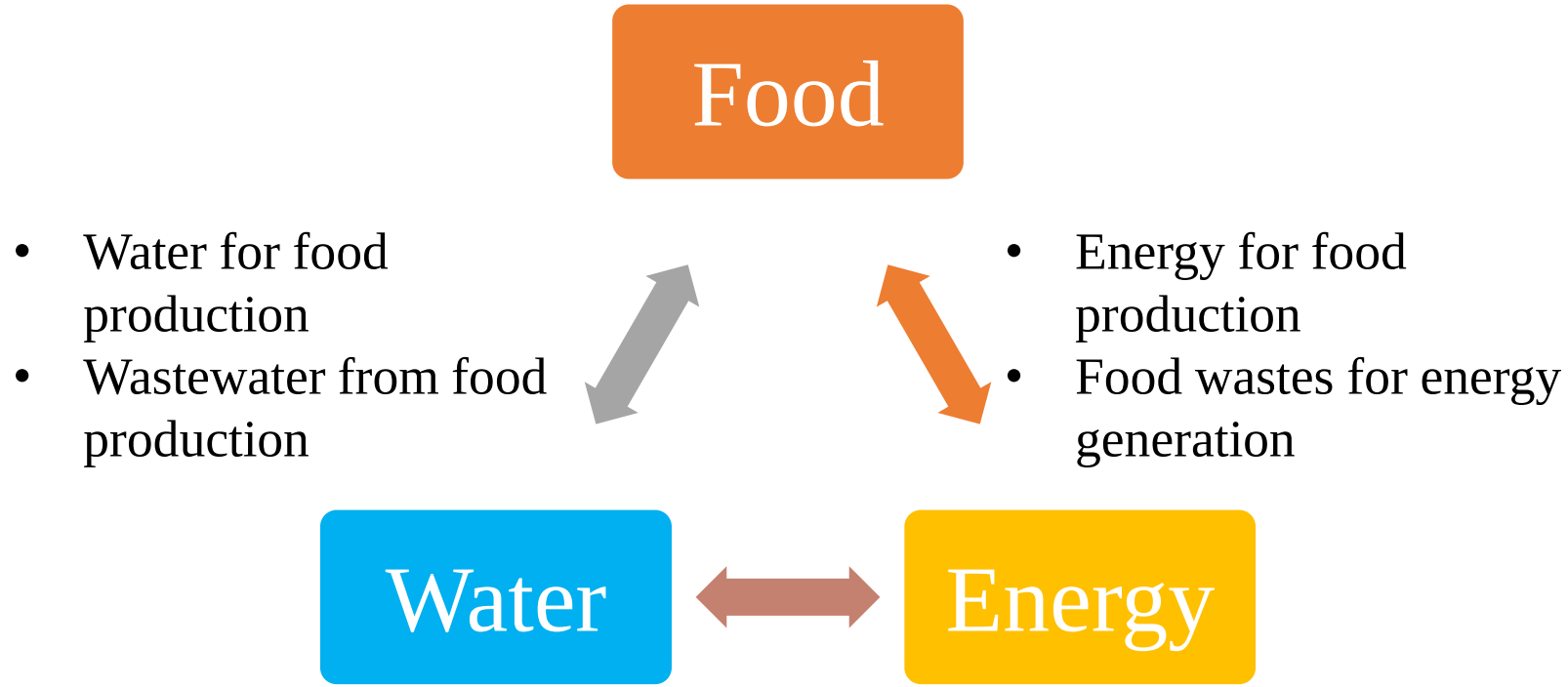
An integrated e-commerce platform for agricultural products and food processing

Integrated solutions for circular systems

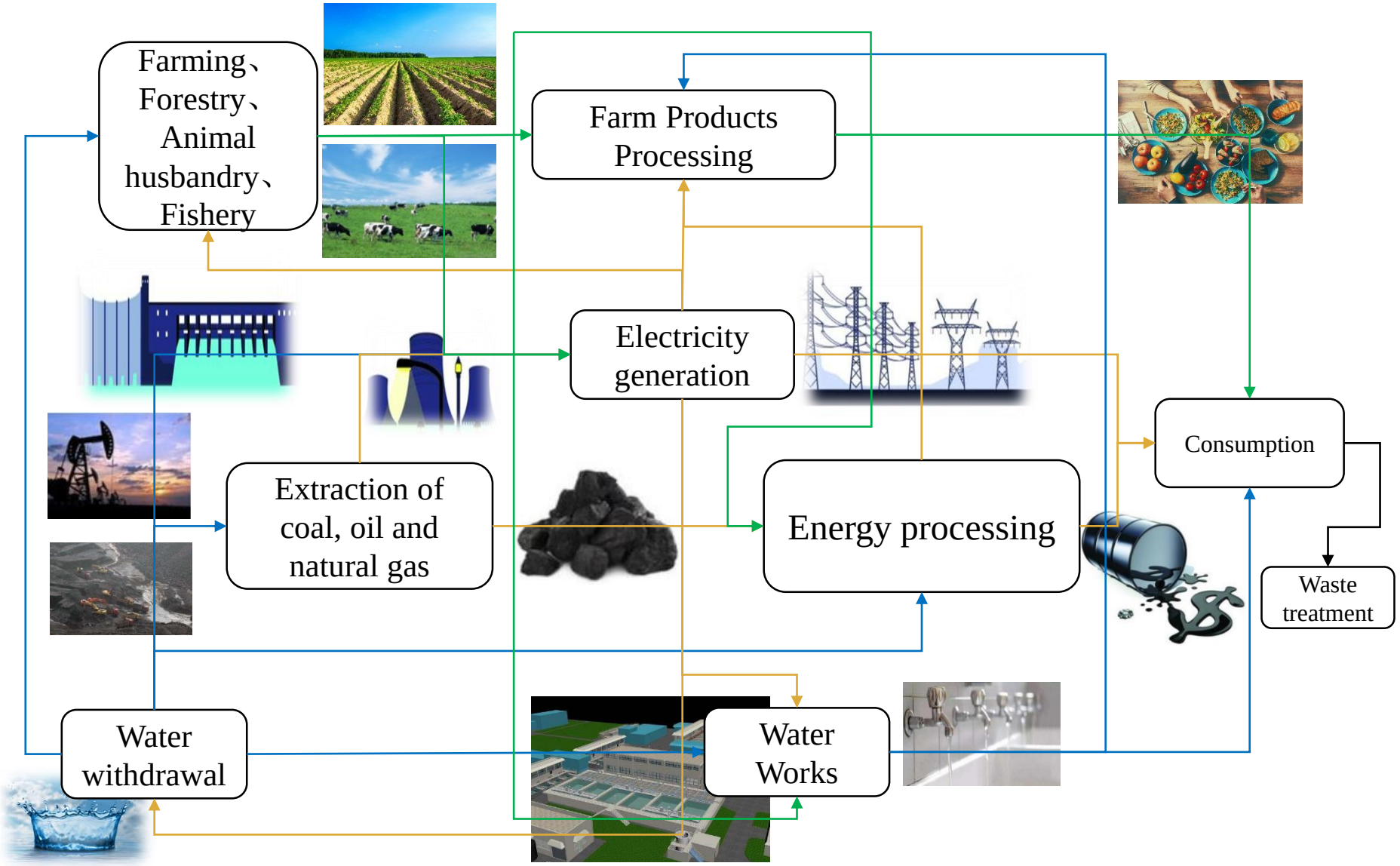
Understanding nexus in a system

Food-Energy-Water nexus

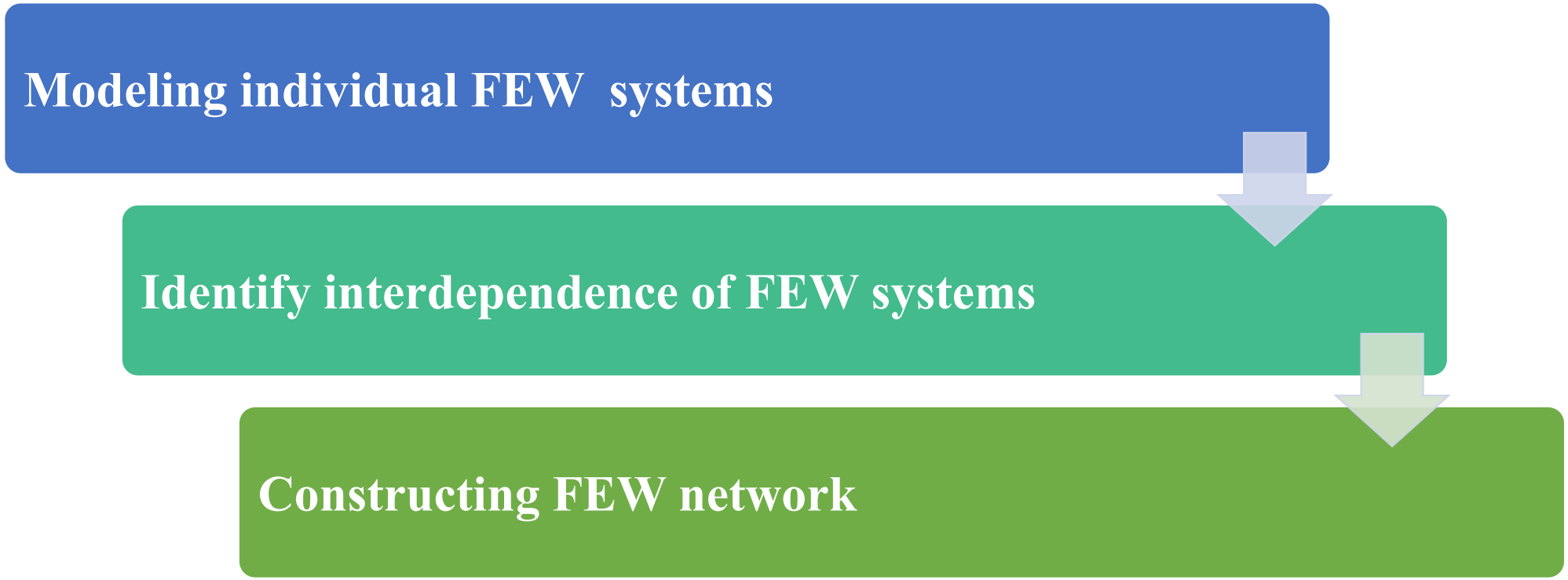
Food, energy and water systems are intertwined



Food, energy and water systems are intertwined

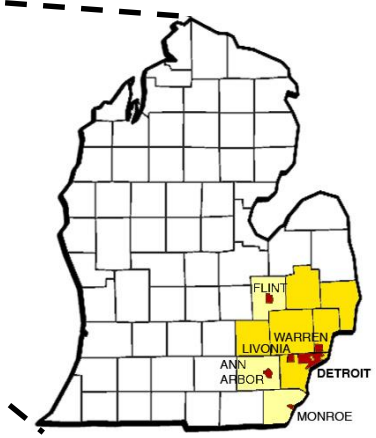


Material and Energy Flow Analysis



Case study

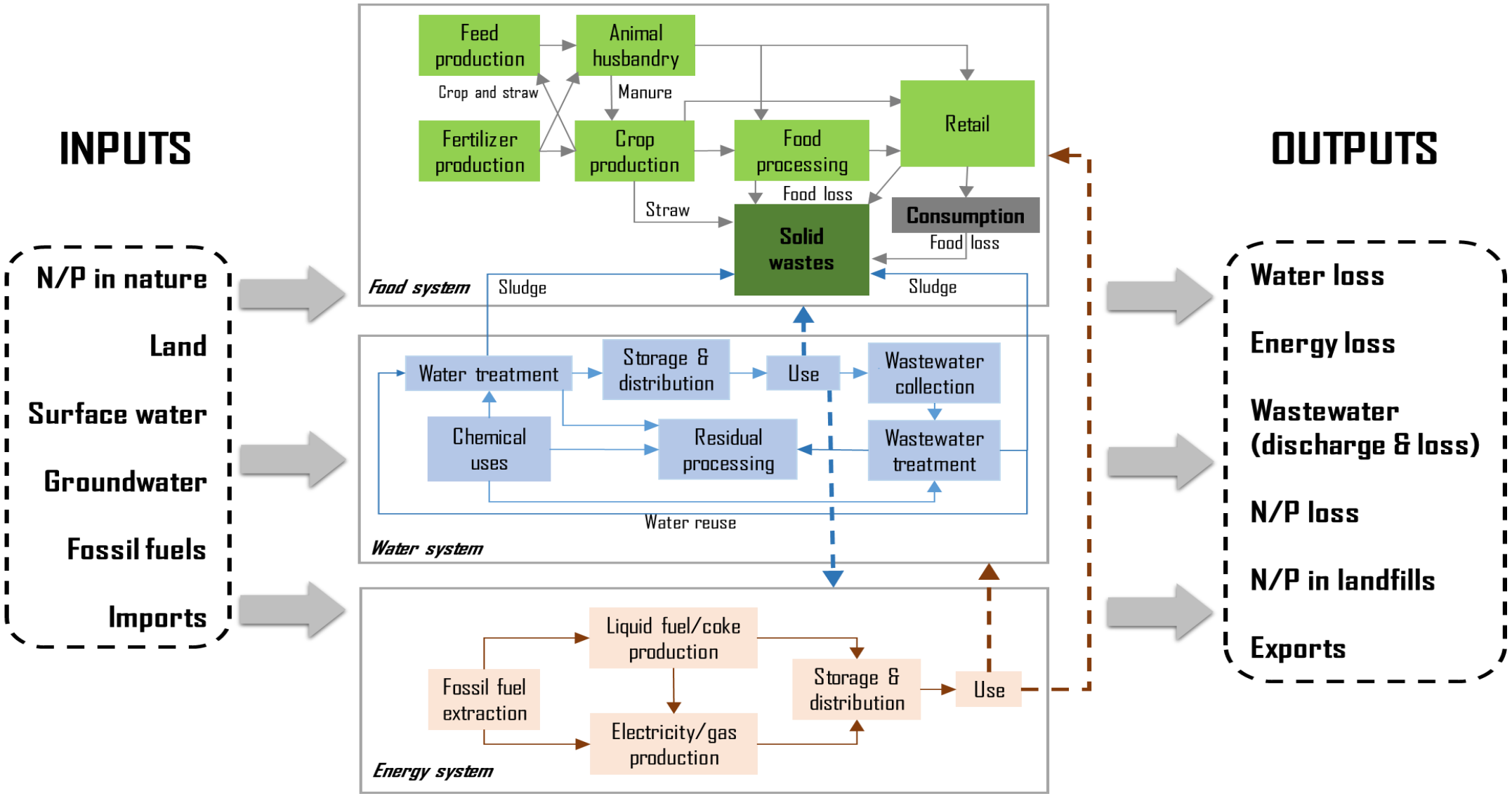
- City-region concept: core and surrounding areas
- Detroit Metropolitan Area (DMA): six counties
- Time point: 2012



Michigan State

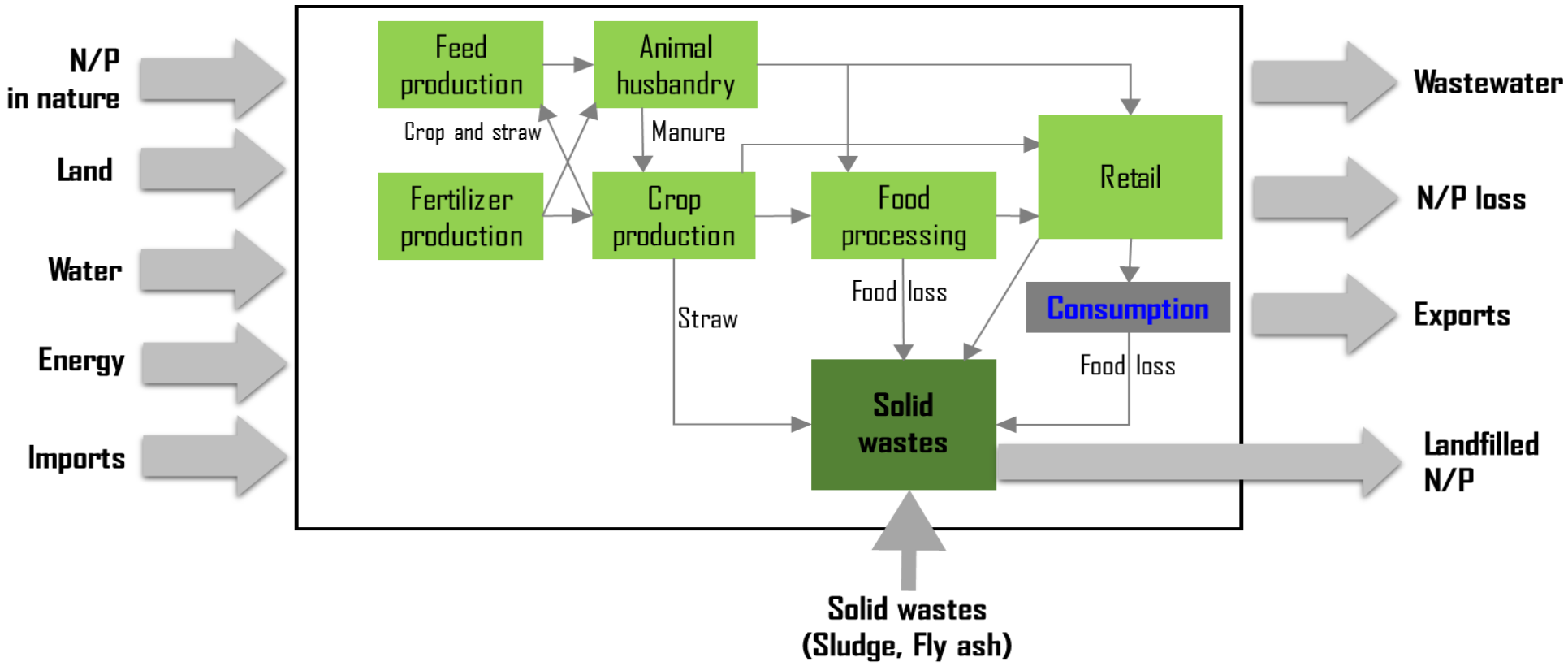
11th most populous in US

Layout and structure of the FEW network



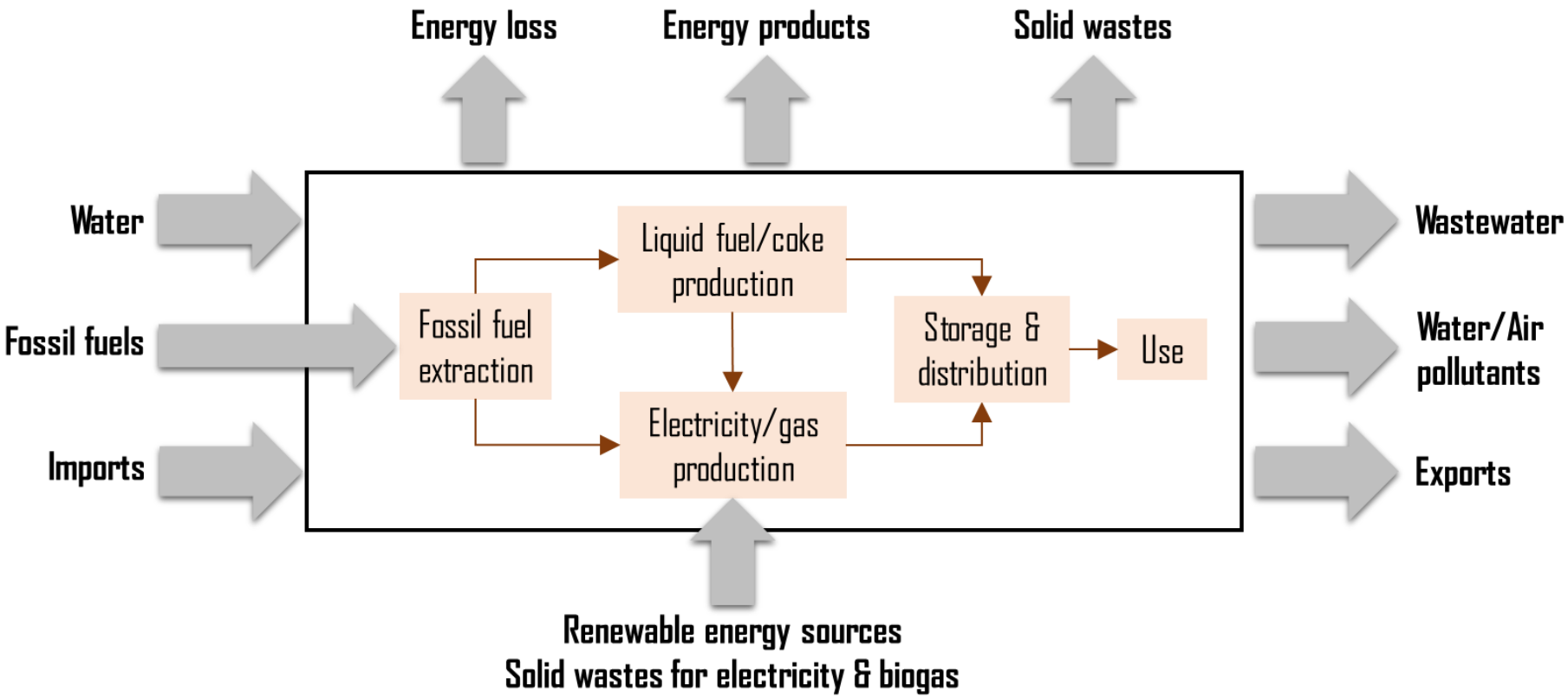
Food system

- Food supply chain: N/P fixation, production, processing, retail, consumption, food wastes, discharges



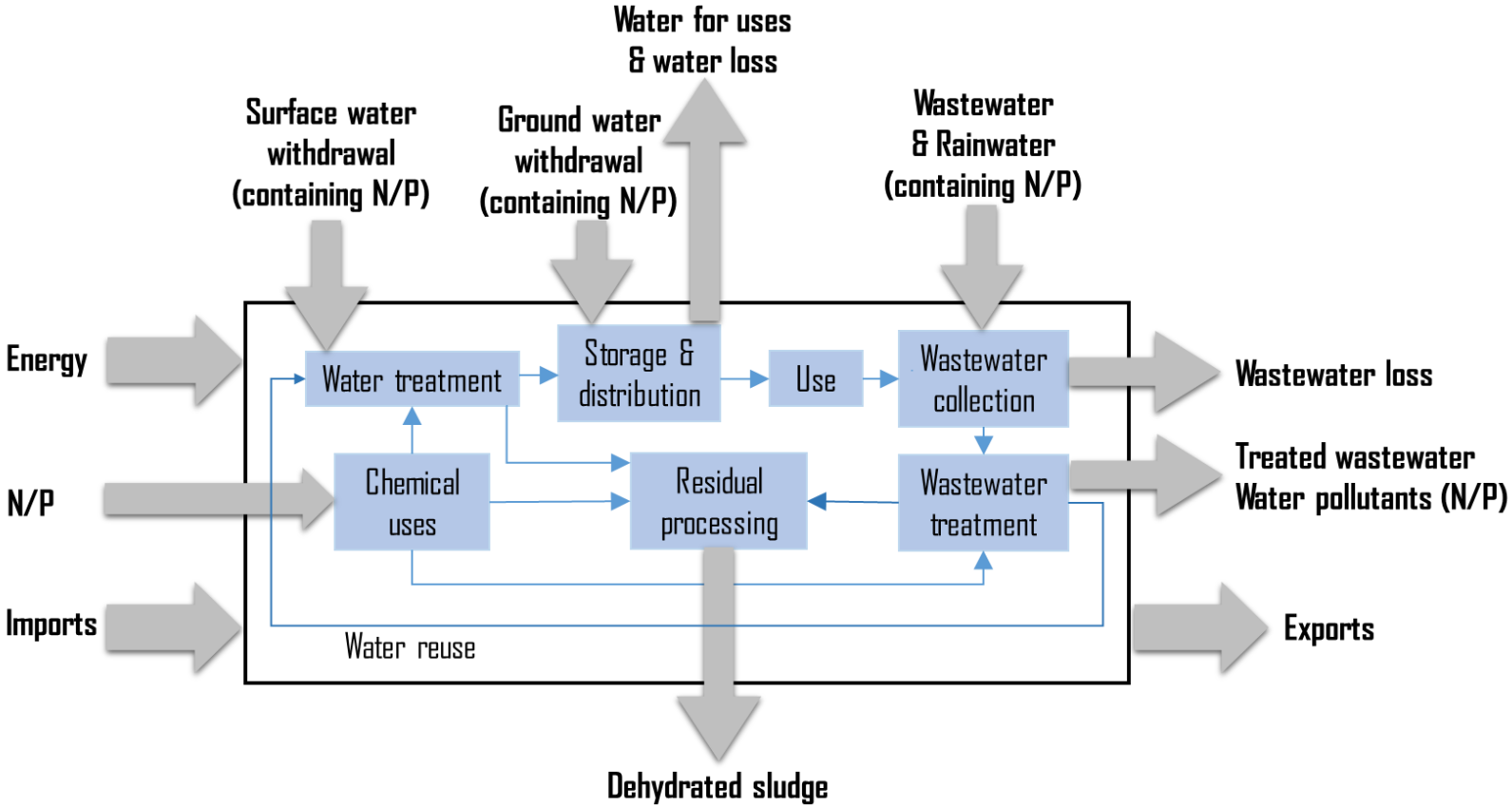
Energy system

•Energy supply chain: fossil fuel extraction, fossil fuel processing, electricity generation, energy consumption, emissions



Water system

• Water supply chain: water withdrawal, water treatment, water supply & uses, wastewater collection, wastewater treatment, residual processing, emissions



Results: general inputs and outputs

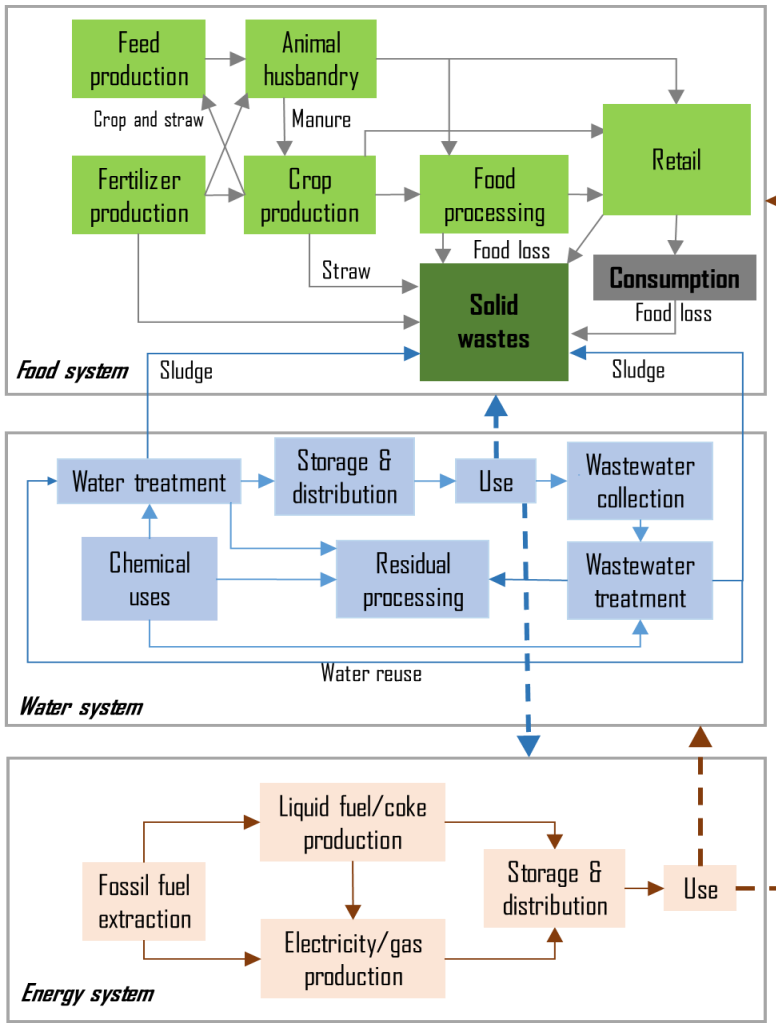
INPUTS

Domestic

N	19.2 kt
P	1.8 kt
Water	4.7 Bt
Energy	6 PJ

Imports

N	76.8 kt
P	15.3 kt
Energy	1,034 PJ



OUTPUTS

Domestic

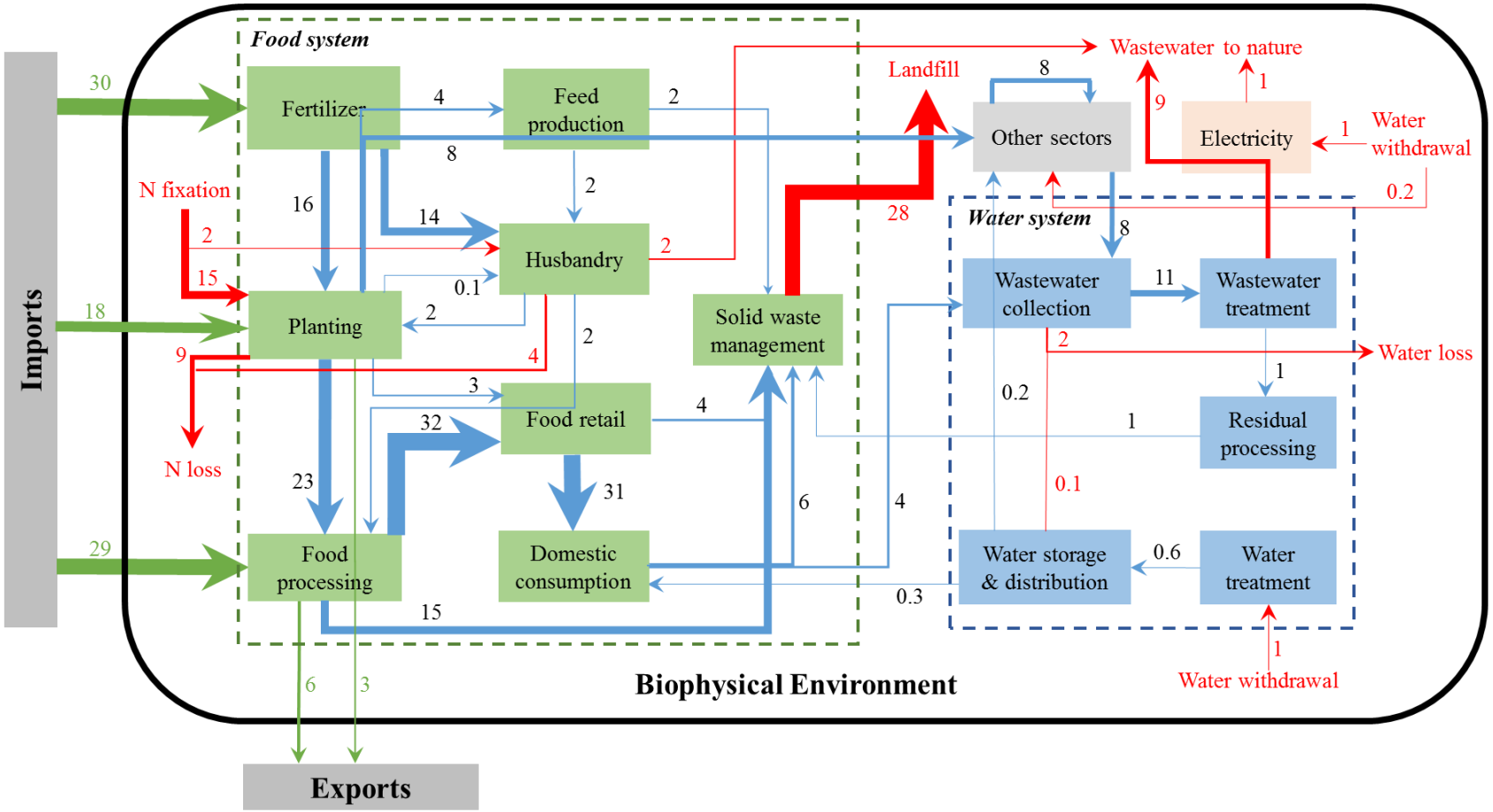
N to nature	56.4 kt
P to nature	9.3 kt
Wastewater	4.3 Bt
Water loss	333 Mt
Heat loss	1,002 PJ

Exports

N	9.6 kt
P	5.1 kt
Energy	38 PJ

Results: N flows

- Food system: N input 95.5 kt, N output 65.4 kt
- Water system: N input 13 kt, N output 12.6 kt
- Energy system: N input & output 1 kt

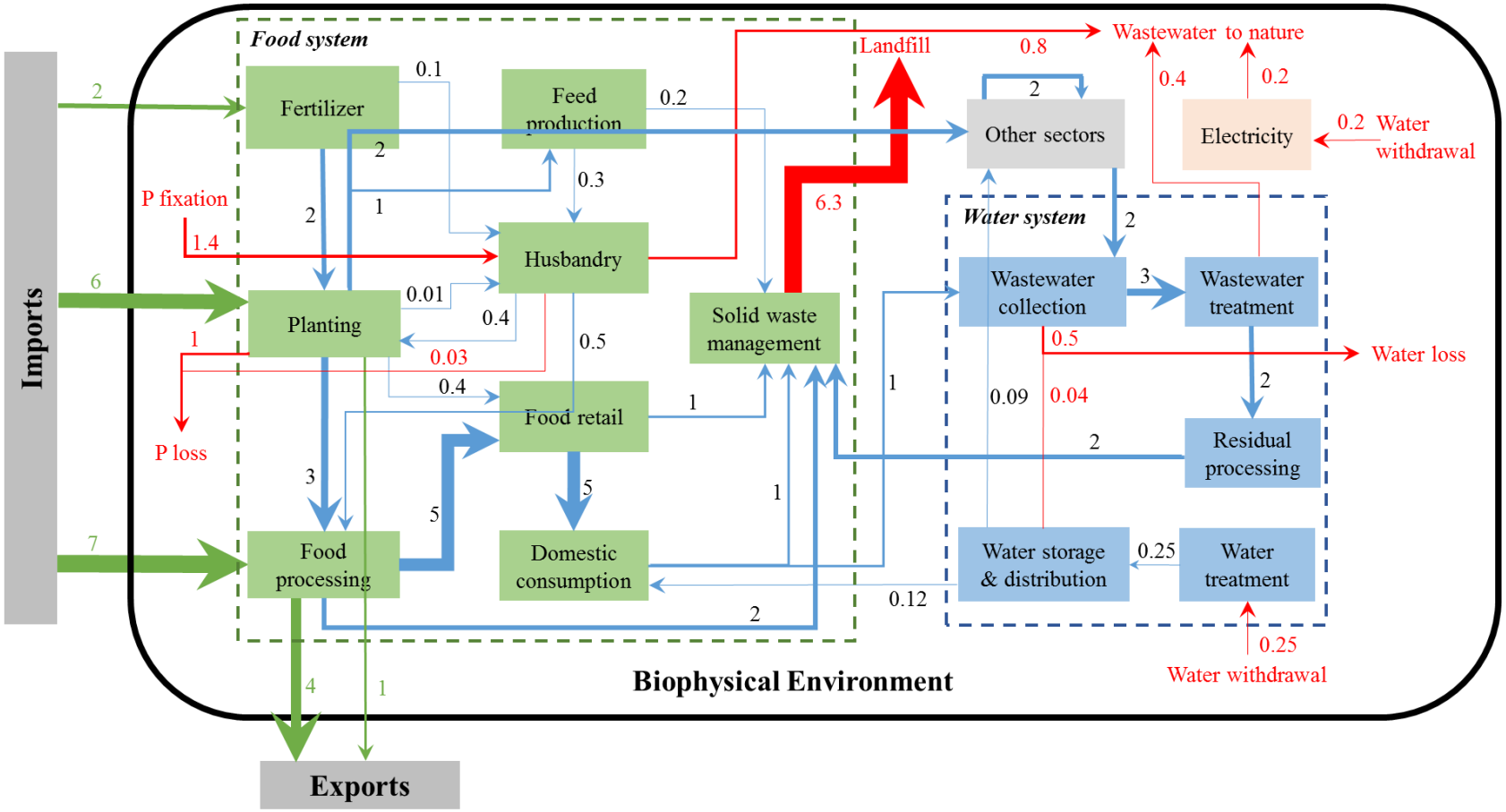


Results: P flows

Food system: P input 19.1 kt, P output 16.3 kt

Water system: P input 3.2 kt, P output 3.0 kt

Energy system: P input & output 0.2 kt

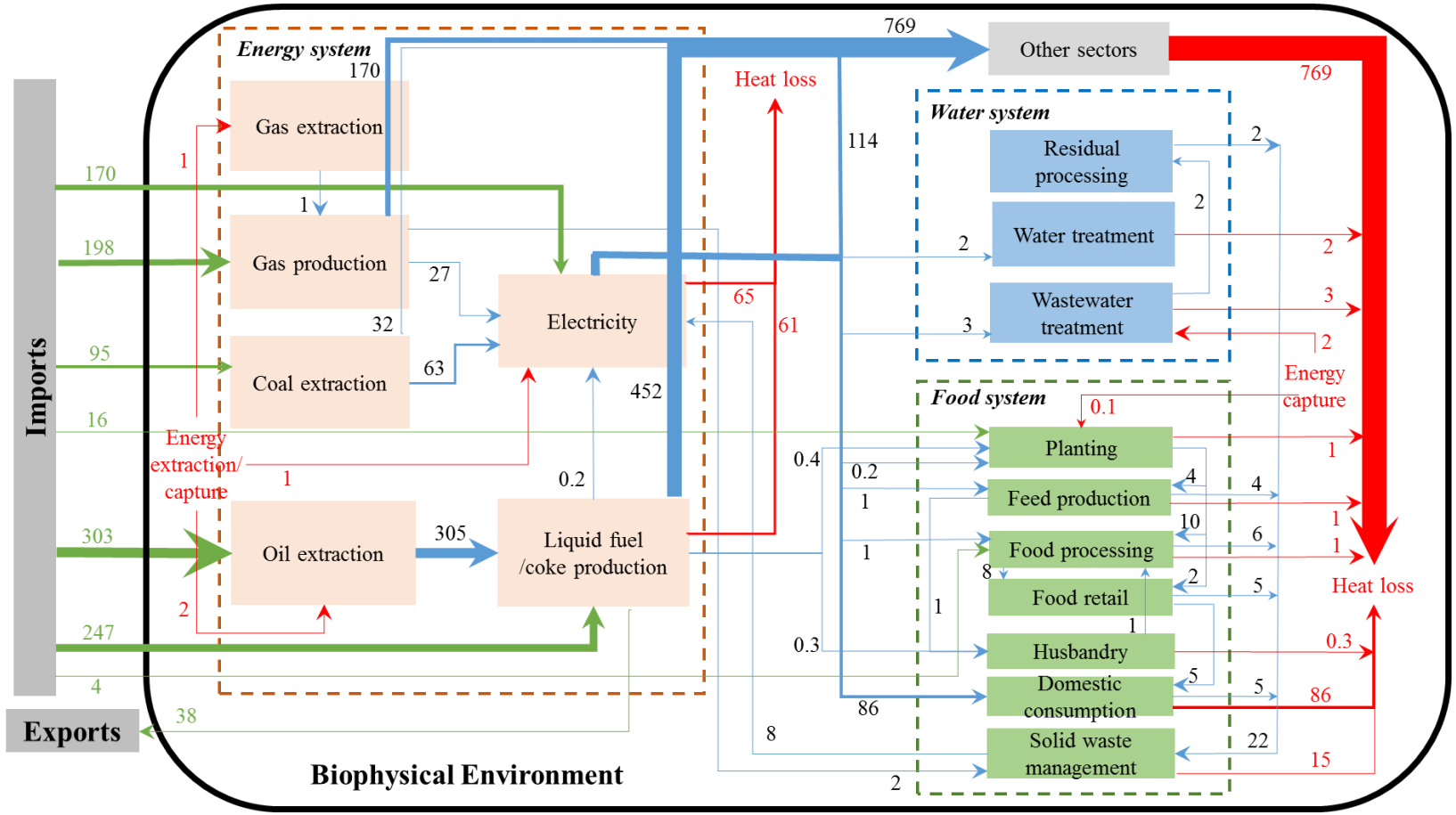


Results: Energy flows

Food system: input & output 113 PJ

Water system: input & output 7 PJ

Energy system: input & output 1,027 PJ

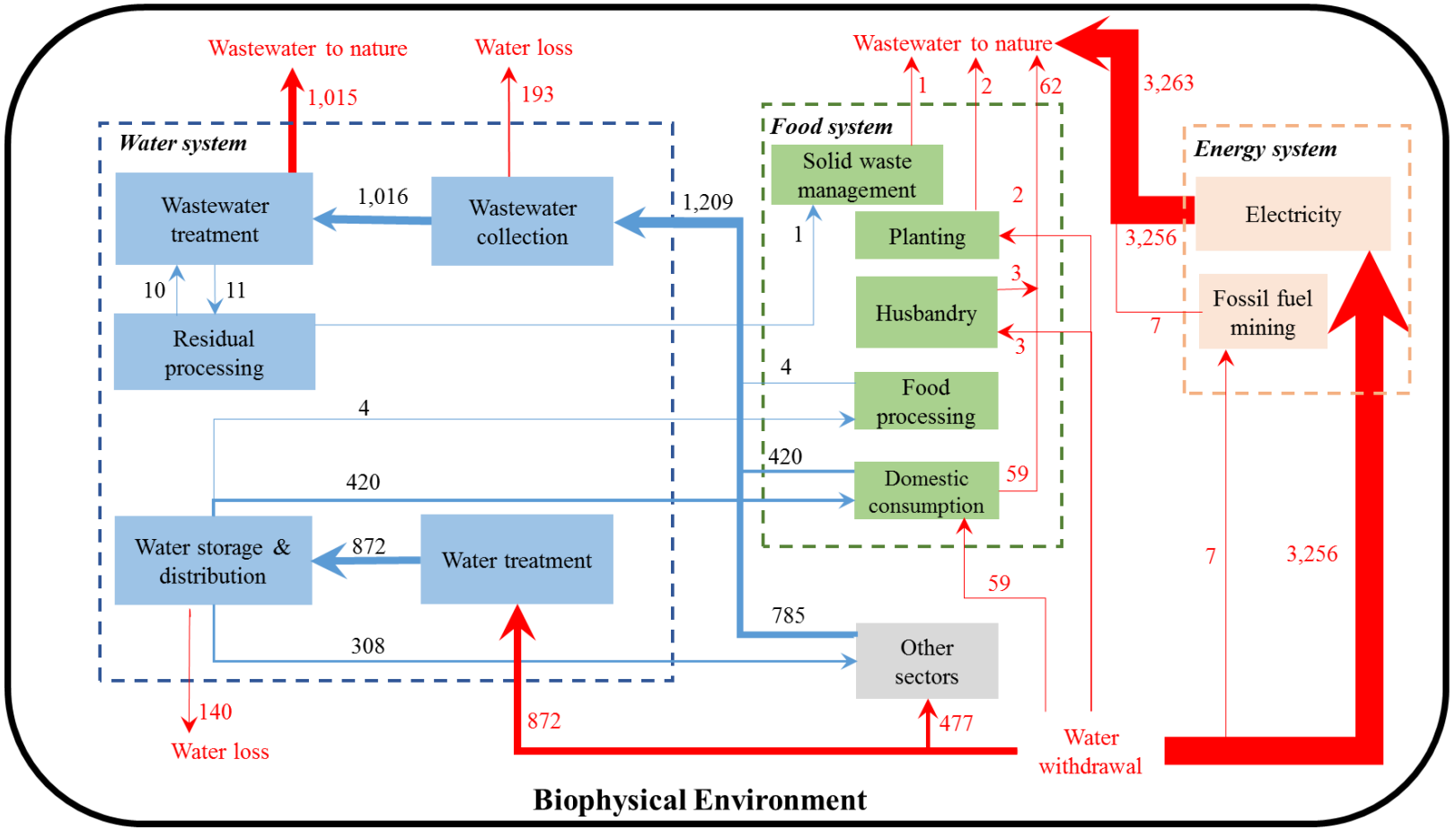


Results: Water flows

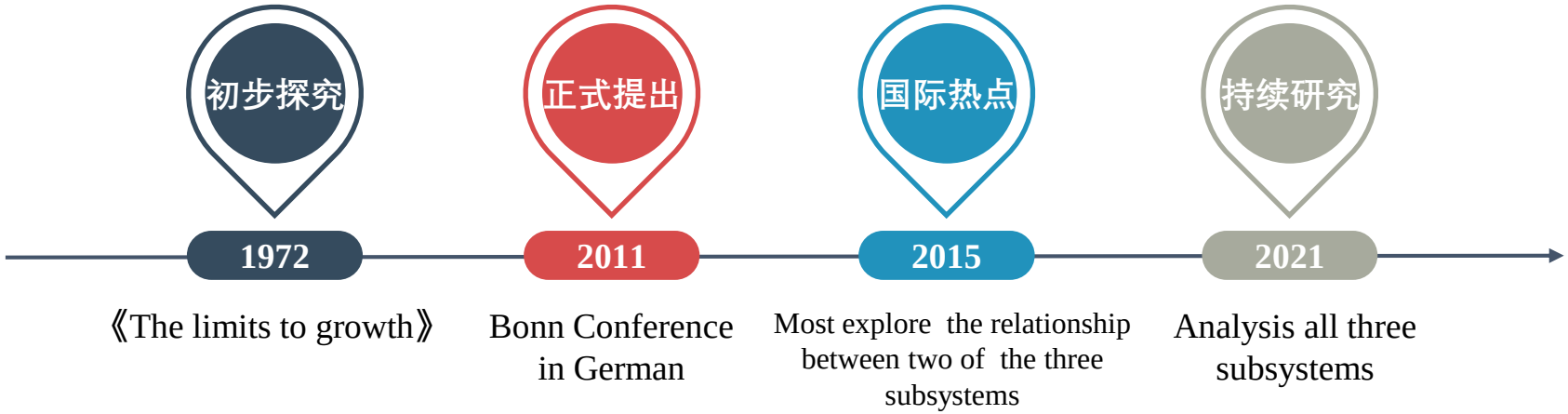
Food system: input & output 489 Mt

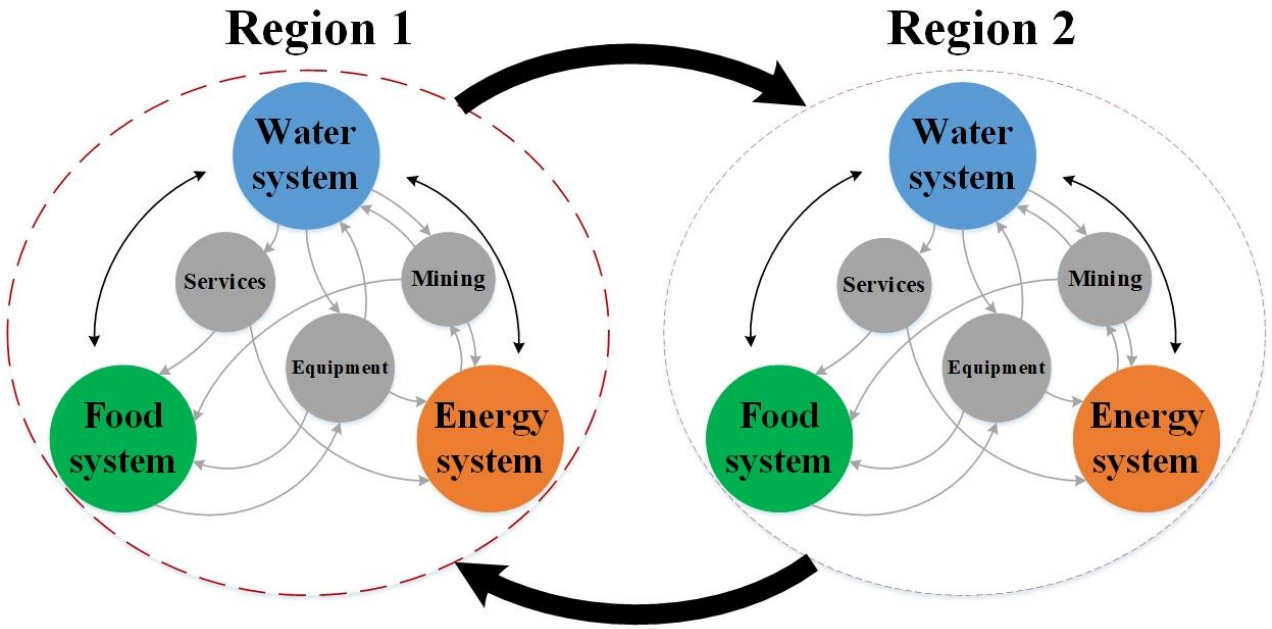
Water system: input & output 2,081 Mt

Energy system: input & output 3,263 Mt



Spatial Food-Energy-Water nexus





- How to quantify the direct and indirect spatial interconnection of food-energy-water systems?

Environmentally Extended Multi-Regional Input-Output model

2012 China 31 provinces 72sectors

Output / Input			Sectors: Beijing (Sector 1 … Sector n)	…	Sectors: Xinjiang (Sector 1 … Sector m)	Final Demand: Beijing HC	Beijing GC	Beijing FC	Beijing CI	…	Final Demand: Xinjiang HC	Xinjiang GC	Xinjiang FC	Xinjiang CI	Exports	Total Output
Sectors	Beijing	Sector 1 Sector m	**Intermediate flow matrix (Z)**			**Final demand matrix (Y)**										**Total output vector (X)**
	…	…														
	Xinjiang	Sector 1 Sector m														
	Value Added		**Primary input vector (V)**													
	Total Input		**Total input vector (X')**													
Physical Input			Sector													
Resource	Category	1 n	**Satellite accounts (P)**													
Waste	Category	n+1 n+k														

$$f = p \times (\hat{x})^{-1}$$

Row balance

$Z+Y=X$

$x=(\mathbf{I}-\mathbf{A})^{-1}y$

Leontief Model

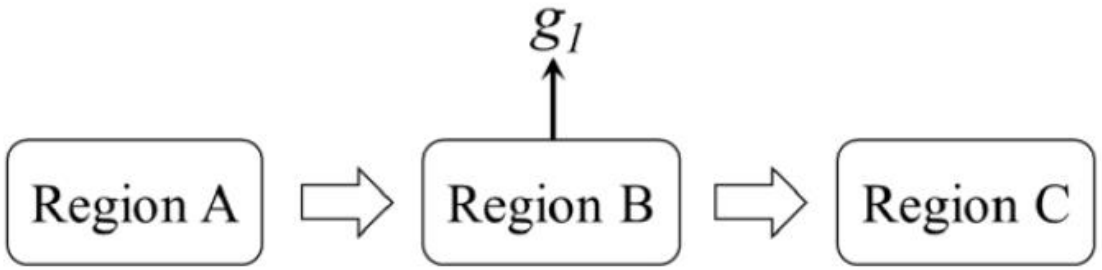
Colum balance

$Z+V=X'$

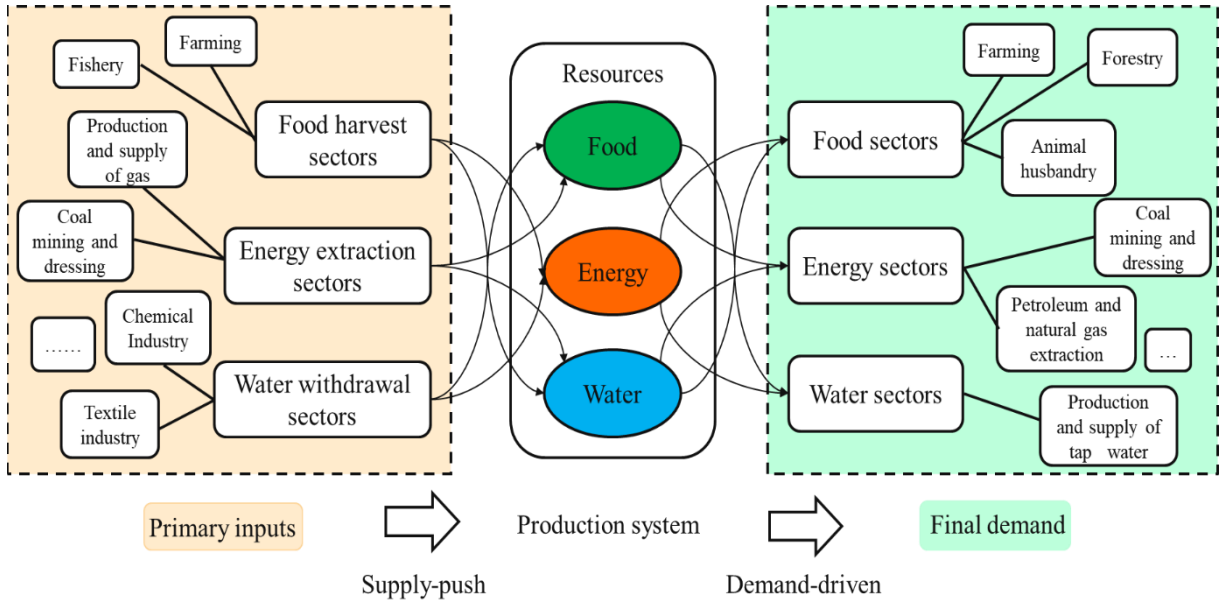
$x=v(\mathbf{I}-\mathbf{B})^{-1}$

Ghosh Model

Environmentally Extended Multi-Regional Input-Output model



Accounting methods	Region A	Region B	Region C
Production-based	0	g_1	0
Consumption-based	0	0	g_1
Income-based	g_1	0	0



1 **Consumption-based**

Leontief Model

$$\boldsymbol{w}_{cf} = \boldsymbol{f}_w \times (\mathbf{I} - \mathbf{A})^{-1} \times \boldsymbol{y}_{fi}$$

$$\boldsymbol{w}_{ce} = \boldsymbol{f}_w \times (\mathbf{I} - \mathbf{A})^{-1} \times \boldsymbol{y}_{ei}$$

Water withdrawals induced by final demand of food and energy products

2 **Income-based**

Ghosh Model

$$\boldsymbol{f}_{inw} = \boldsymbol{v}_{wi} \times (\mathbf{I} - \mathbf{B})^{-1} \times \boldsymbol{f}_f{}'$$

$$\boldsymbol{e}_{inw} = \boldsymbol{v}_{wi} \times (\mathbf{I} - \mathbf{B})^{-1} \times \boldsymbol{f}_e{}'$$

Food harvest and energy extraction enabled by primary inputs of sectors with water withdrawals

FEW Nexus from the Demand Perspective

Taking water subsystem as the core

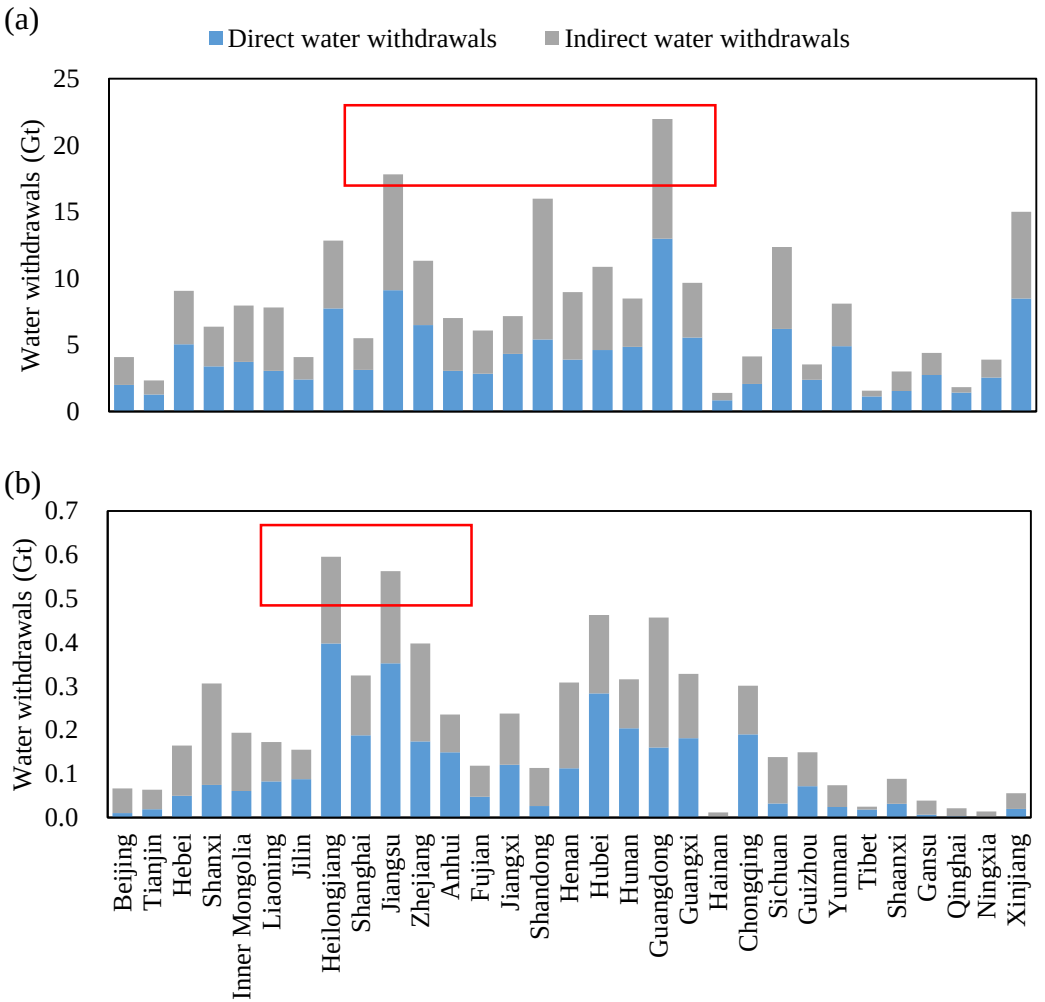


Fig. Direct and indirect water withdrawals in China induced by final demand of food (a) and energy (b) products in each province

In 2012, China's final demand of food products drove 251 billion tons (Gt) of water withdrawals, while final demand of energy products drove 7 Gt of water withdrawals.

- The proportion of indirect water withdrawals induced by final demand of food products in each province is over **22%**, indicating its significance.
- The final demand of energy products in most provinces drives **more indirect water withdrawals** than direct water withdrawals.
- Guangdong, Jiangsu, Shandong, Heilongjiang are critical regions for water withdrawals.

FEW Nexus from the Demand Perspective

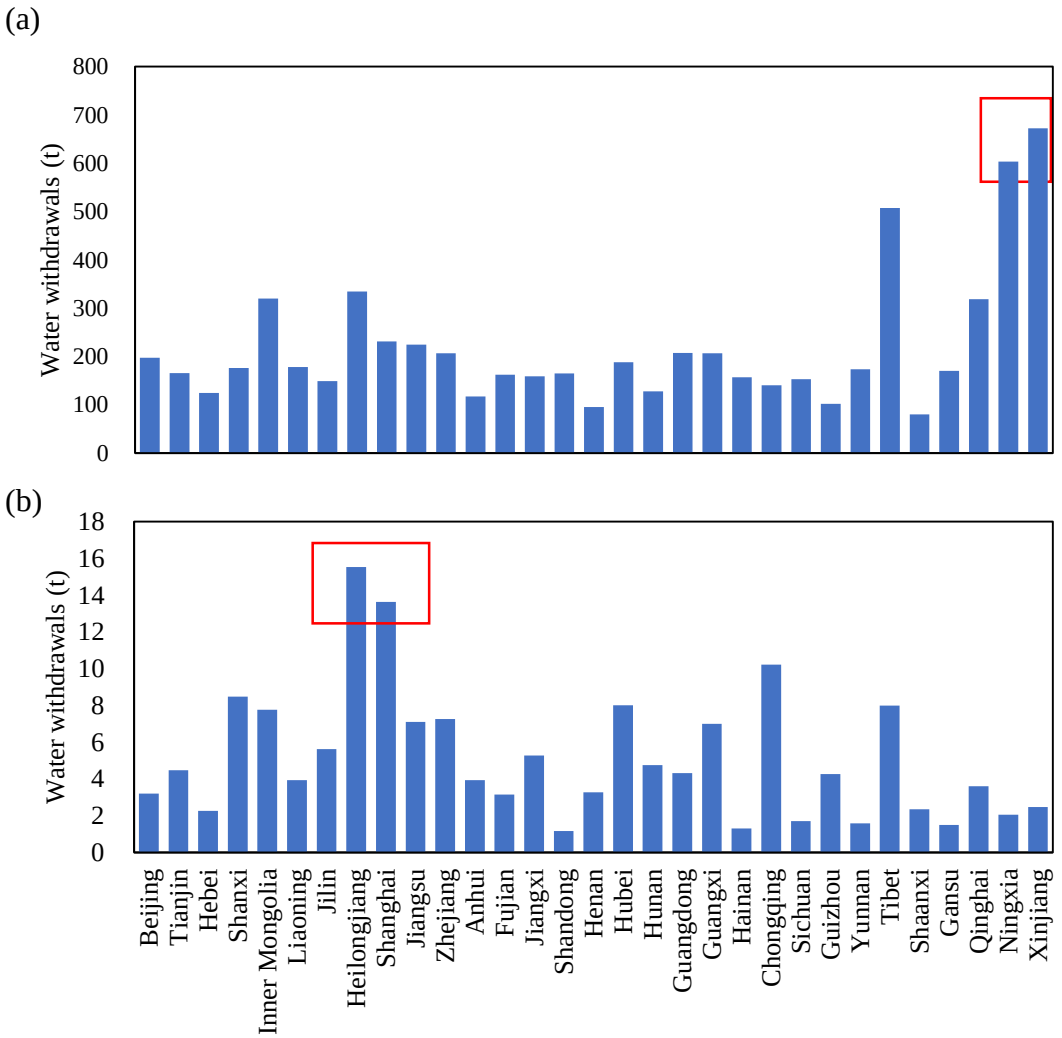
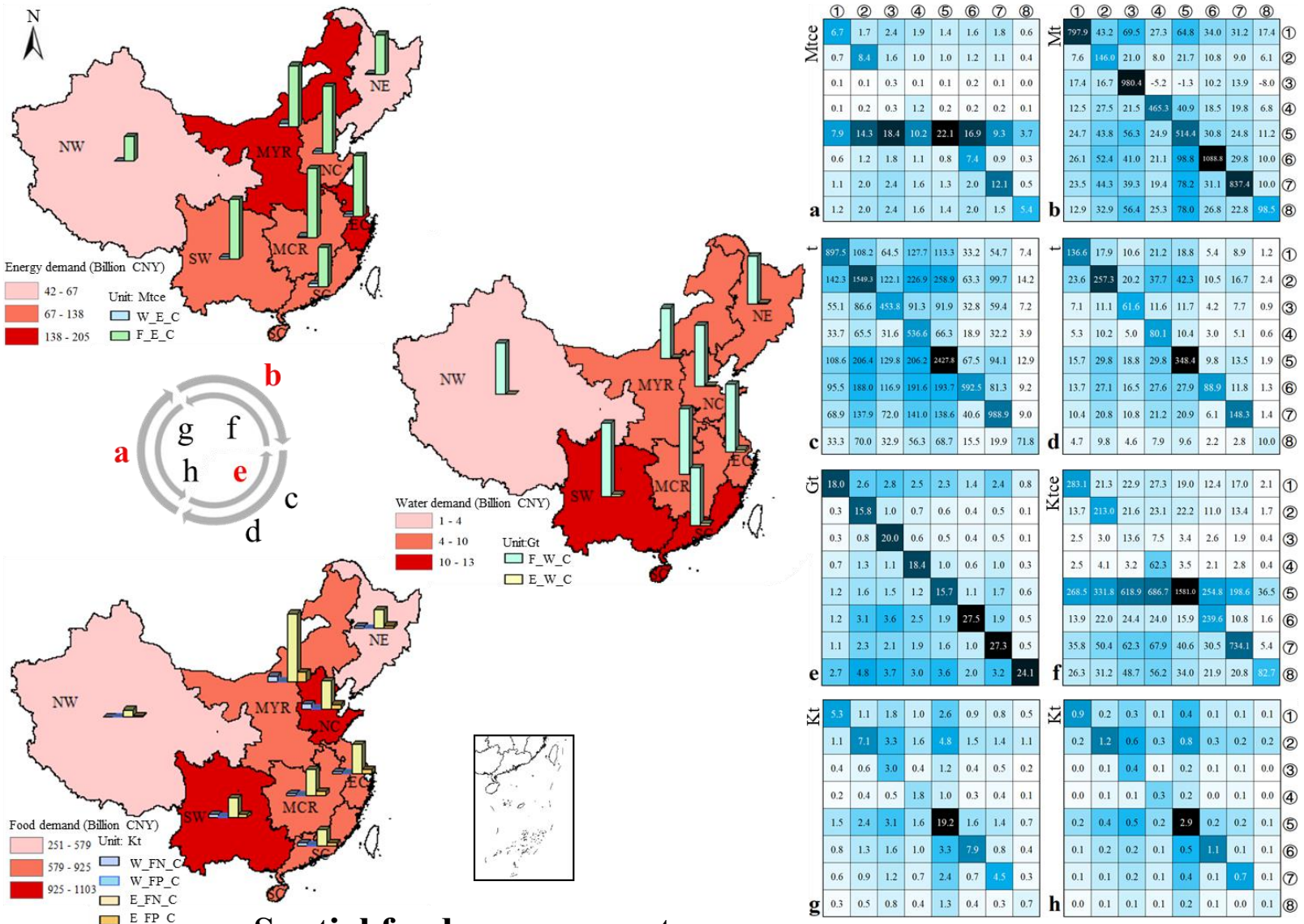


Fig. National water withdrawals induced by per capita final demand of food products (a) and energy products (b) in each province

- Water withdrawals driven by the final demand of food products in less populated **Xinjiang** are also large, mainly due to the relatively high water withdrawal intensity of the agriculture in Xinjiang.
- On a per capita basis, final demand of energy products in **Heilongjiang** drives a large amount of water withdrawals, as well as **Shanghai**.

FEW Nexus from the Demand Perspective



Spatial food–energy–water nexus

- The interprovincial virtual water flows occupy **37%** and **27%** of the total water withdrawals induced by the final demand of food and energy products, respectively.

Flows

a From the northern regions to the coastal developed regions

b From the MCR, NW, and NE regions to the MYR, NC, and EC regions

e From the MYR and NW regions to the MCR, NC, EC, and SC regions

FEW Nexus from the Demand Perspective

Results at sector level

- *Farm products processing*
- *Rice*
- *Swine*

- *Production of thermal power*
- *Petroleum processing, coking and nuclear fuel processing*
- *Production and supply of gas*

Water withdrawals induced by the final demand of food and energy products are overestimated based on Liu's original MRIO tables. Sectoral disaggregation contributes to the accuracy of results.

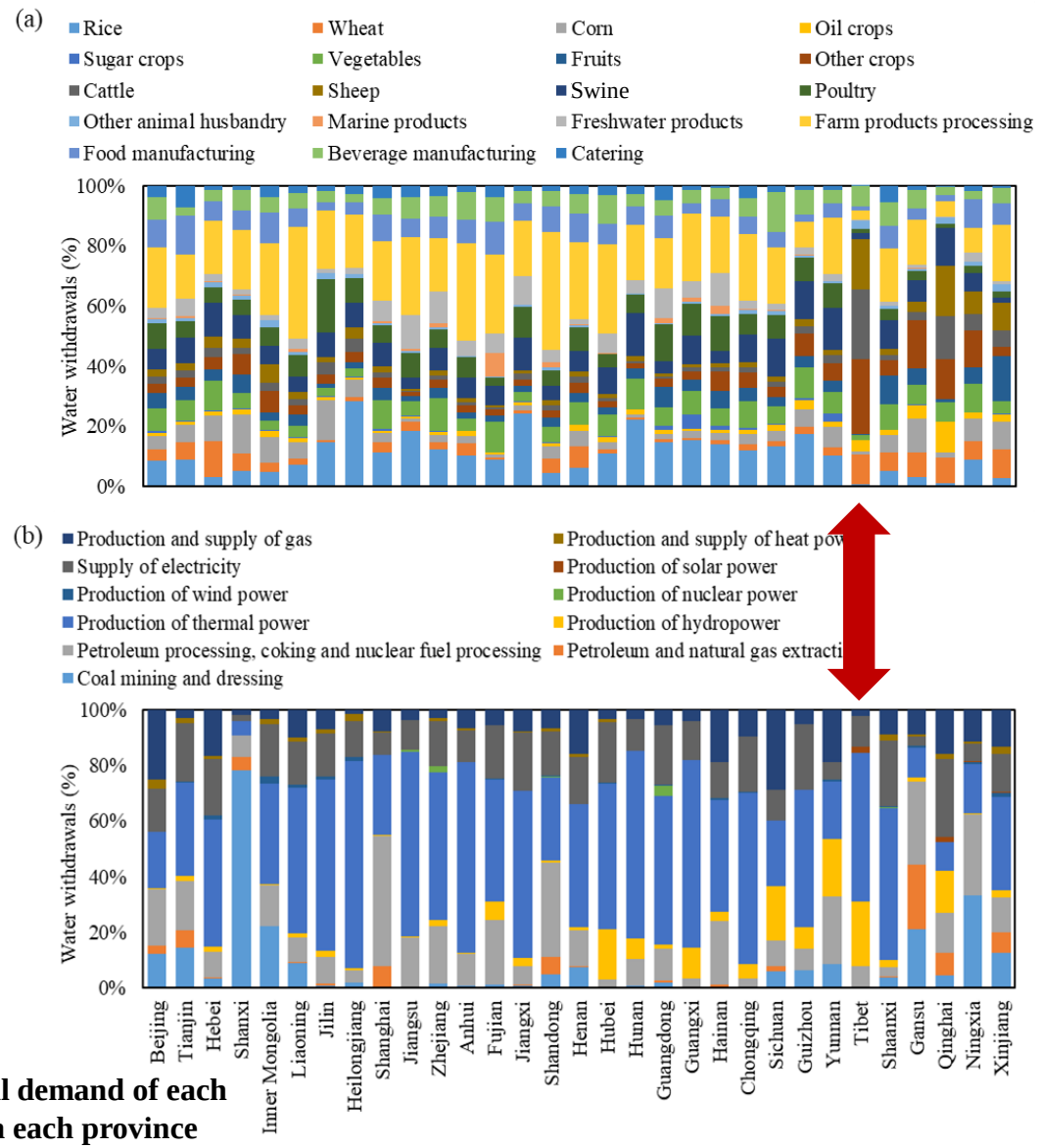


Fig. Water withdrawals induced by the final demand of each food sector (a) and each energy sector (b) in each province

FEW Nexus from the Supply Perspective

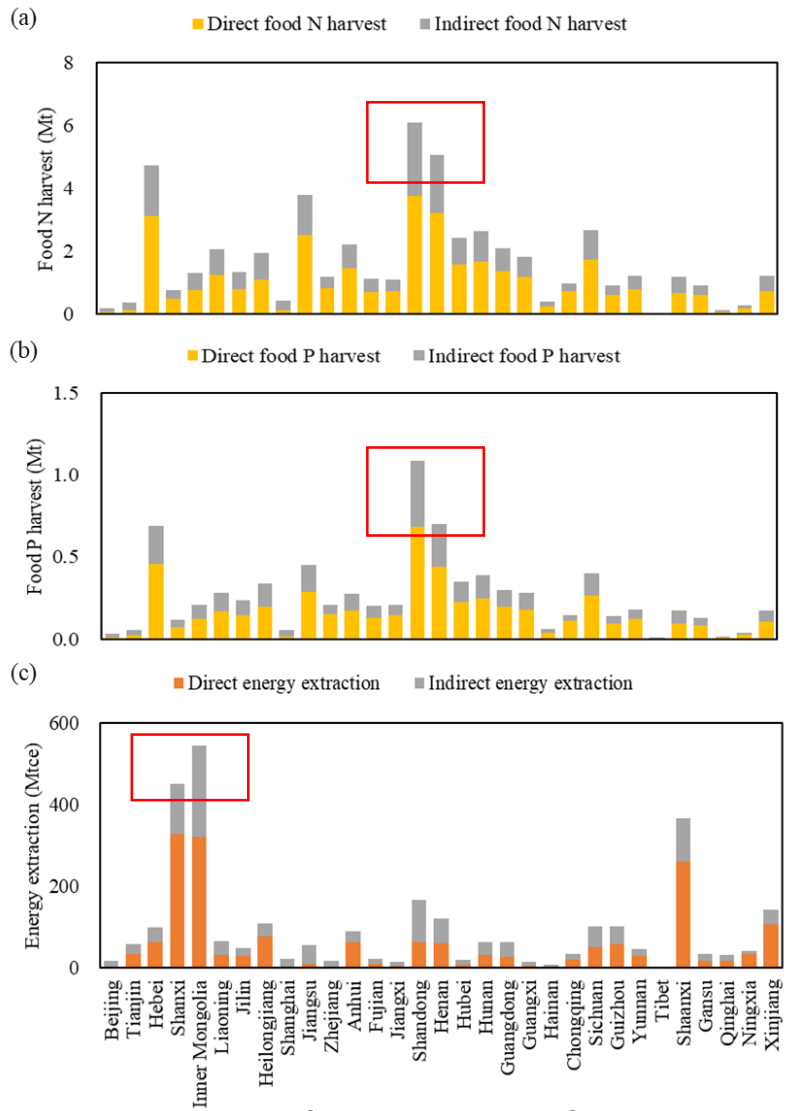


Fig. Direct and indirect food N harvest (a), food P harvest (b), and energy extraction (c) in China enabled by primary inputs of sectors with water withdrawals in each province

In 2012, primary inputs of sectors with water withdrawals enabled 53 Mt of food nitrogen harvest and 8 Mt of food phosphorus harvest. Meanwhile, primary inputs of sectors with water withdrawals enabled the extraction of 2956 Mt of standard coal equivalents (Mtce).

- The proportion of indirect food harvest enabled by primary inputs of sectors with water withdrawals in each province is over **26%.**

- The direct energy extraction enabled by the primary inputs of sectors with water withdrawals is 1756 Mtce, and the enabled indirect energy extraction is 1200 Mtce.

FEW Nexus from the Supply Perspective

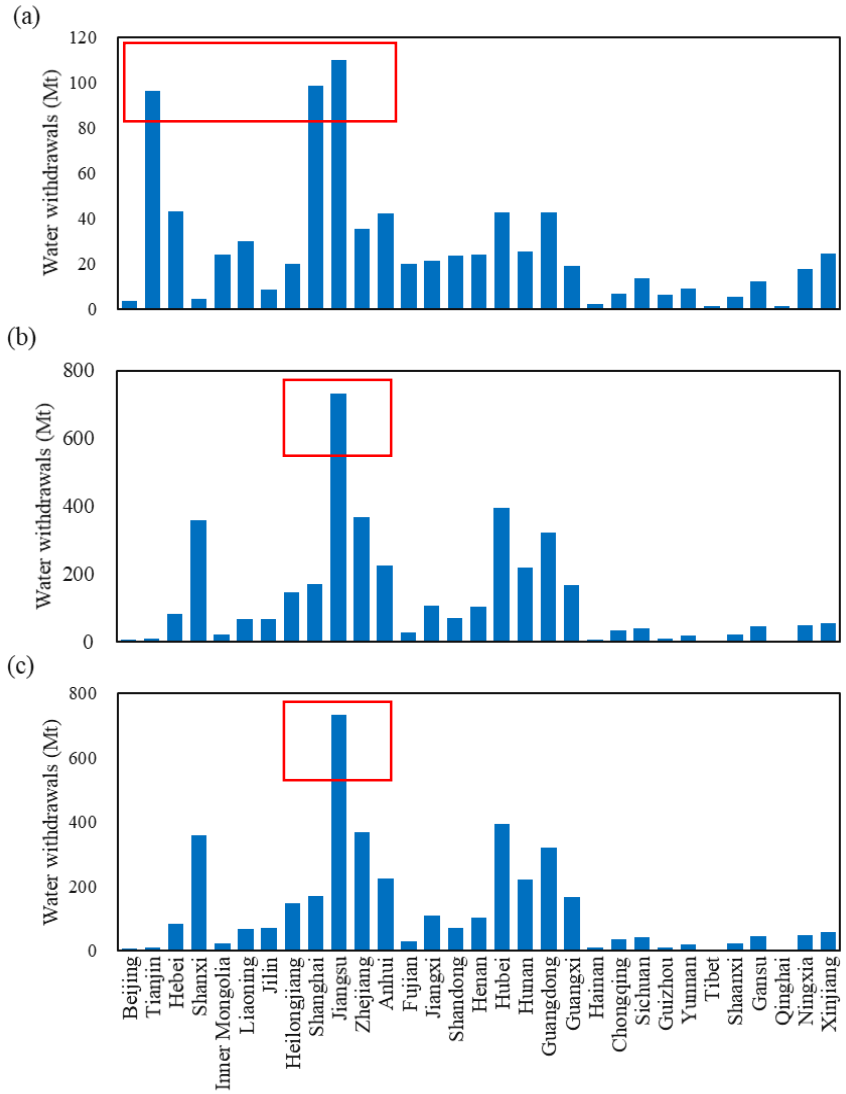
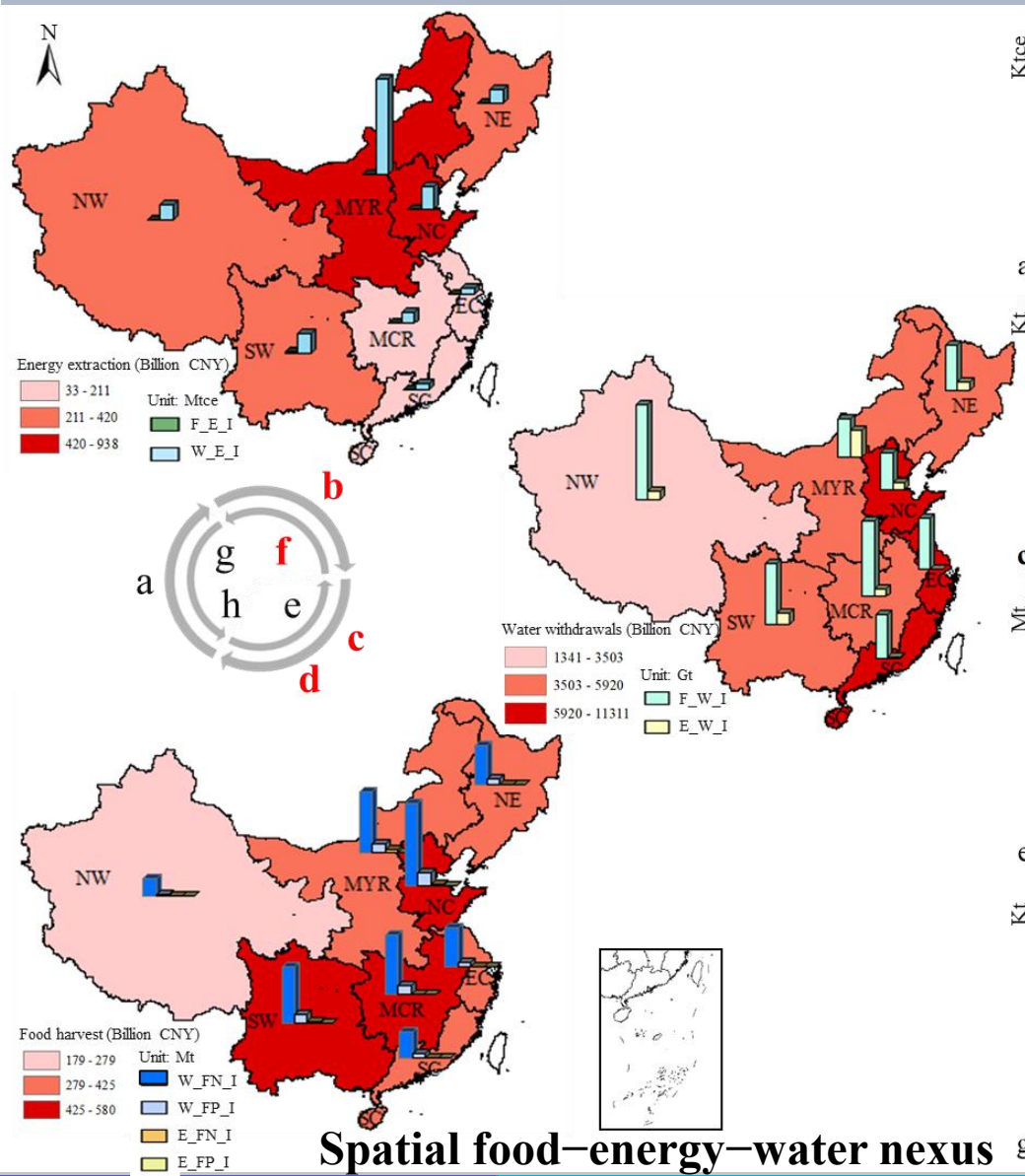


Fig. Water withdrawals of each province enabled by primary inputs of energy extraction sectors in Tianjin (a), Shanxi (b), and Inner Mongolia (c)

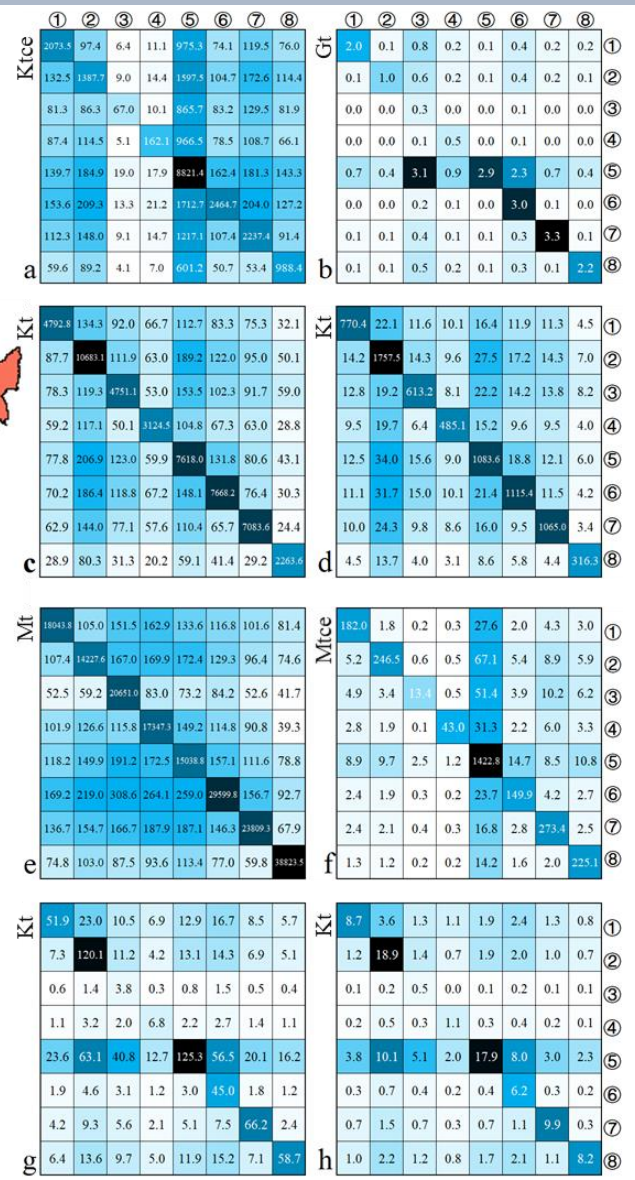
- Primary inputs of sectors with water withdrawals mainly occur in **coastal regions** (e.g., Guangdong, Shandong, and Jiangsu) and enable local energy extraction and food harvest.

- Primary inputs of energy extraction sectors in Tianjin, Shanxi, and Inner Mongolia have extensive impacts on water withdrawals in the East Coast regions (e.g., **Jiangsu** and **Zhejiang**).

FEW Nexus from the Supply Perspective



Spatial food–energy–water nexus



- The interprovincial energy extraction and food harvest enabled by primary inputs of water withdrawal sectors account for **13%** and **10%** of the total enabled energy extraction and food harvest.

Flows

b From the NE, NC, MYR, and NW regions to the MCR, EC, SC, and SW regions

c-d From the NE, and SW regions to the NC, and SC regions

f From the coastal regions to the MYR, NW, and SW regions

FEW Nexus from the Supply Perspective

Results at sector level

- *Vegetables*
- *Corn*
- *Chemical industry*

- *Coal mining and dressing*
- *Petroleum and natural gas extraction*
- *Petroleum, coking and nuclear fuel processing*

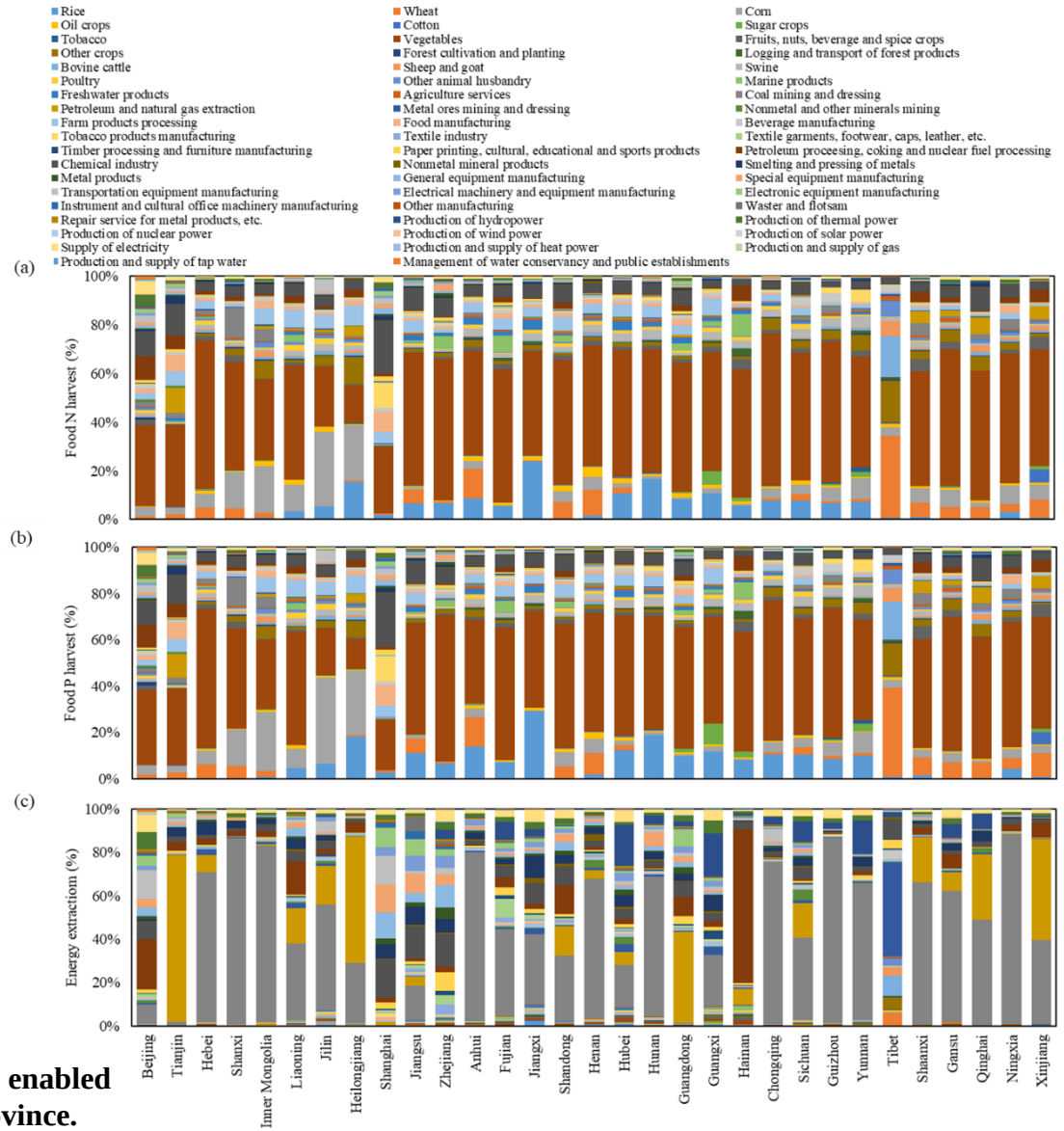
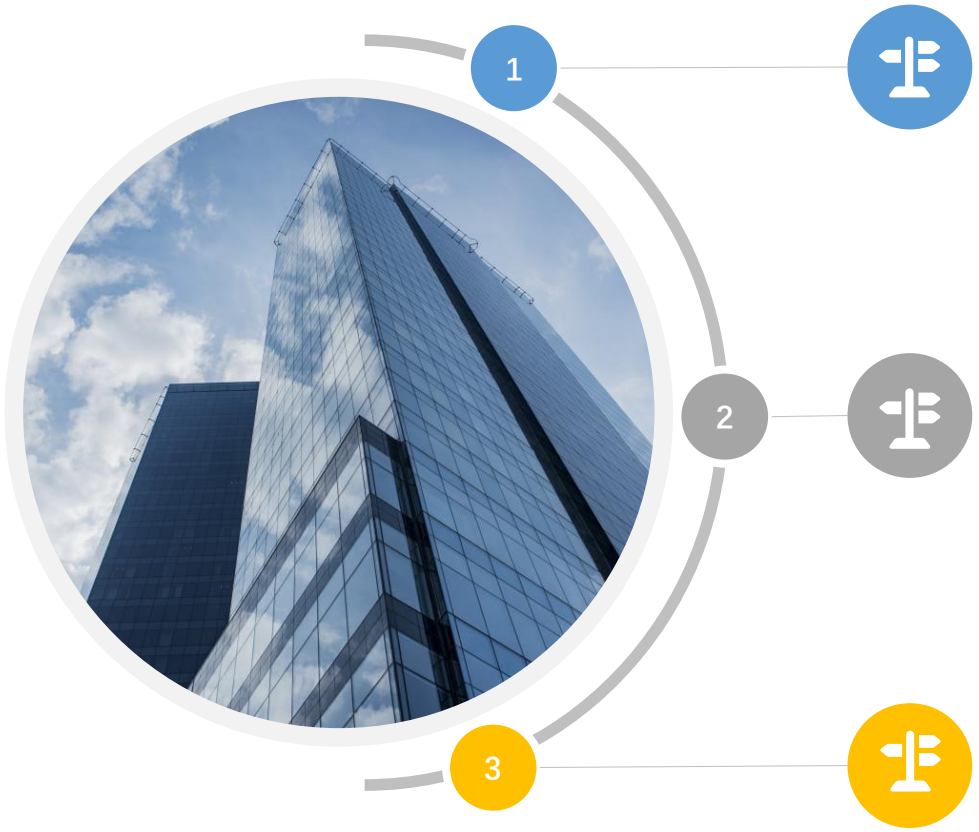


Fig. Food N harvest (a), food P harvest (b), and energy extraction (c) enabled by primary inputs of each sector with water withdrawals in each province.

Potential policies in the manual



- Adopting green fiscal measures to support circular business models
- Removing fiscal subsidies on fossil fuels and introducing market-based mechanisms to put a price on carbon externalities

- Incorporating circularity criteria into sustainable public procurement schemes
- Promoting integrated infrastructure planning for a circular economy

- Fostering local value chains by supporting local businesses, particularly small and medium enterprises

Thank you !

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