



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

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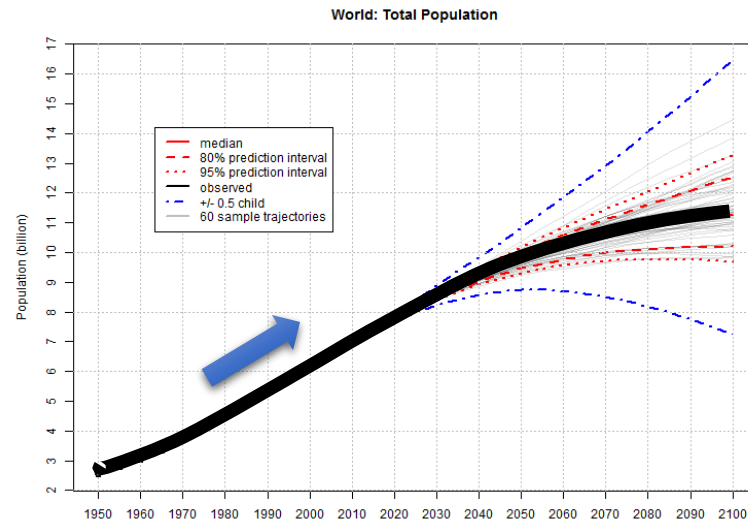
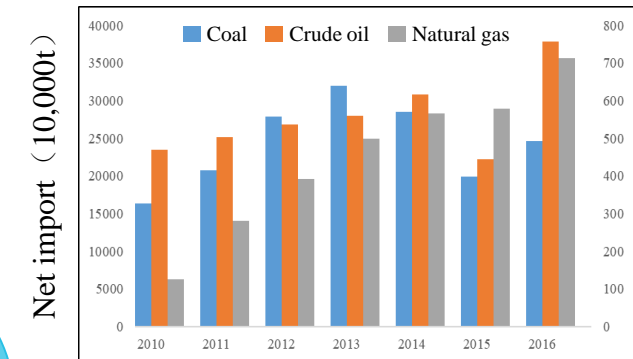
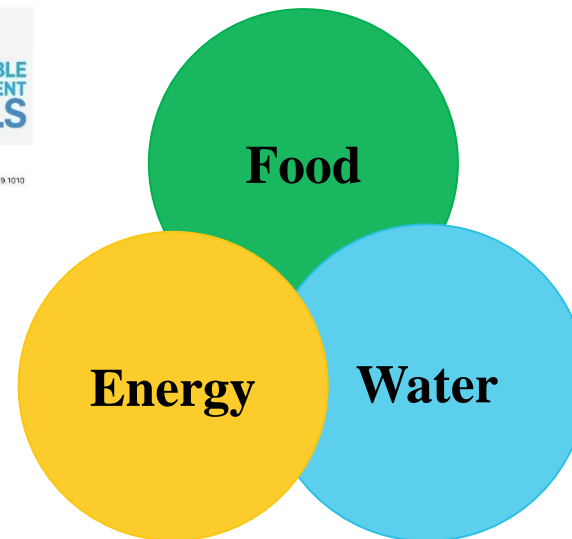
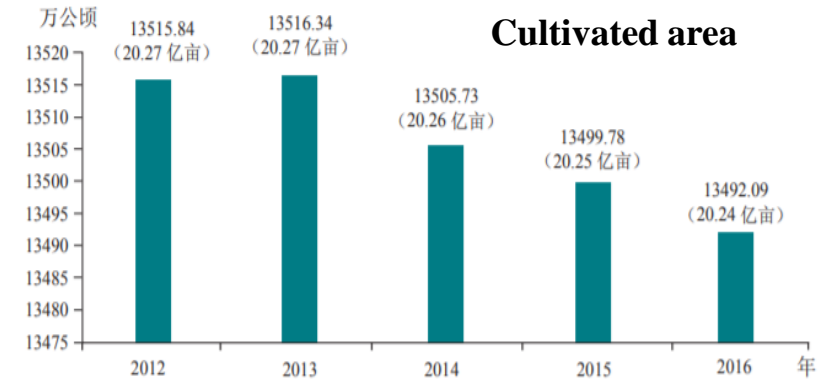
# **Selected case studies in the manual**



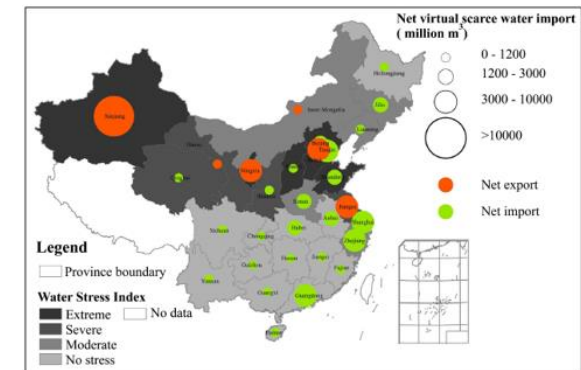
# Food-Energy-Water and Sustainability



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For queries on usage, contact: dpc@trollback.com



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017).  
World Population Prospects: The 2017 Revision. <http://esa.un.org/unpd/wpp/>

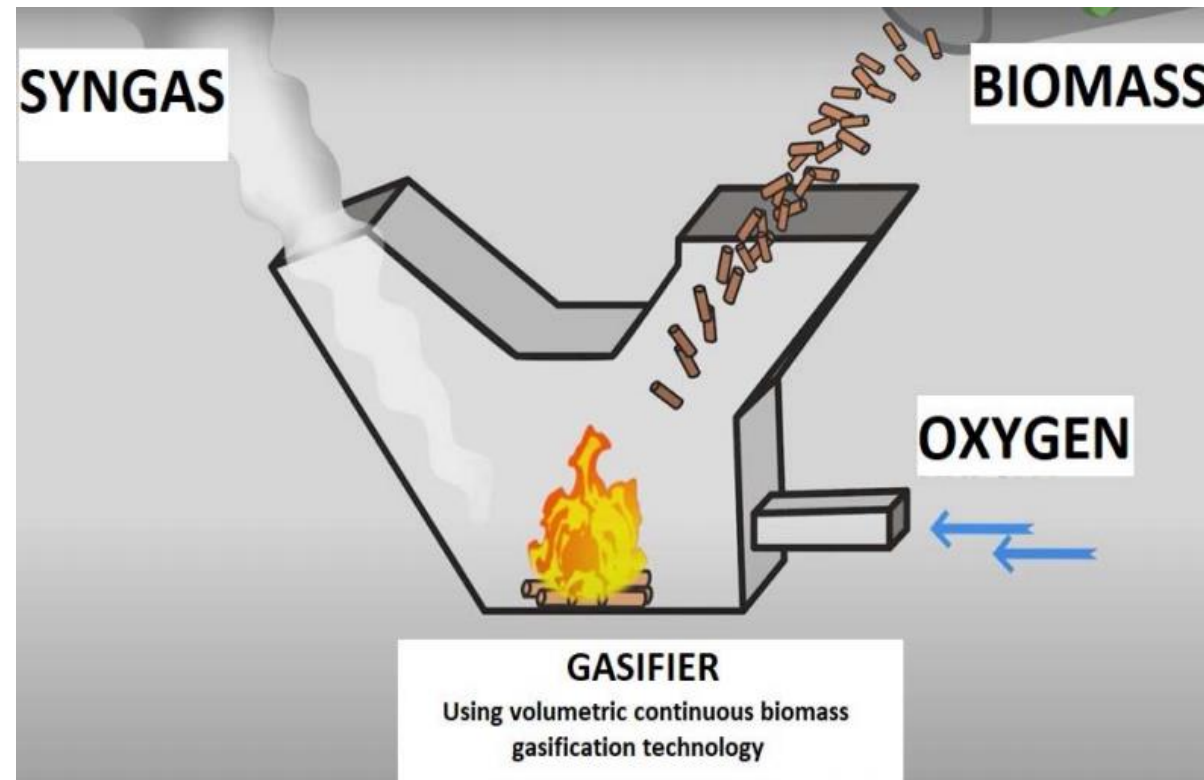


Zhao X., et al. 2018. Measuring scarce water saving from interregional virtual water flows in China. Environ. Res. Lett. 13.

## Case study in Energy sector of the manual

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- Biomass gasification technology for local communities



The biomass gasification project by Oxfam

## Case study in Energy sector of the manual

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- Smart home technologies for greater energy-efficiency



Xiaomi smart home integrated appliances

## Case study in Water and Food sector of the manual

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- 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

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- 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**



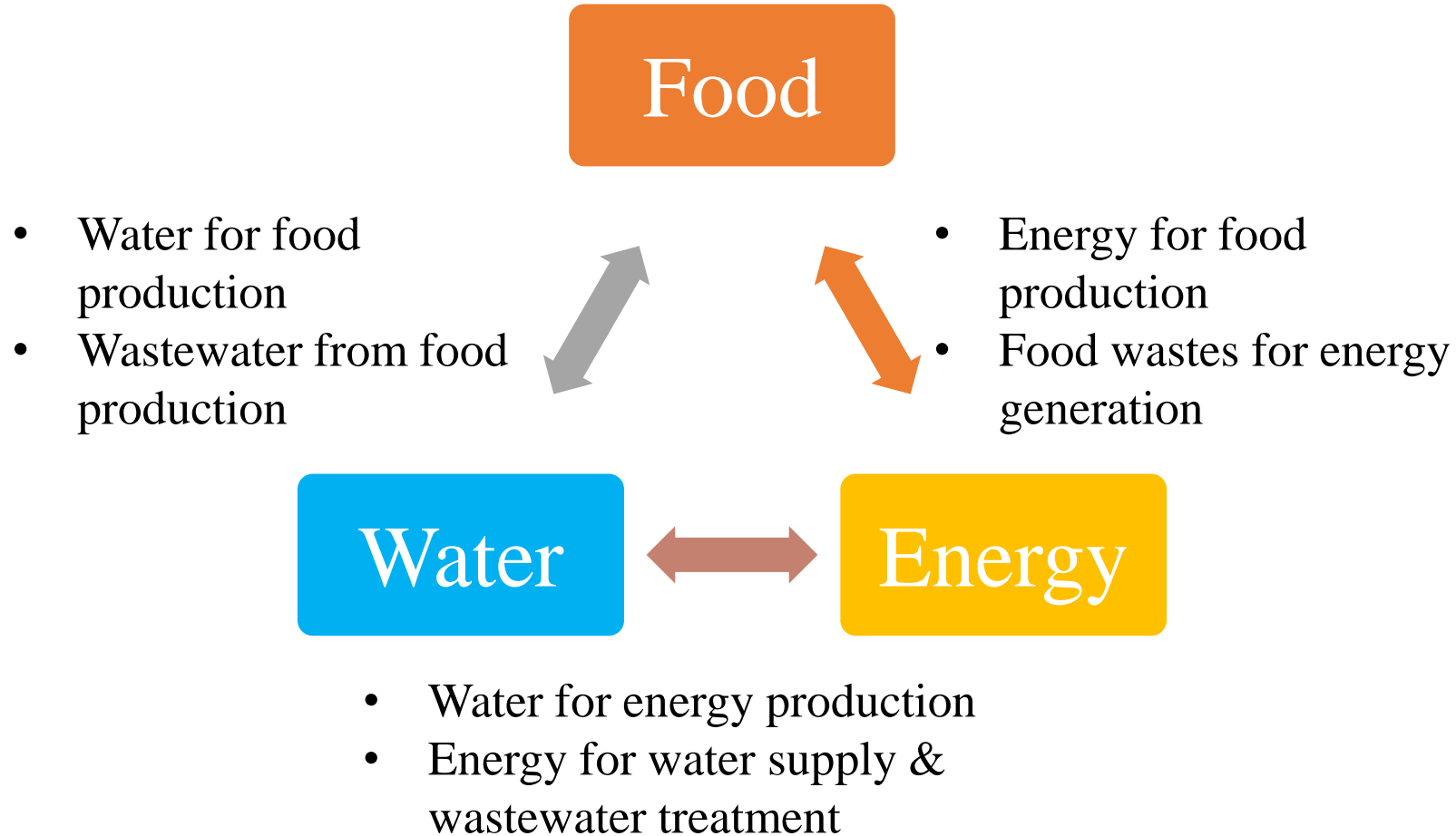


# Food-Energy-Water nexus



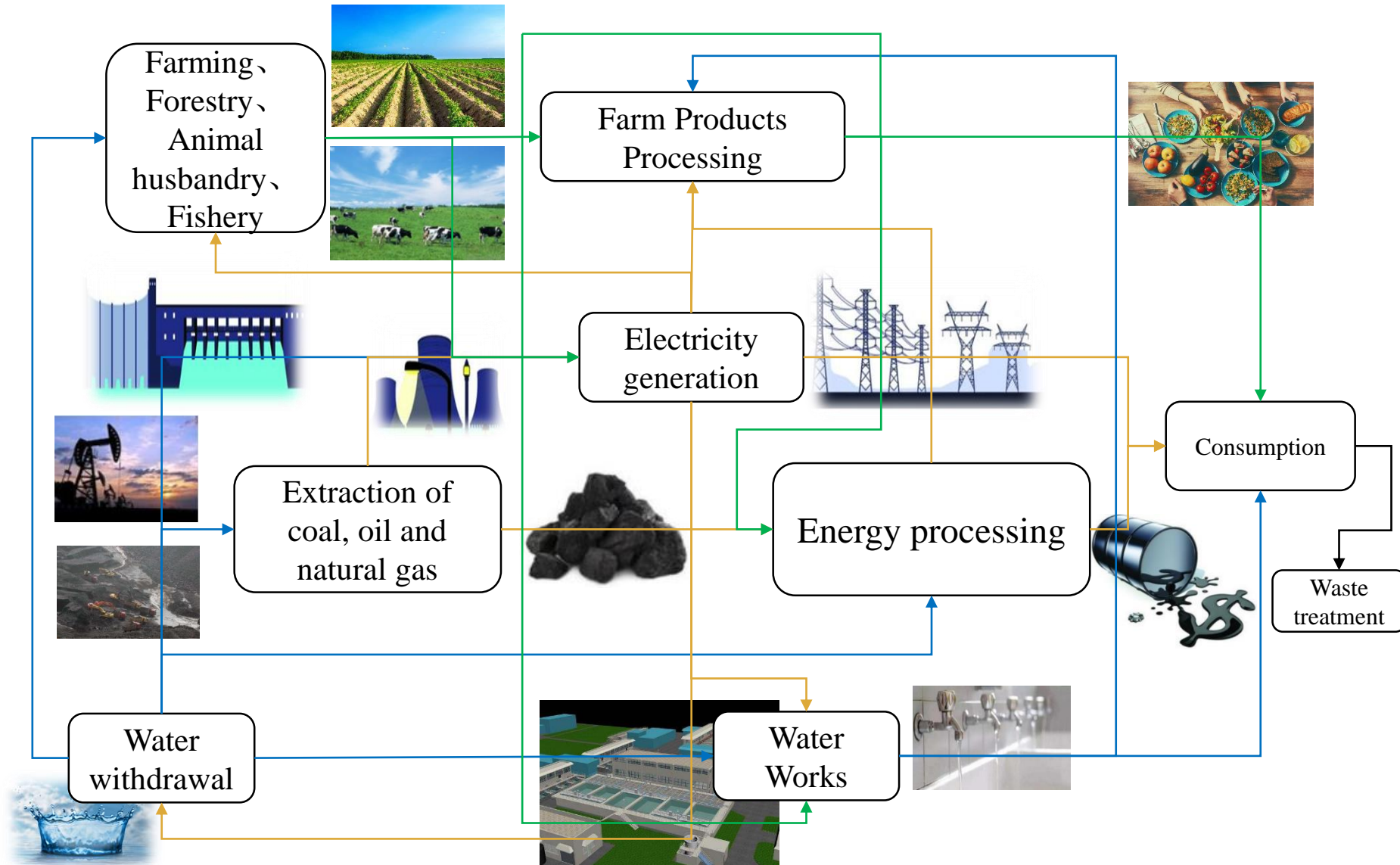
# Food, energy and water systems are intertwined

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# Food, energy and water systems are intertwined



# Material and Energy Flow Analysis

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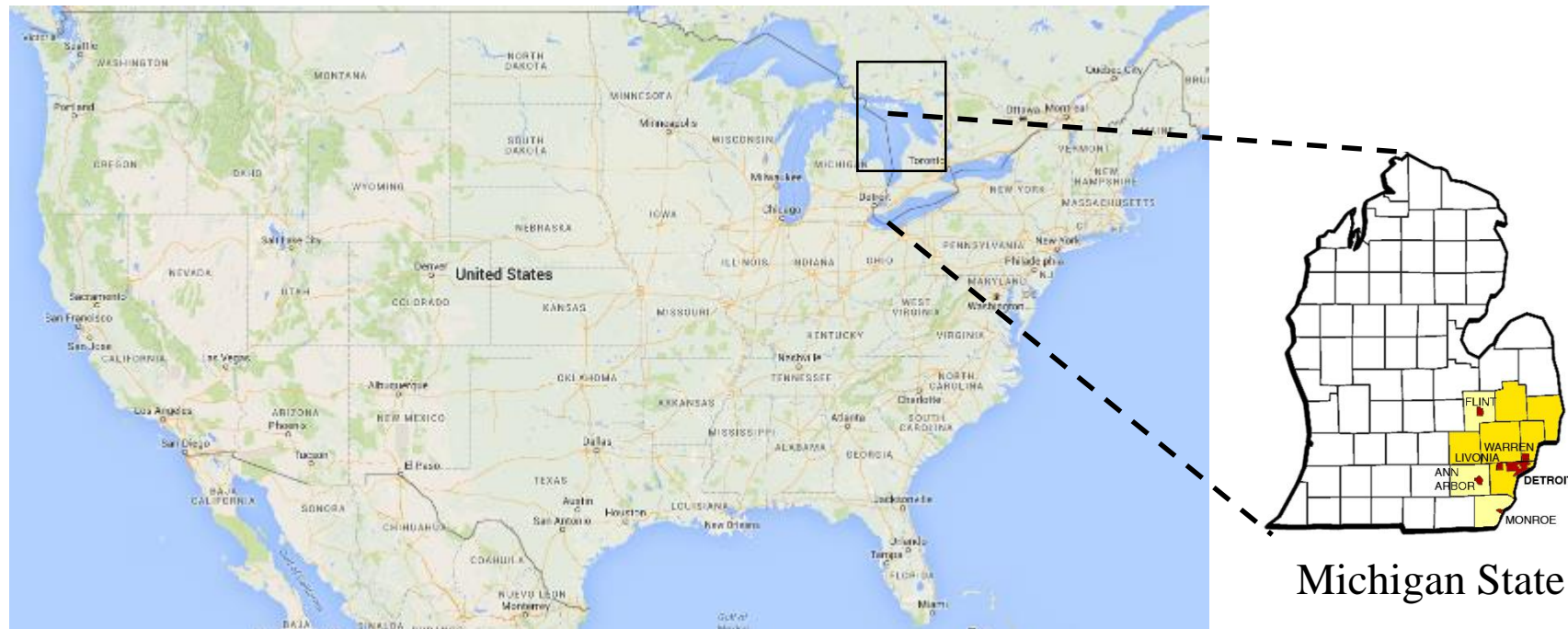
**Modeling individual FEW systems**

**Identify interdependence of FEW systems**

**Constructing FEW network**

## Case study

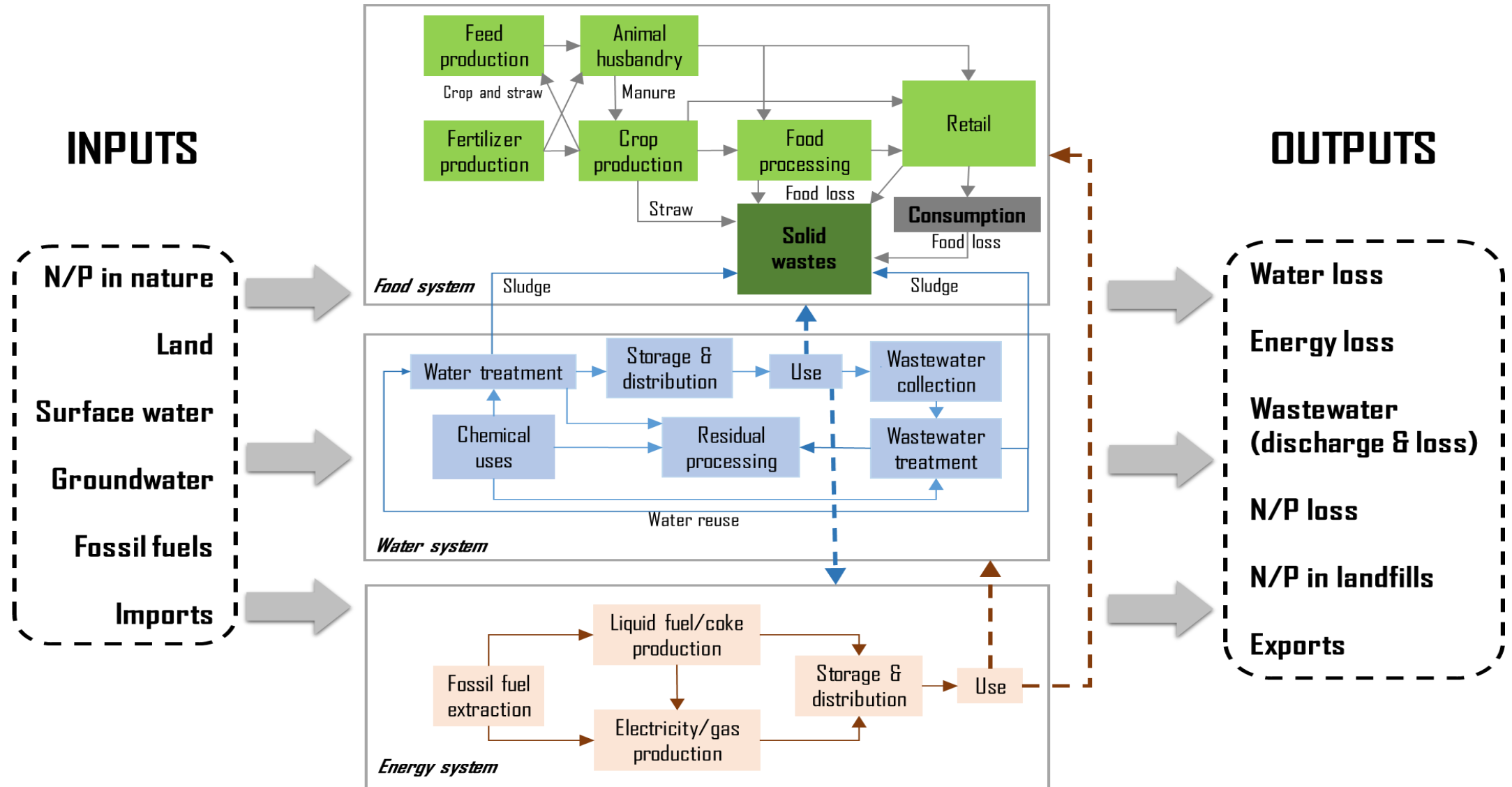
- City-region concept: core and surrounding areas
- Detroit Metropolitan Area (DMA): six counties
- Time point: 2012



11<sup>th</sup> most populous in US

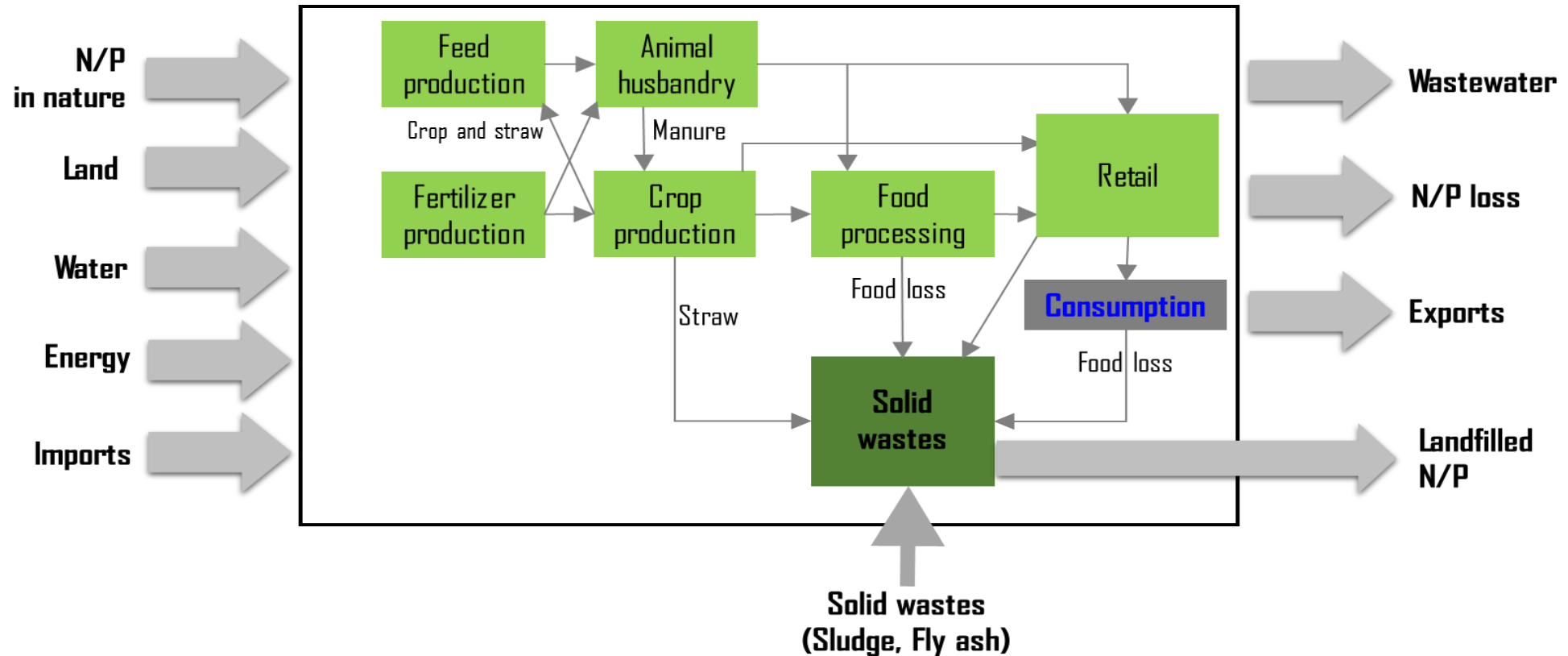


# Layout and structure of the FEW network



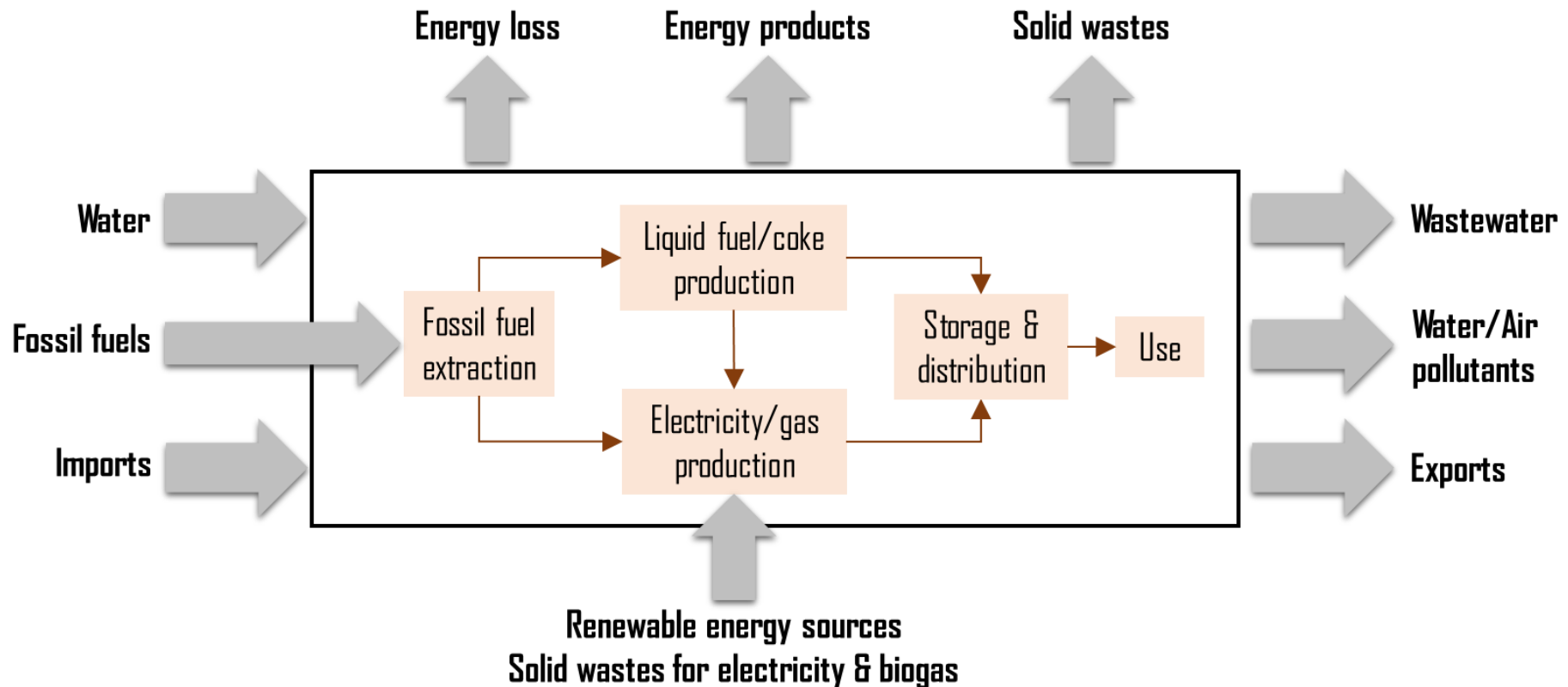
# Food system

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



# Energy system

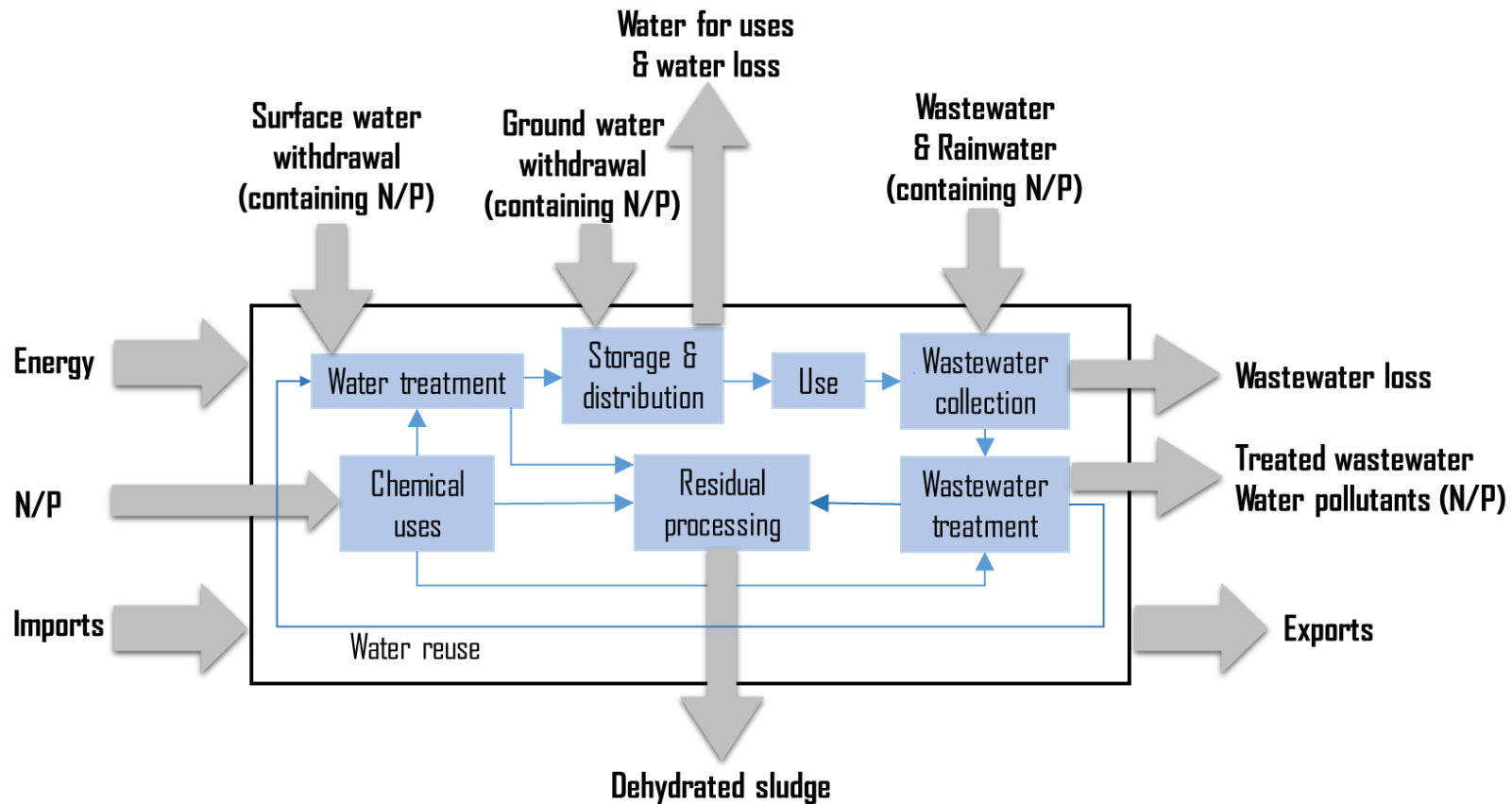
- **Energy supply chain:** fossil fuel extraction, fossil fuel processing, electricity generation, energy consumption, emissions





# Water system

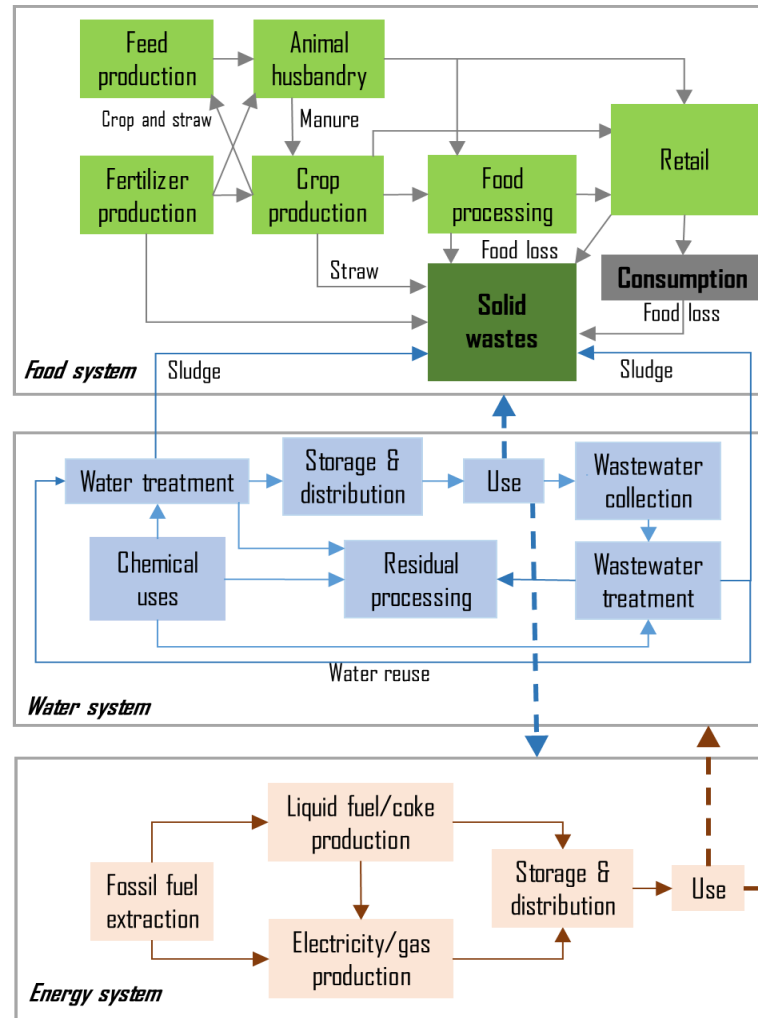
- **Water supply chain:** water withdrawal, water treatment, water supply & uses, wastewater collection, wastewater treatment, residual processing, emissions



# 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

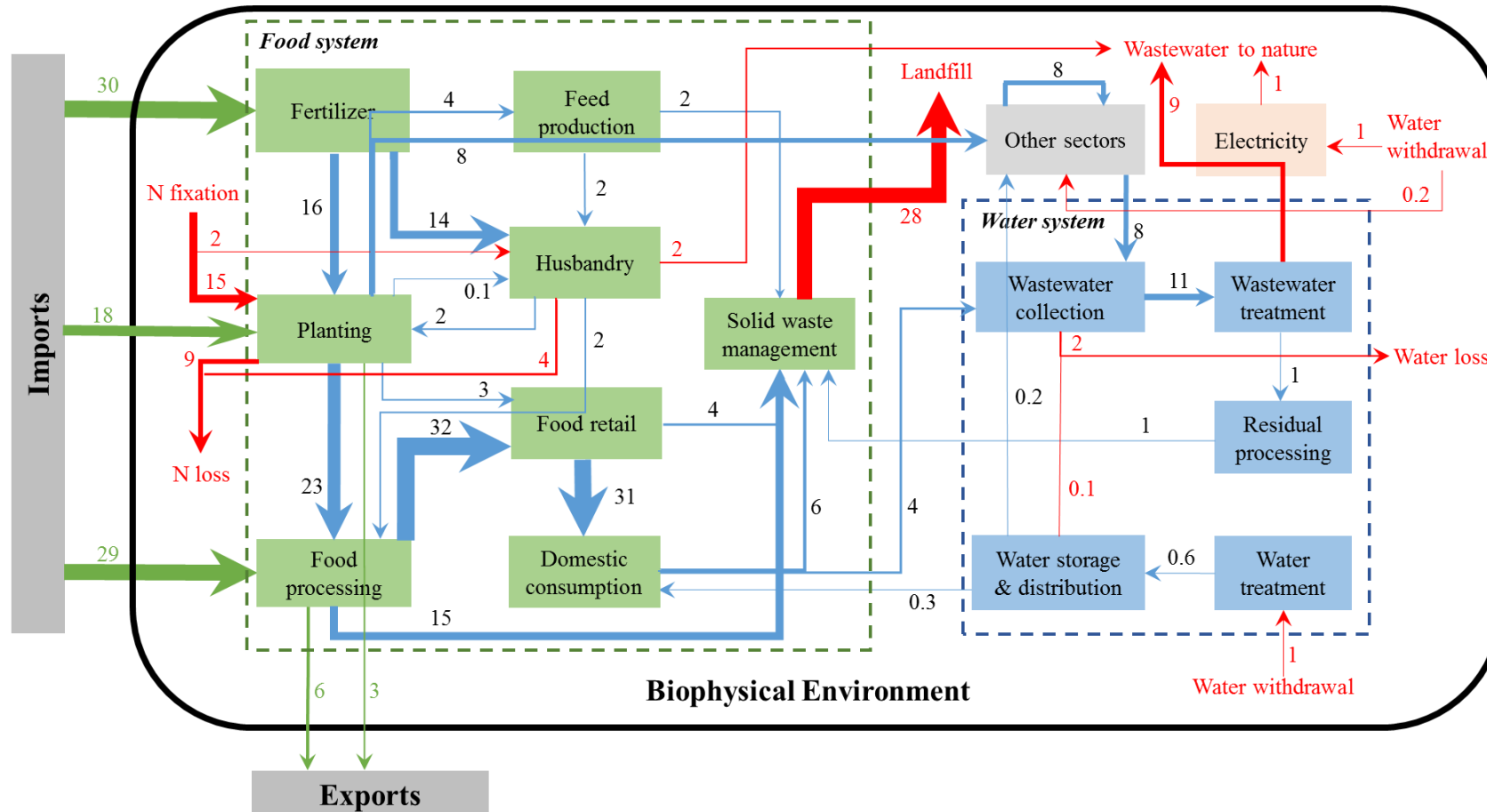


## OUTPUTS

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



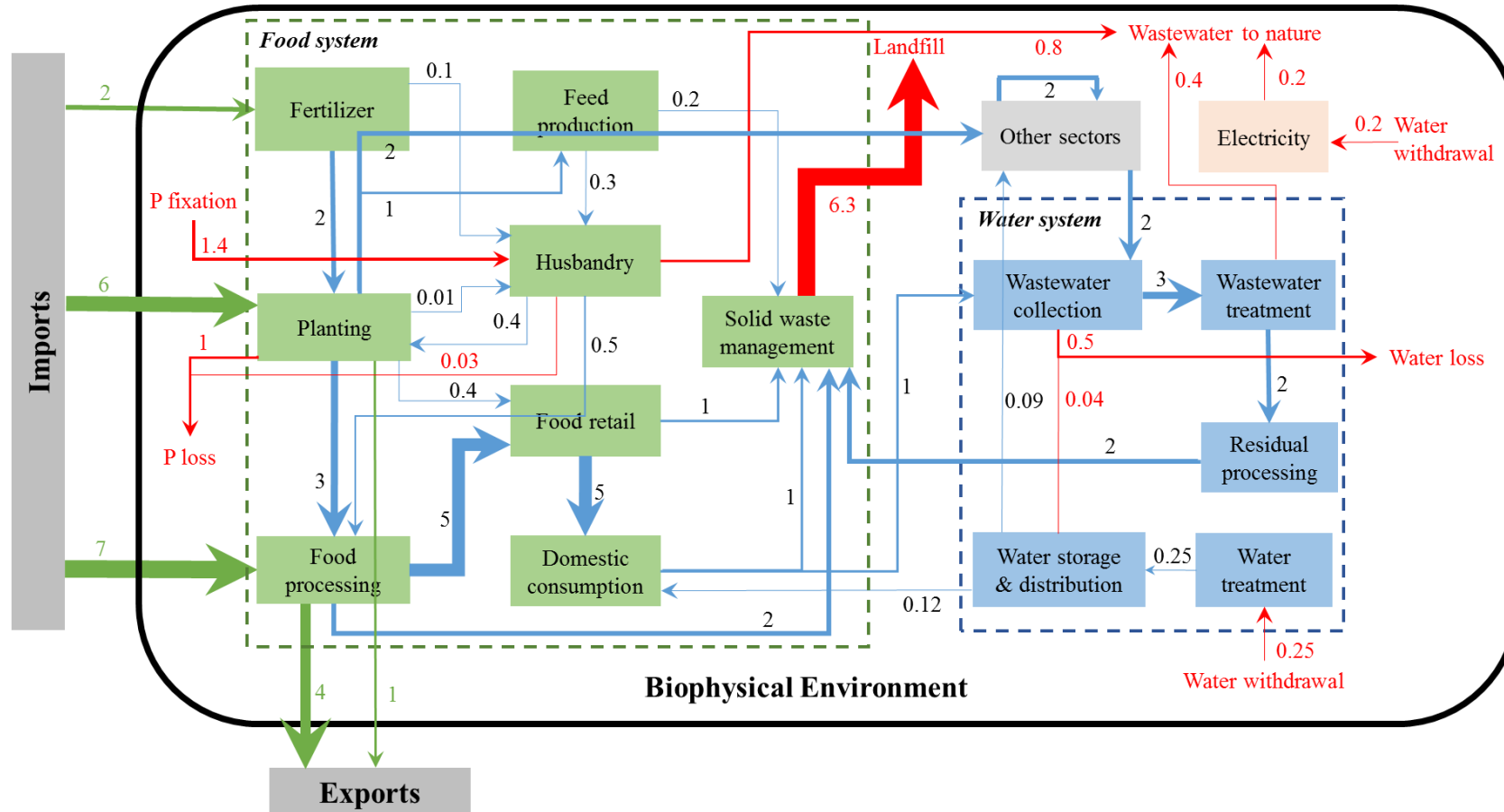


# Results: P flows

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

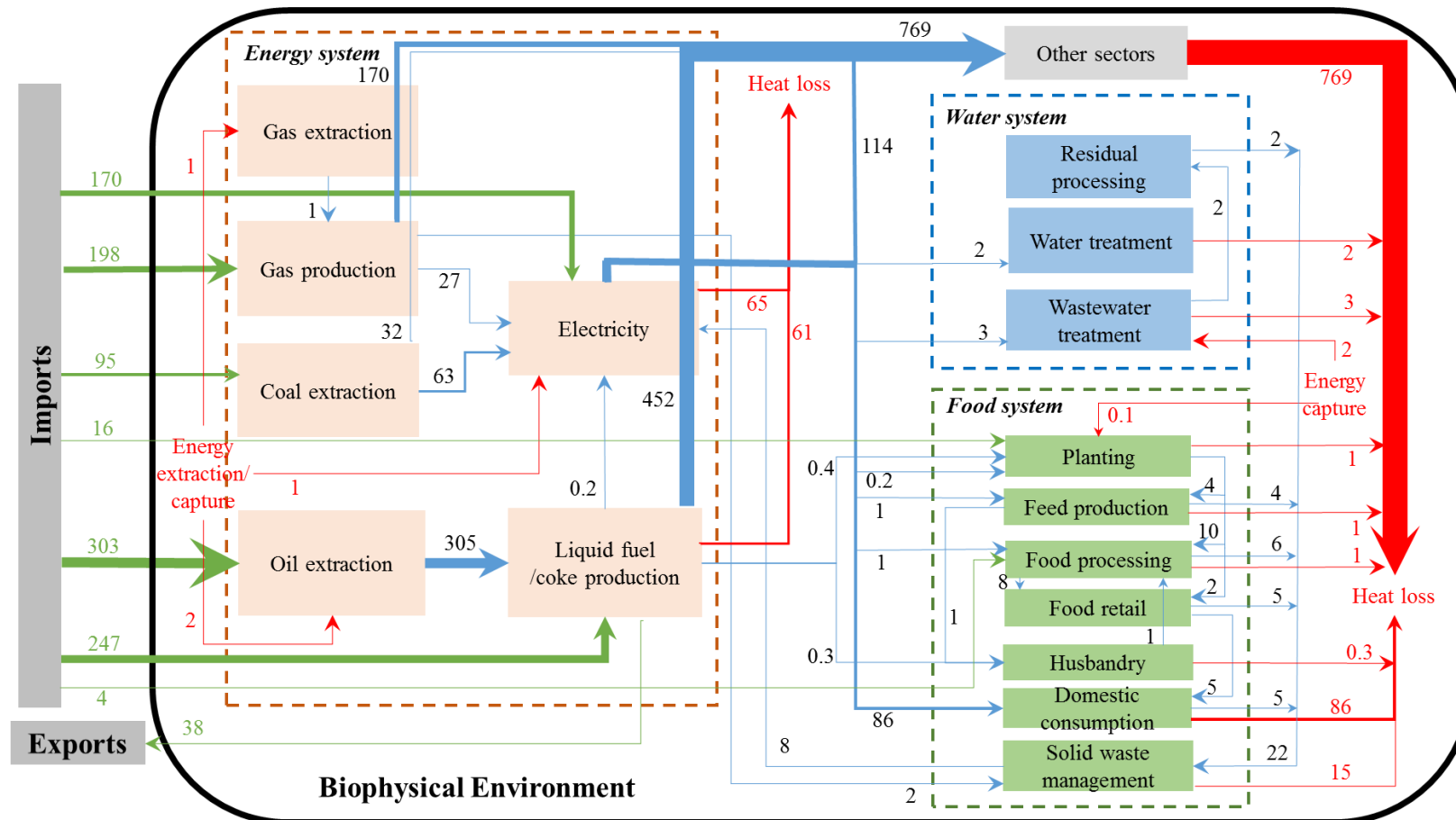


# Results: Energy flows

Food system: input & output 113 PJ

Water system: input & output 7 PJ

Energy system: input & output 1,027 PJ

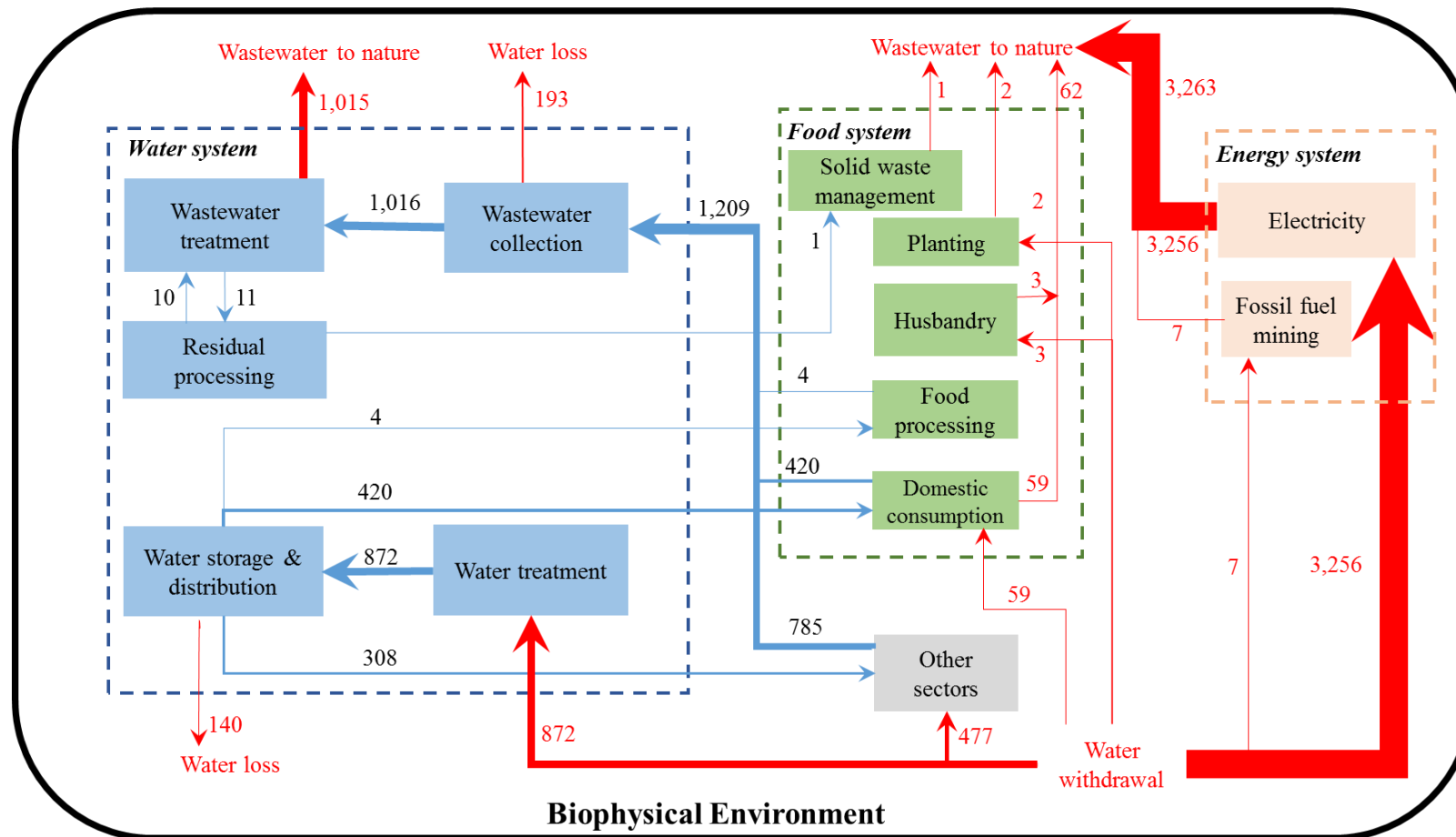


# Results: Water flows

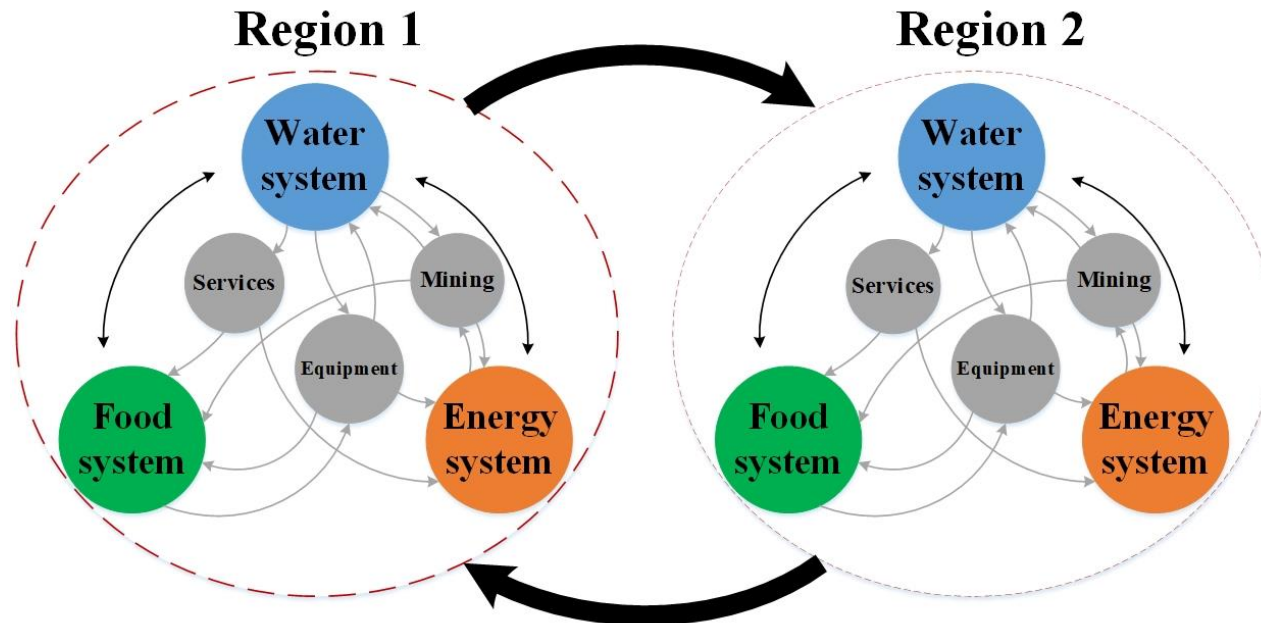
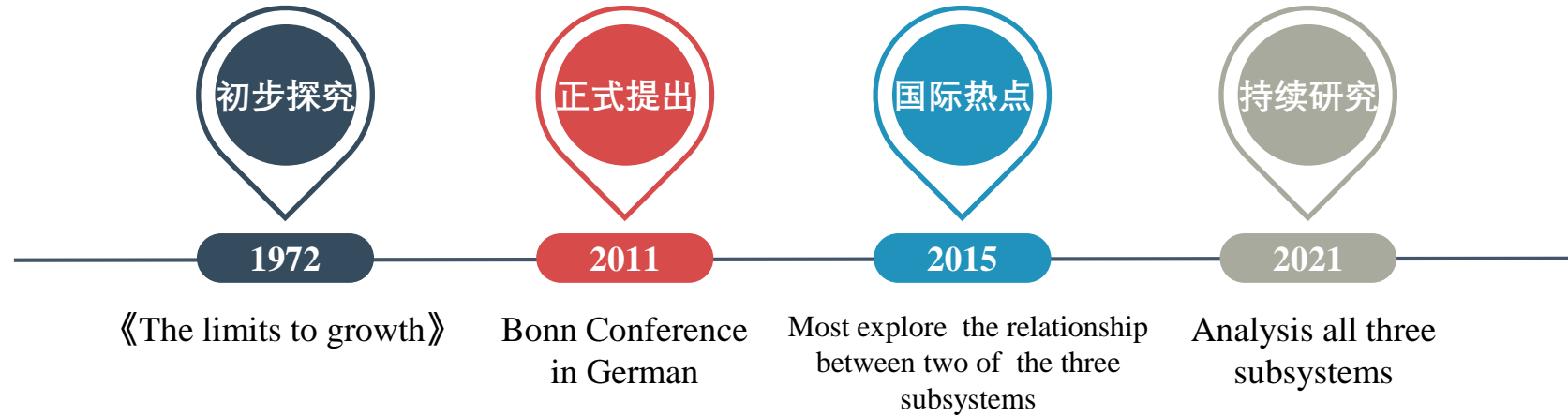
Food system: input & output 489 Mt

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 72 sectors

Output			Sectors		Final Demand								Exports	Total Output
			Beijing	Xinjiang	Beijing				Xinjiang					
Input	Sector 1 ... Sector n		Sector 1 ... Sector m		HC	GC	FC	CI	...	HC	GC	FC	CI	
	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												

Row balance

Column balance

$$Z + Y = X$$

$$Z + V = X'$$



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

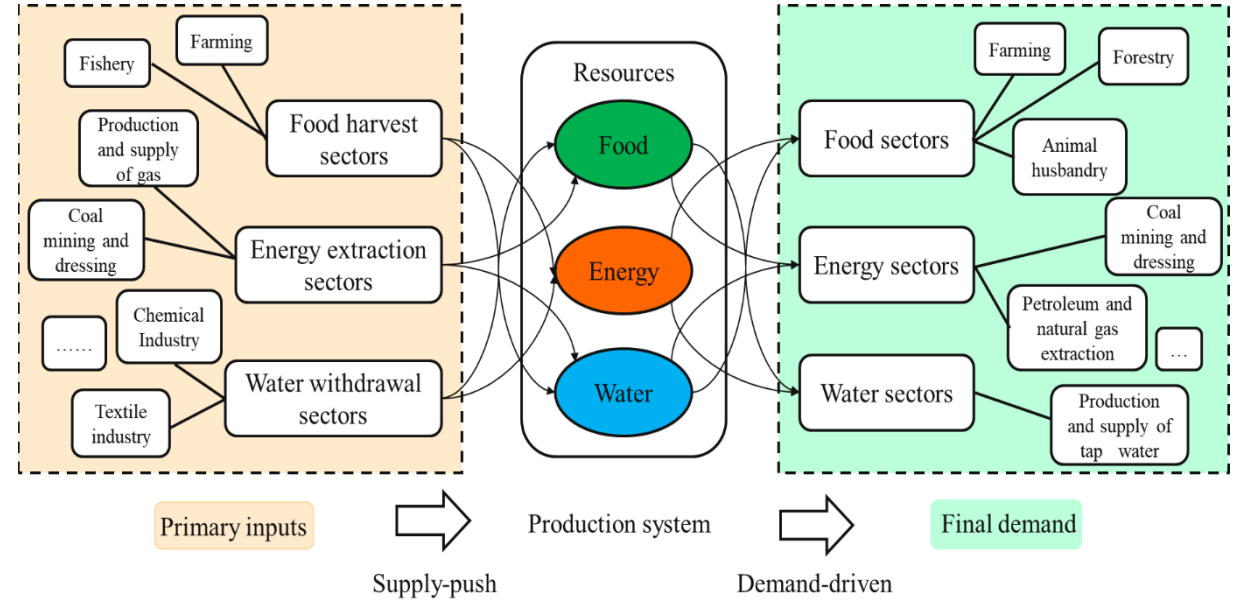
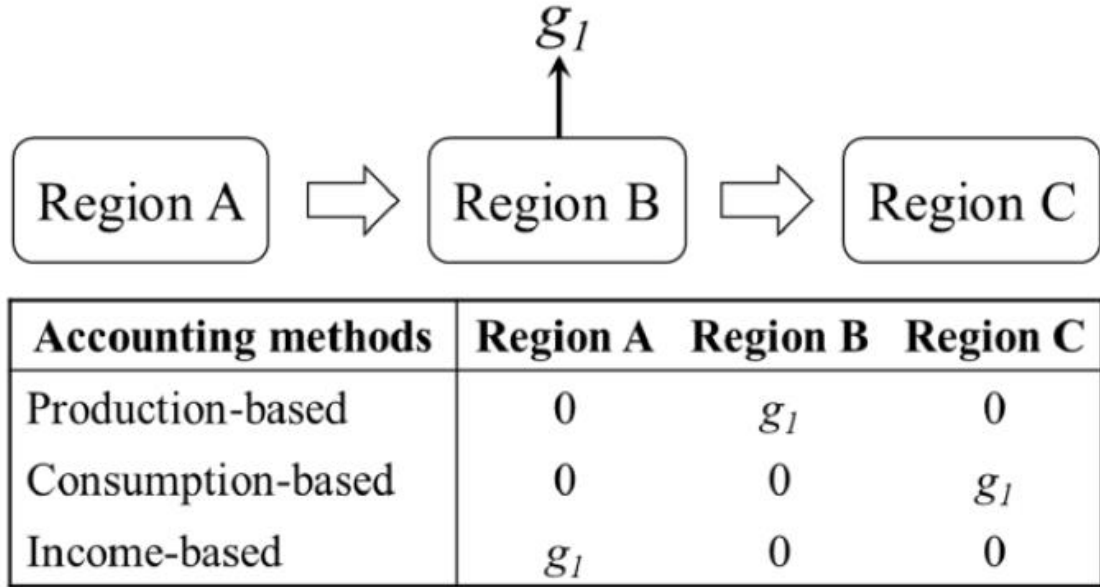
$$x = v(I - B)^{-1}$$

Leontief Model

Ghosh Model

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

# Environmentally Extended Multi-Regional Input-Output model



1 Consumption-based

Leontief Model

$$w_{cf} = f_w \times (I - A)^{-1} \times y_{fi}$$

$$w_{ce} = f_w \times (I - A)^{-1} \times y_{ei}$$

Water withdrawals induced by final demand of food and energy products

2 Income-based

Ghosh Model

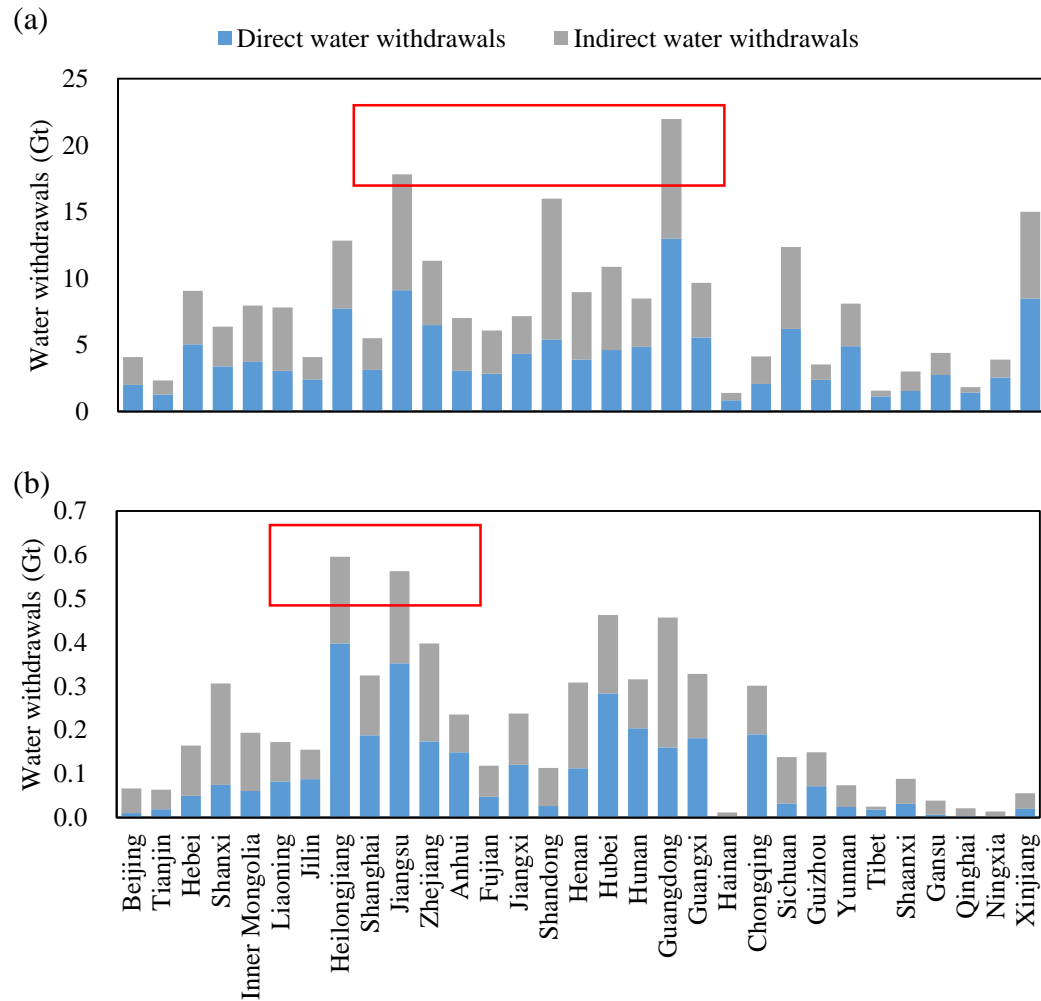
$$f_{inw} = v_{wi} \times (I - B)^{-1} \times f_f'$$

$$e_{inw} = v_{wi} \times (I - B)^{-1} \times f_e'$$

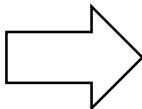
Food harvest and energy extraction enabled by primary inputs of sectors with water withdrawals

# FEW Nexus from the Demand Perspective

## Taking water subsystem as the core



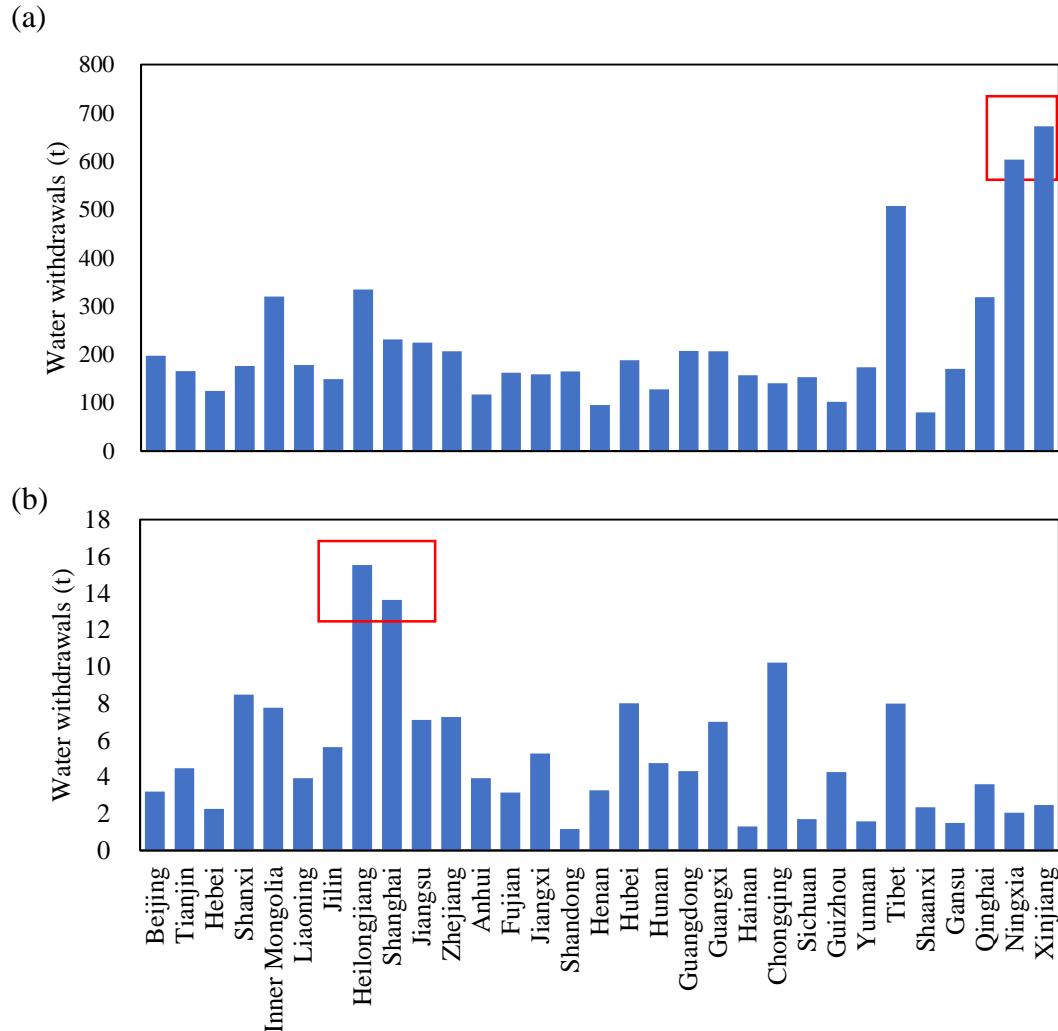
In 2012, China's final demand of food products drove 251 billion tons (Gt) of water withdrawals, while final demand of energy products drove 7 Gt of water withdrawals.



- 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.

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

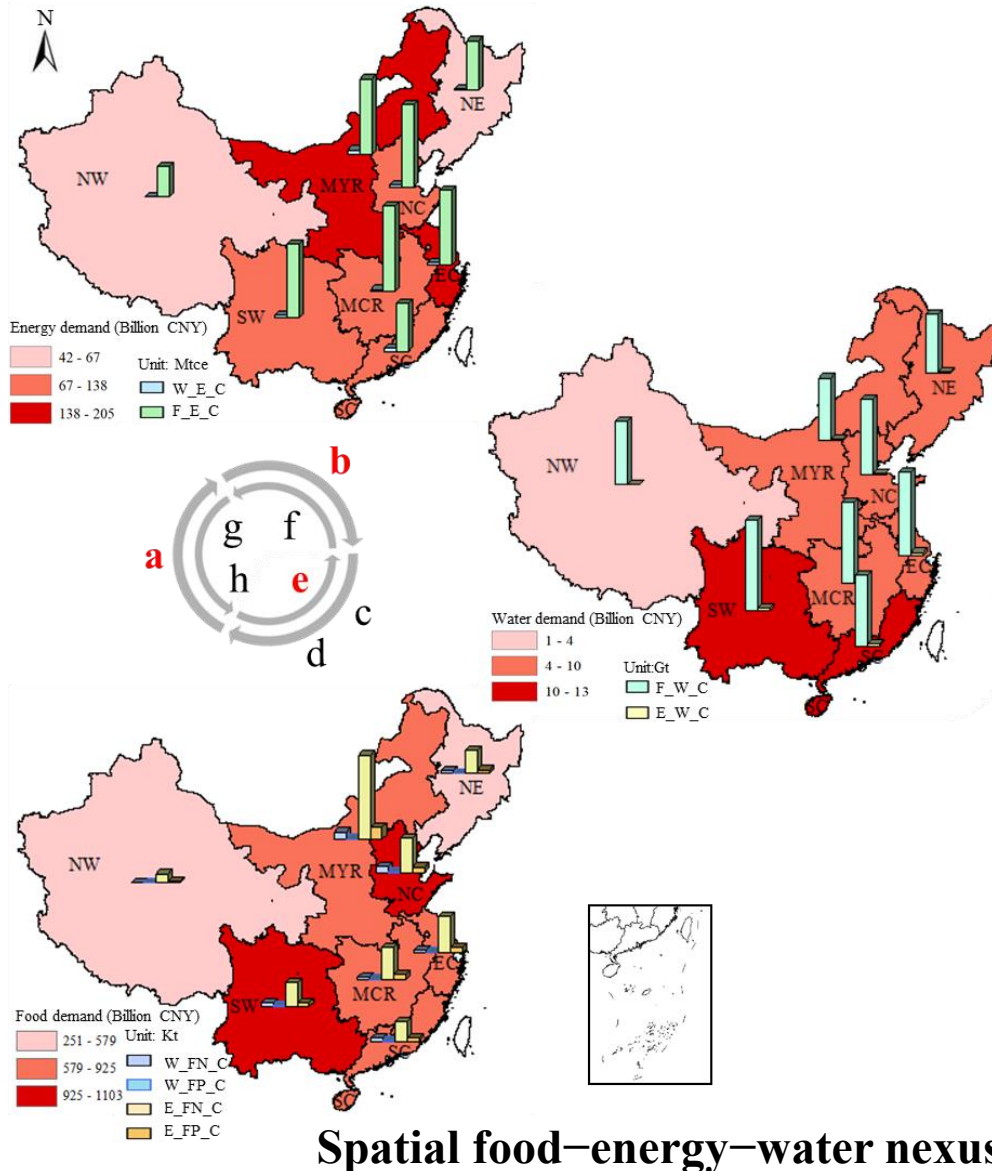
# FEW Nexus from the Demand Perspective



- 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**.

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

# FEW Nexus from the Demand Perspective



	①	②	③	④	⑤	⑥	⑦	⑧	
<b>a</b>	Mtce	6.7	1.7	2.4	1.9	1.4	1.6	1.8	0.6
		0.7	8.4	1.6	1.0	1.0	1.2	1.1	0.4
		0.1	0.1	0.3	0.1	0.1	0.2	0.1	0.0
		0.1	0.2	0.3	1.2	0.2	0.2	0.2	0.1
		7.9	14.3	18.4	10.2	22.1	16.9	9.3	3.7
		0.6	1.2	1.8	1.1	0.8	7.4	0.9	0.3
		1.1	2.0	2.4	1.6	1.3	2.0	12.1	0.5
		1.2	2.0	2.4	1.6	1.4	2.0	1.5	5.4
<b>b</b>	Mtce	797.9	43.2	69.5	27.3	64.8	34.0	31.2	17.4
		7.6	146.9	21.0	8.0	21.7	10.8	9.0	6.1
		17.4	16.7	980.4	-5.2	-1.3	10.2	13.9	-8.0
		12.5	27.5	21.5	465.3	40.9	18.5	19.8	6.8
		24.7	43.8	56.3	24.9	514.4	30.8	24.8	11.2
		26.1	52.4	41.0	21.1	98.8	1088.3	29.8	10.0
		23.5	44.3	39.3	19.4	78.2	31.1	837.4	10.0
		12.9	32.9	56.4	25.3	78.0	26.8	22.8	98.5
<b>c</b>	Gt	897.5	108.2	64.5	127.7	113.3	33.2	54.7	7.4
		142.3	1549.3	122.1	226.9	258.9	63.3	99.7	14.2
		55.1	86.6	453.8	91.3	91.9	32.8	59.4	7.2
		33.7	65.5	31.6	536.6	66.3	18.9	32.2	3.9
		108.6	206.4	129.8	206.2	2427.8	67.5	94.1	12.9
		95.5	188.0	116.9	191.6	193.7	592.5	81.3	9.2
		68.9	137.9	72.0	141.0	138.6	40.6	988.9	9.0
		33.3	70.0	32.9	56.3	68.7	15.5	19.9	71.8
<b>d</b>	Ktce	136.6	17.9	10.6	21.2	18.8	5.4	8.9	1.2
		23.6	257.3	20.2	37.7	42.3	10.5	16.7	2.4
		7.1	11.1	61.6	11.6	11.7	4.2	7.7	0.9
		5.3	10.2	5.0	80.1	10.4	3.0	5.1	0.6
		15.7	29.8	18.8	29.8	348.4	9.8	13.5	1.9
		13.7	27.1	16.5	27.6	27.9	88.9	11.8	1.3
		10.4	20.8	10.8	21.2	20.9	6.1	148.3	1.4
		4.7	9.8	4.6	7.9	9.6	2.2	2.8	10.0
<b>e</b>	Gt	18.0	2.6	2.8	2.5	2.3	1.4	2.4	0.8
		0.3	15.8	1.0	0.7	0.6	0.4	0.5	0.1
		0.3	0.8	20.0	0.6	0.5	0.4	0.5	0.1
		0.7	1.3	1.1	18.4	1.0	0.6	1.0	0.3
		1.2	1.6	1.5	1.2	15.7	1.1	1.7	0.6
		1.2	3.1	3.6	2.5	1.9	27.5	1.9	0.5
		1.1	2.3	2.1	1.9	1.6	1.0	27.3	0.5
		2.7	4.8	3.7	3.0	3.6	2.0	3.2	24.1
<b>f</b>	Ktce	283.1	21.3	22.9	27.3	19.0	12.4	17.0	2.1
		13.7	213.0	21.6	23.1	22.2	11.0	13.4	1.7
		2.5	3.0	13.6	7.5	3.4	2.6	1.9	0.4
		2.5	4.1	3.2	62.3	3.5	2.1	2.8	0.4
		268.3	331.8	618.9	686.7	1581.0	254.8	198.6	36.5
		13.9	22.0	24.4	24.0	15.9	239.6	10.8	1.6
		35.8	50.4	62.3	67.9	40.6	30.5	734.1	5.4
		26.3	31.2	48.7	56.2	34.0	21.9	20.8	82.7
<b>g</b>	Kt	5.3	1.1	1.8	1.0	2.6	0.9	0.8	0.5
		1.1	7.1	3.3	1.6	4.8	1.5	1.4	1.1
		0.4	0.6	3.0	0.4	1.2	0.4	0.5	0.2
		0.2	0.4	0.5	1.8	1.0	0.3	0.4	0.1
		1.5	2.4	3.1	1.6	19.2	1.6	1.4	0.7
		0.8	1.3	1.6	1.0	3.3	7.9	0.8	0.4
		0.6	0.9	1.2	0.7	2.4	0.7	4.5	0.3
		0.3	0.5	0.8	0.4	1.3	0.4	0.3	0.7
<b>h</b>	Kt	0.9	0.2	0.3	0.1	0.4	0.1	0.1	0.1
		0.2	1.2	0.6	0.3	0.8	0.3	0.2	0.2
		0.0	0.1	0.4	0.1	0.2	0.1	0.1	0.0
		0.0	0.1	0.1	0.3	0.2	0.0	0.1	0.0
		0.2	0.4	0.5	0.2	2.9	0.2	0.2	0.1
		0.1	0.2	0.2	0.1	0.5	1.1	0.1	0.1
		0.1	0.1	0.2	0.1	0.4	0.1	0.7	0.1
		0.0	0.1	0.1	0.1	0.2	0.1	0.0	0.1

➤ 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.

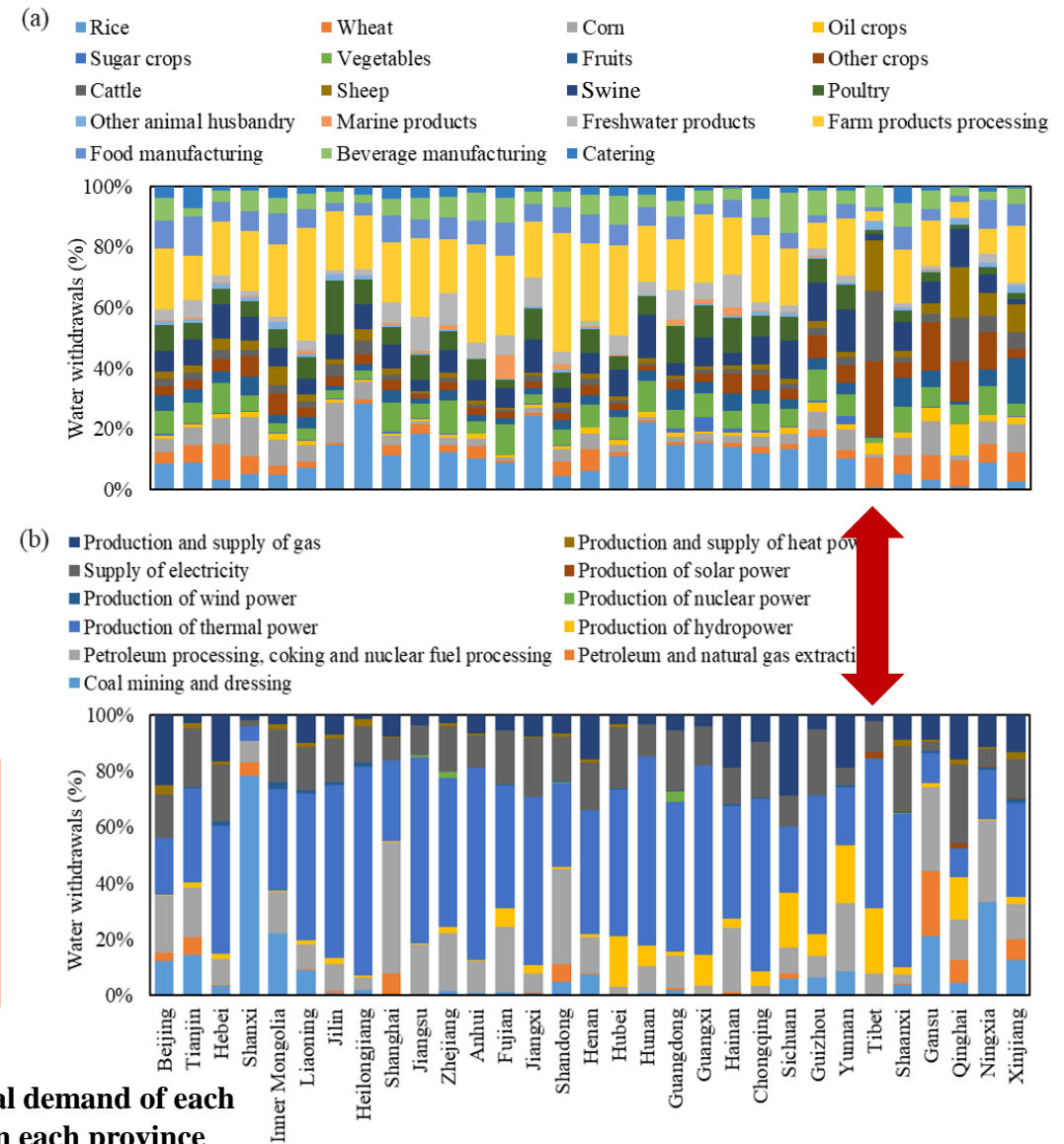
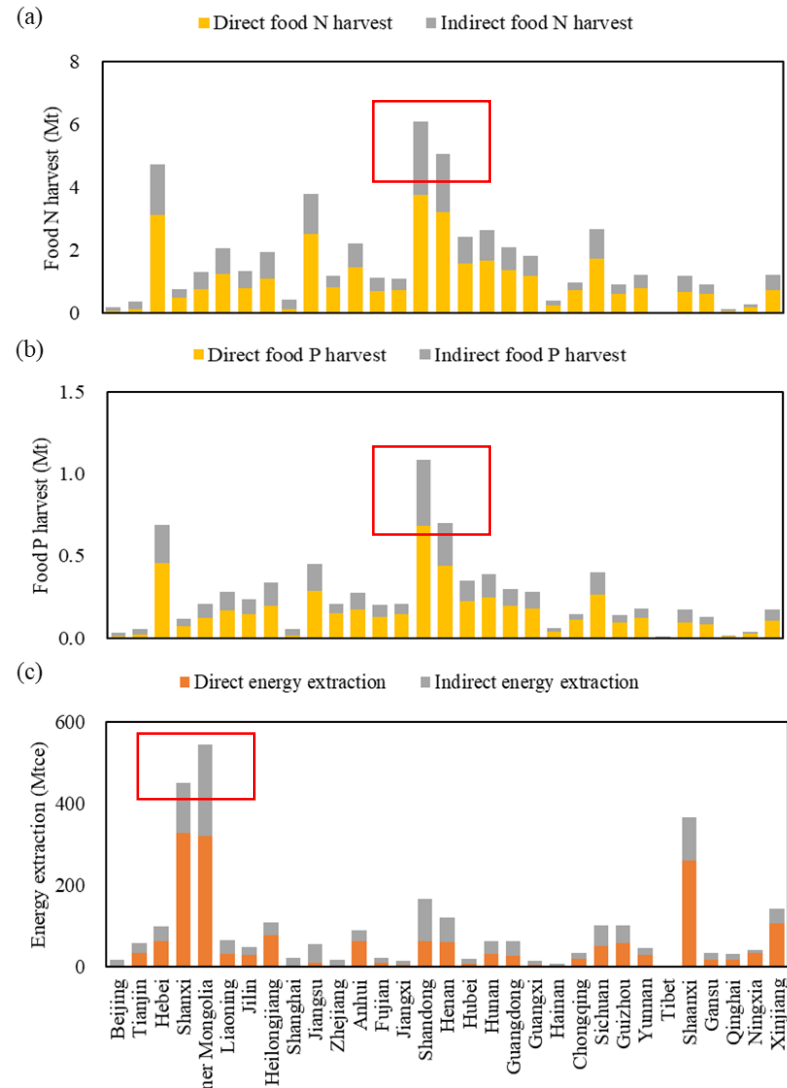
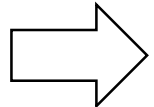


Fig. Water withdrawals induced by the final demand of each food sector (a) and each energy sector (b) in each province

# FEW Nexus from the Supply Perspective



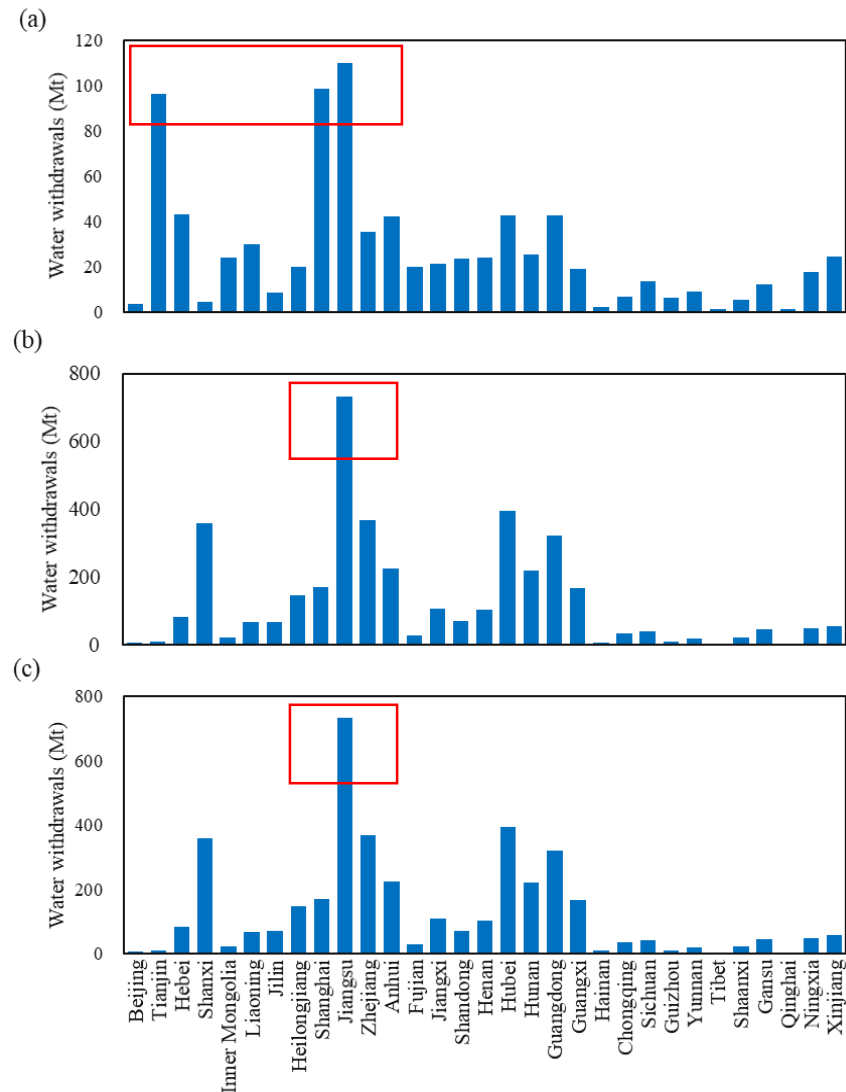
In 2012, primary inputs of sectors with water withdrawals enabled 53 Mt of food nitrogen harvest and 8 Mt of food phosphorus harvest. Meanwhile, primary inputs of sectors with water withdrawals enabled the extraction of 2956 Mt of standard coal equivalents (Mtce).



- 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.

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

# FEW Nexus from the Supply Perspective



➤ 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**).

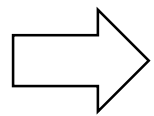
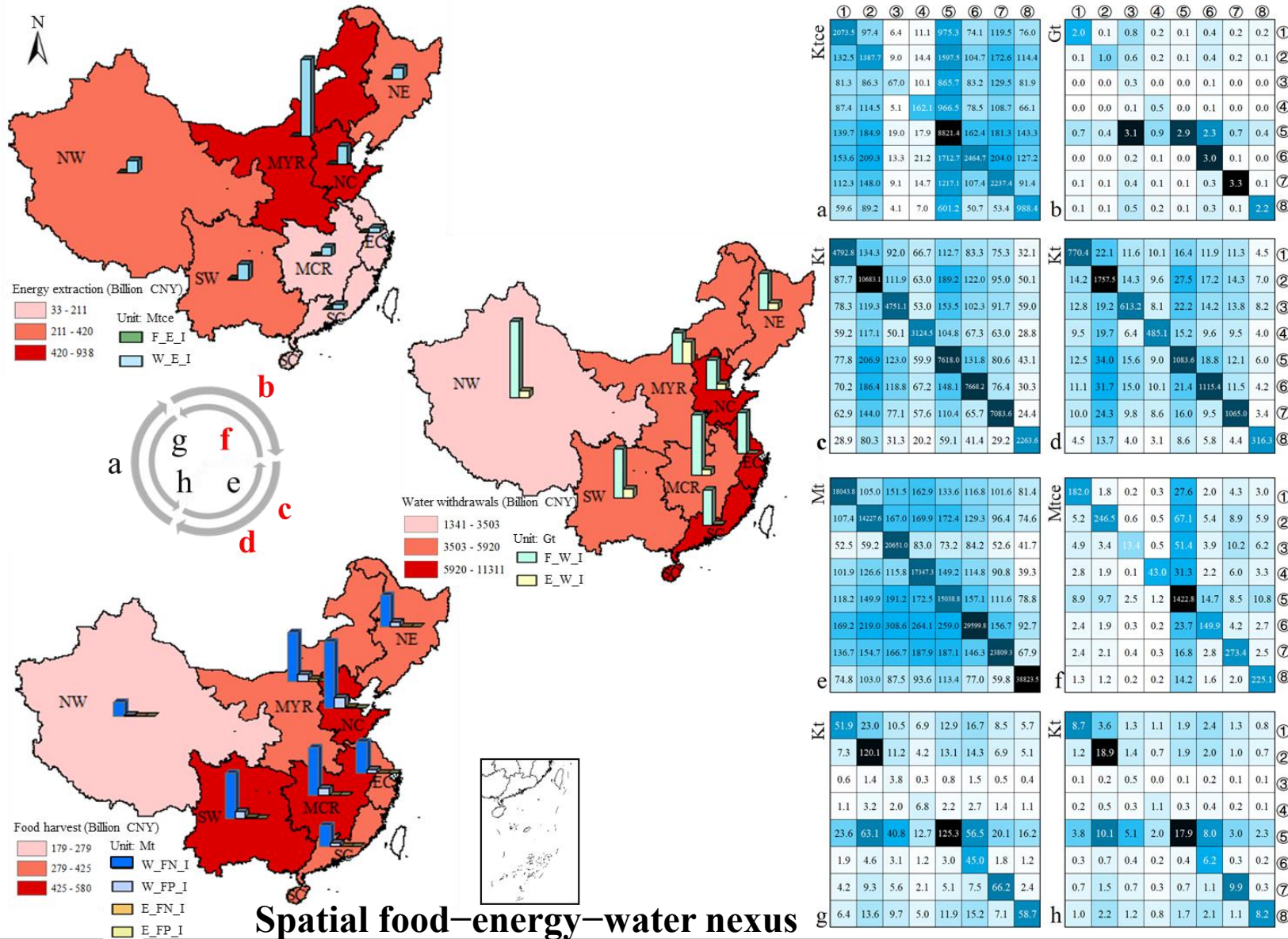


Fig. Water withdrawals of each province enabled by primary inputs of energy extraction sectors in Tianjin (a), Shanxi (b), and Inner Mongolia (c)

# FEW Nexus from the Supply Perspective



➤ 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

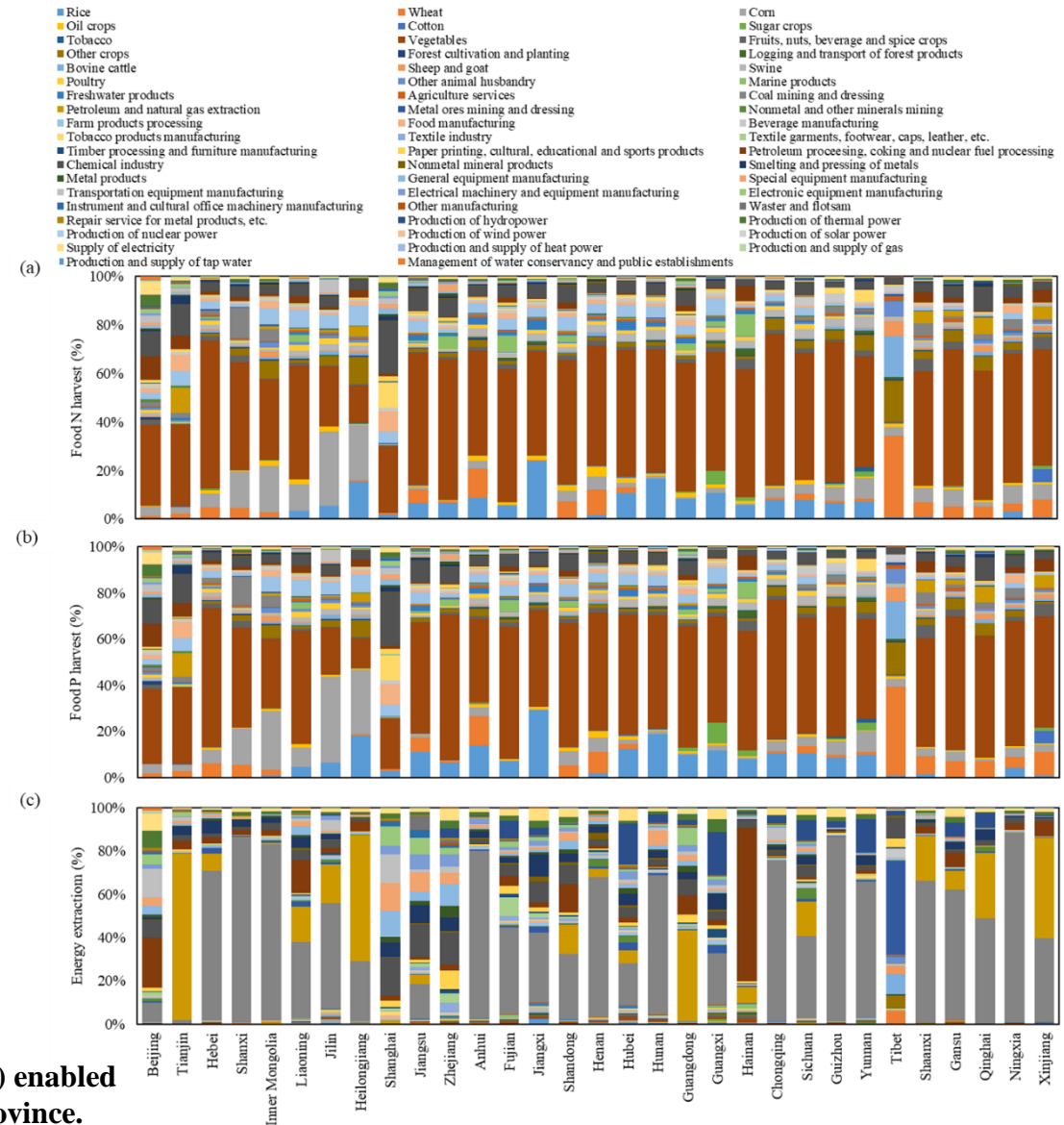
**c-d** From the NE, and SW regions to the NC, and SC regions

**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

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- 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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