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Realizing the Global Methane Pledge by 2030 via Key Pathways in Inter-country Production and Consumption Networks

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1. Introduction

- Methane (CH_4) possesses a higher global-warming potential compared to CO_2, up to 84 times as powerful as CO_2 over a 20-year time frame. CH_4 is responsible for around 30% of the observed global temperatures rise since the Industrial Revolution, making it the second-largest contributor after CO_2.
- There is an increasing recognition that swift and sustained reductions in methane emissions are crucial for mitigating near-term global warming(Powell, 2023).
- Notably, most CH_4 emissions were associated with the world production linkages network (Oita et al., 2016; Torreggiani et al., 2018).
- The intricate production networks within industries of individual economy and across different economies hold significant untapped potential for mitigating CH_4 emissions, an aspect that has unfortunately received limited evaluation.
- After COP28, the pressing need to explore collaborative fields among nations to effectively reduce CH_4 emissions has become increasingly evident.

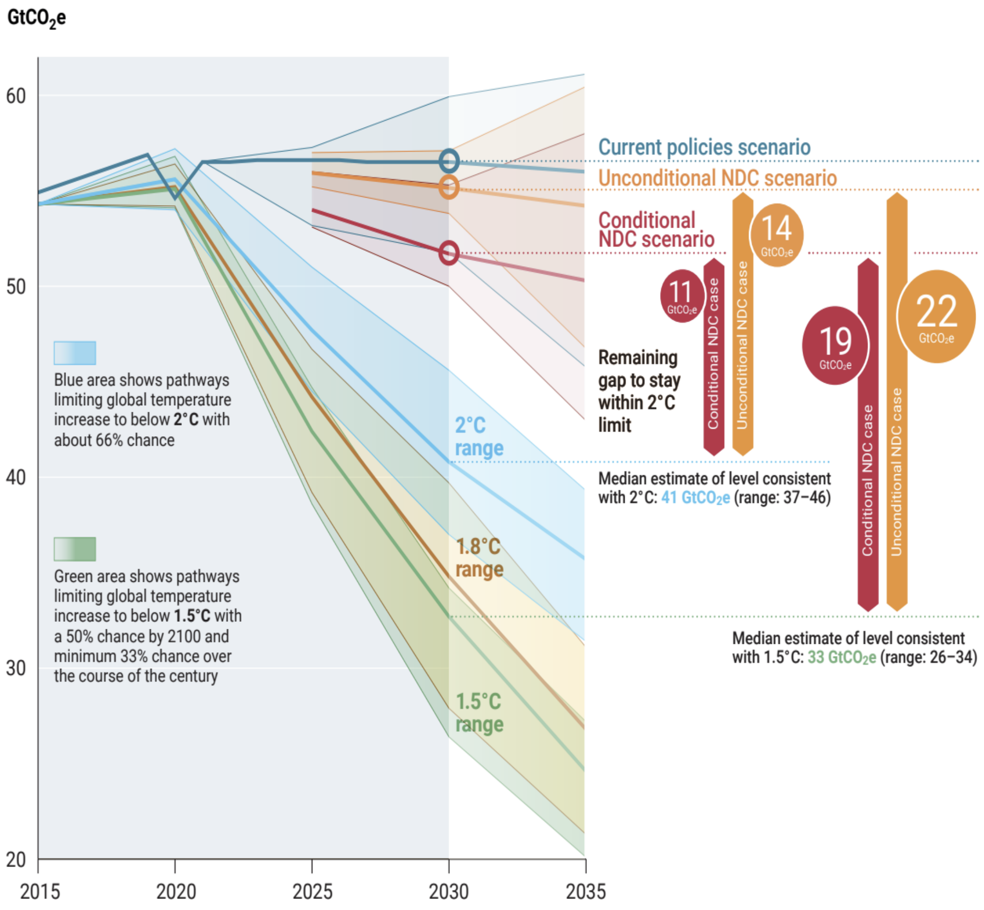
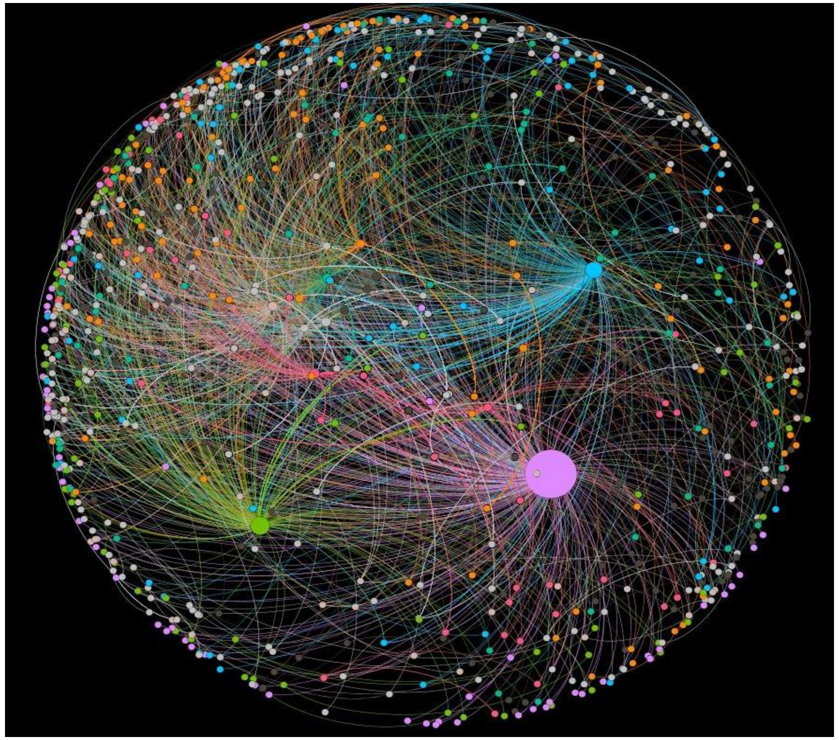


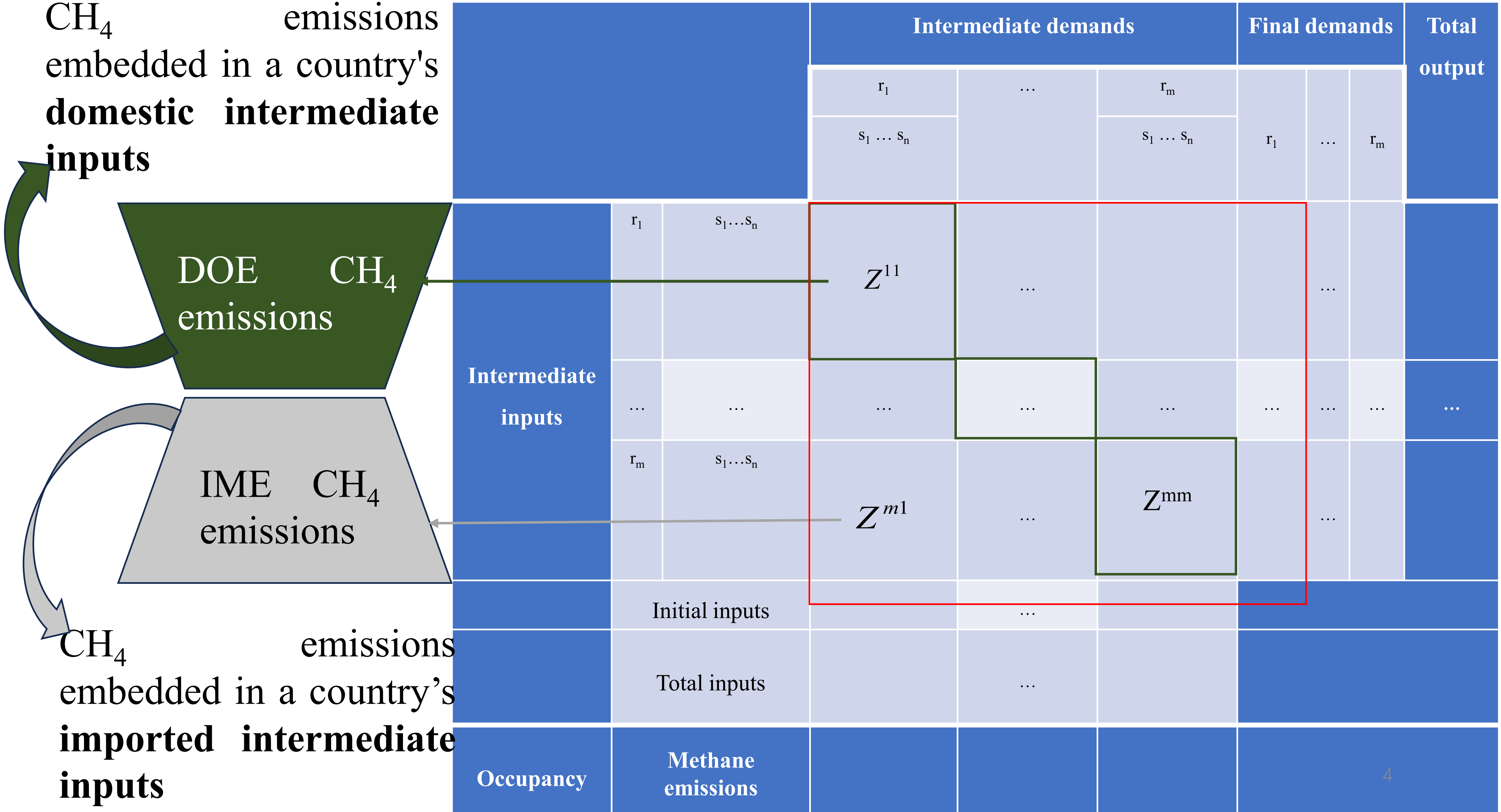
Figure 1. GHG emissions under different scenarios and the emissions gap in 2030 and 2035(UNEP, 2023)

2. Research aims

- to identify key pathways within the world **production network** by which CH_4 emissions can be reduced the most effectively.
- to make a valuable contribution by offering effective suggestions for international collaborative efforts in formulating evidence-based environmental policies and actions to reduce CH_4 emissions.



3. Methodology



3. Methodology

Step 1. divide matrix $\boldsymbol{Z}$ into limited number of layers

Step 2. calculate the embedded methane emissions for linkages in each layer of $\boldsymbol{Z}$

Step 3. set the first threshold and the incidence matrixes

Step 4. add up the incidence matrix of each layer and calculate their average

Step 5. set the second threshold and the incidence matrixes

Step 6. calculate $\boldsymbol{GME}=\left(\boldsymbol{GME}_{ij}\right)$

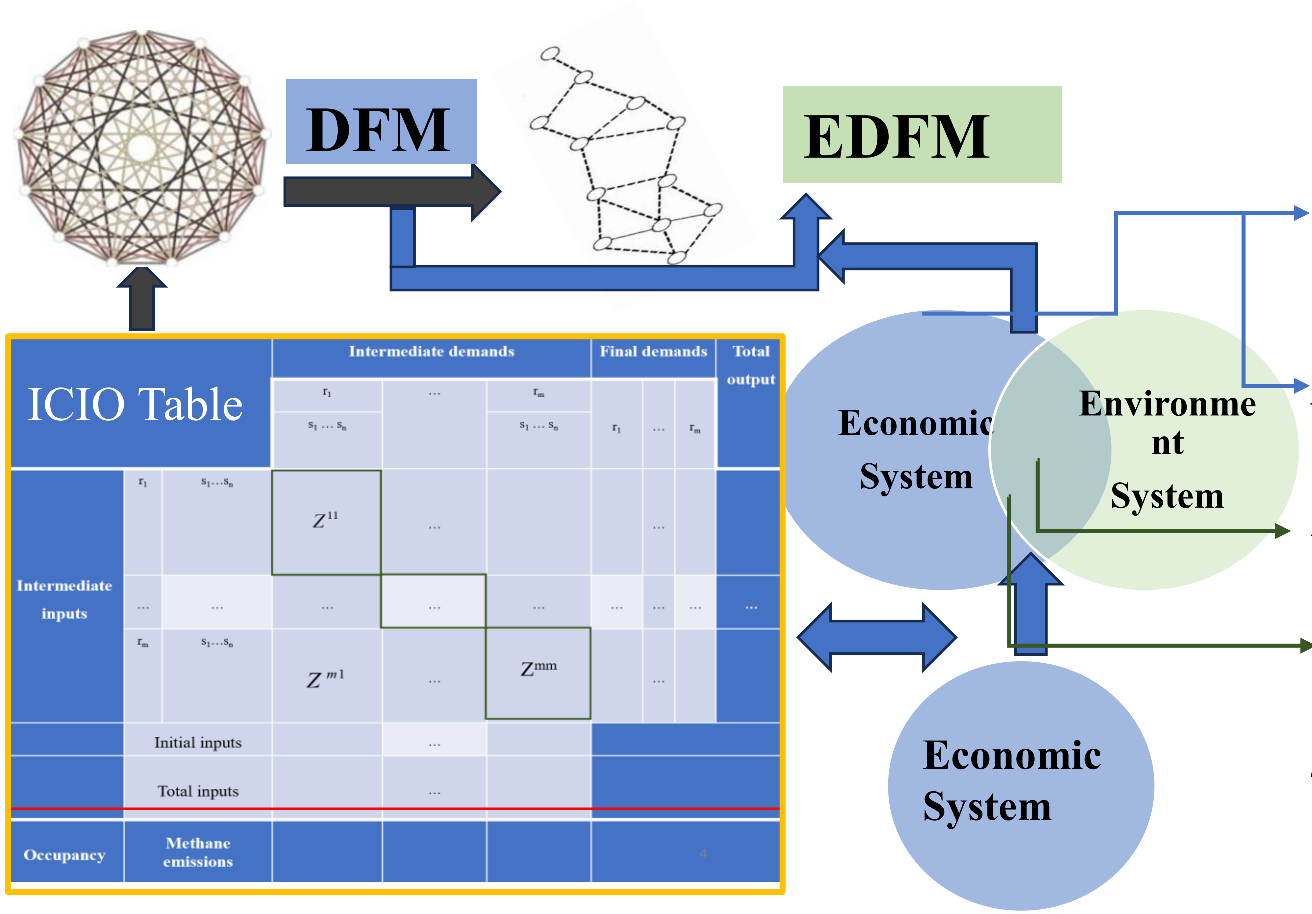
If $\boldsymbol{GME}_{ij}$=2, sector *i* and sector *j* are called as leading sectors of methane emissions. The network combined by the conjunctions among all the leading sectors is called as **the key pathways of methane emissions**.

This method is an extension of DFM method (Liu, 2018) in environment research. We call it EDFM in abbreviation.

Different with the previous studies, this method was from a view of industrial conjunctions in the world production and consumption linkages network to identify the key pathways of methane emissions.

The EDFM method is proposed to identify key pollutant emission pathways within complex economic-environmental systems.

The strength of the EDFM lies in its ability to identify key pathways from the perspective of inter-industry linkages, addressing the question of which specific economic activities, in which countries and sectors, drive how much methane emission.



$$Z_t = A_t *< \left(I + A_t + {A_t}^2 + {A_t}^3 + \cdots\right) * F_t >$$
$$= A_t *< F_t > + A_t *< A_t * F_t > + A_t * < (A_t)^2 * F_t > + \cdots$$

$$L_t^h = A_t *< (A_t)^h * F_t >$$

$$DME_{j,t}^s = \frac{ME_{j,t}^s}{xc_{j,t}^s}$$

$$DMEL_t^h = L_t^h *< DME_t >$$

$$TRME1_t = \frac{1}{k+1} * \sum_{h=0}^{k} \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} DMEL_{i,j,t}^h$$

…

4. Data Source

- The Inter-Country Input-Output (ICIO) Tables (OECD, 2024) and EDGAR 2024 (IEA, 2024) ⟶ **EICIO tables**
- Due to the various sector classification of ICIO and EDGAR v8.0, we have to merge the 23 methane sectors into 14 categories.

- 76 economies with 14 industries in each of the EICIO tables
- 38 OECD member countries and their major trading partners
- 2000-2020 annually

Table 1. EICIO sector code and sector name

Sector Code	Sector Name
1	Electricity and Heat Production
2	Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries
3	Manufacturing Industries and Construction, except Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries
4	Civil Aviation
5	Road and Rail Transportation
6	Water-borne Navigation
7	Other transportation
8	Solid Fuels, Oil and Natural Gas
9	Chemical Industry
10	Metal Industry
11	Enteric Fermentation, Manure Management, Emissions from biomass burning, Rice cultivations
12	Waste Treatment and Discharge, Residential and other sectors
13	Others
14	Household and Government Consumption

Tables 2. Countries/Regions in the EICIO tables

OECD countries		Non-OECD countries	
Abbreviation	Names of Countries	**Abbreviation**	Names of Countries
AUS	Australia	ARG	Argentina
AUT	Austria	BRA	Brazil
BEL	Belgium	BRN	Brunei Darussalam
CAN	Canada	BGR	Bulgaria
CHL	Chile	KHM	Cambodia
COL	Colombia	CHN	China (People's Republic of China)
CRI	Costa Rica	HRV	Croatia
CZE	Czech Republic - Czechia	CYP	Cyprus[2]
DNK	Denmark	IND	India
EST	Estonia	IDN	Indonesia
FIN	Finland	HKG	Hong Kong, China
FRA	France	KAZ	Kazakhstan
DEU	Germany	LAO	Lao People's Democratic Republic
GRC	Greece	MYS	Malaysia
HUN	Hungary	MLT	Malta
ISL	Iceland	MAR	Morocco
IRL	Ireland	MMR	Myanmar
ISR	Israel[1]	PER	Peru
ITA	Italy	PHL	Philippines
JPN	Japan	ROU	Romania
KOR	Korea	RUS	Russian Federation
LVA	Latvia	SAU	Saudi Arabia
LTU	Lithuania	SGP	Singapore
LUX	Luxembourg	ZAF	South Africa
MEX	Mexico	TWN	Chinese Taipei
NLD	Netherlands	THA	Thailand
NZL	New Zealand	TUN	Tunisia
NOR	Norway	VNM	Viet Nam
POL	Poland	ROW	Rest of the World
PRT	Portugal		
SVK	Slovak Republic		
SVN	Slovenia		
ESP	Spain		
SWE	Sweden		
CHE	Switzerland		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		

5. Results

- The key pathways selected by EDFM is representative, whose CH_4 emissions amount accounted for more than 60% of the total CH_4 emissions with only around 0.3% of 1,132,096 sector linkages in each year from 2000 to 2020.
- The annual average number of linkages in the selected key pathways is 2,683, with a standard deviation of 59.

- To optimize the use of annual EICIO tables to capture the phased characteristics of the key pathways, referencing the phases of climate change mitigation actions and global economic growth (see Methods), we segmented the annual key pathways for methane emissions from 2000 to 2020 into four phases: 2000-2007 (phase 1), 2008-2010 (phase 2), 2011-2015 (phase 3), 2016-2020 (phase 4).

5.1 DOE CH_4 emissions

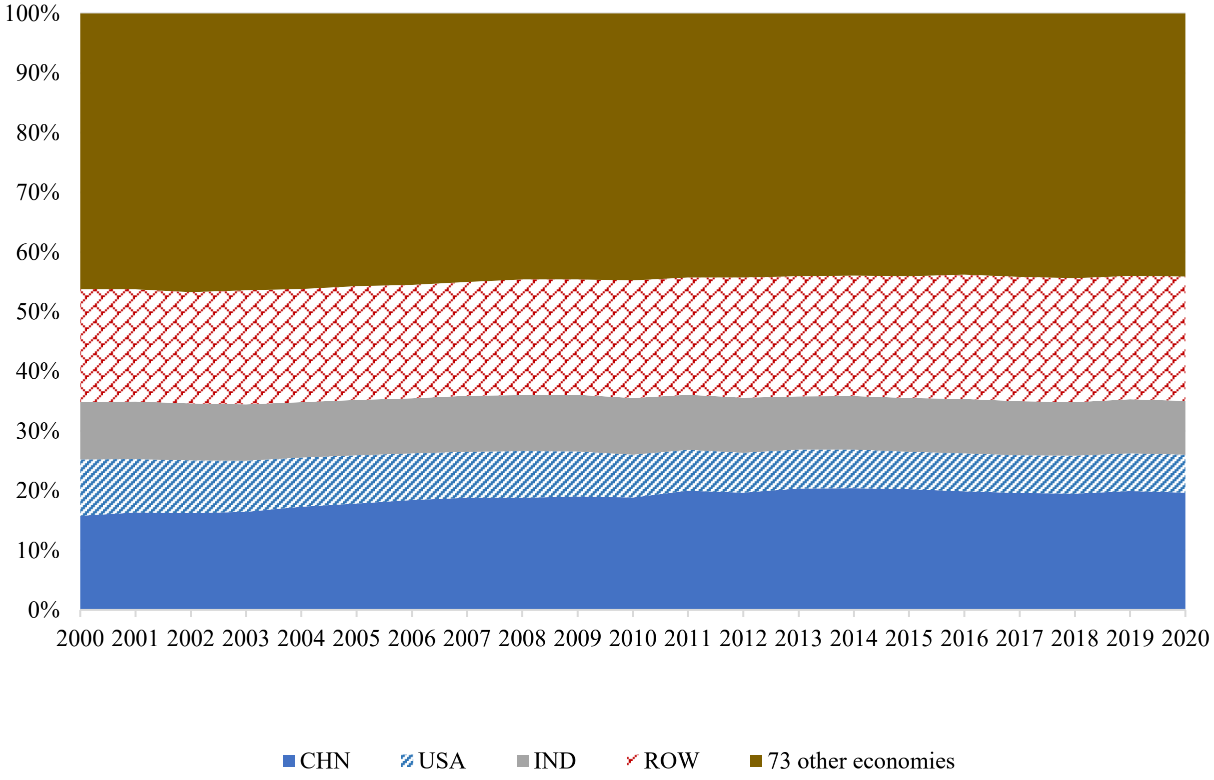


Figure 2. The proportion of the DOE CH_4 emissions of CHN, USA and IND, 73 other economies and the rest of the world (ROW) to the global DOE CH_4 emissions

DOE in the key pathways of China, the United States, and India consistently featured among the top three contributors over the 21 years, collectively contributing in the range 34.5%-36.1% of the DOE in the key pathways from 2000 to 2020

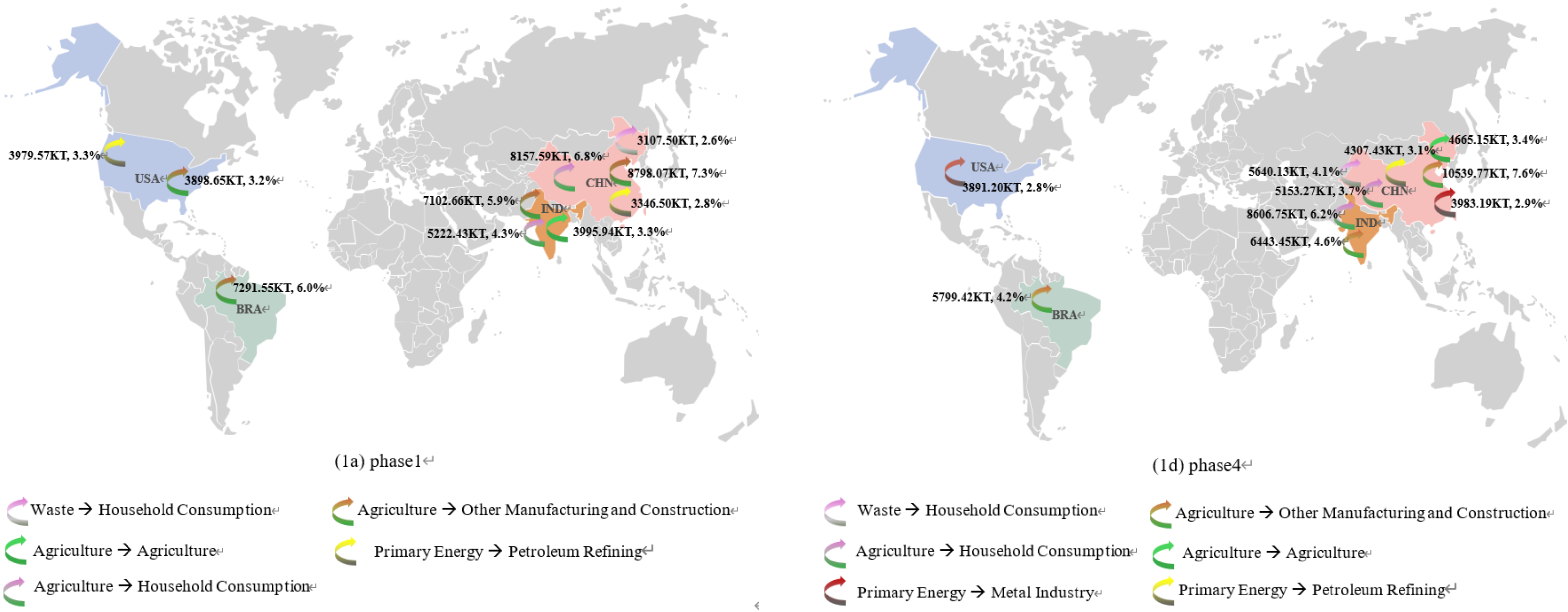
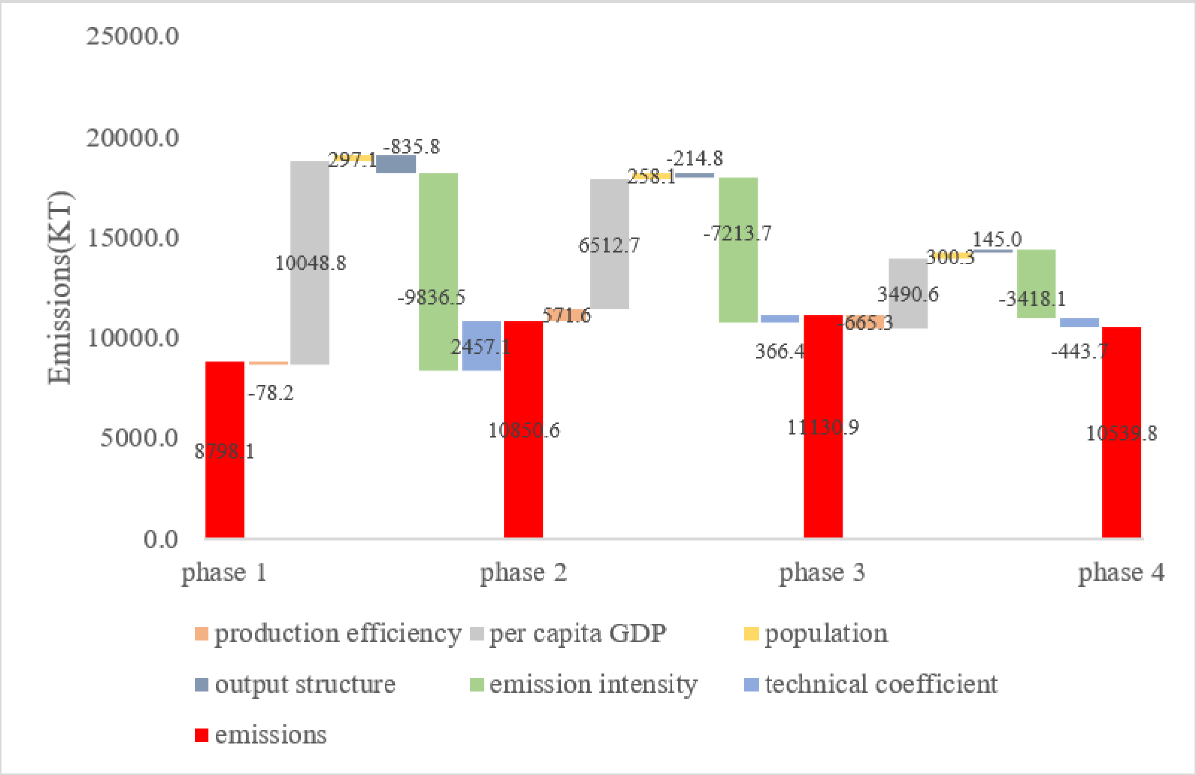


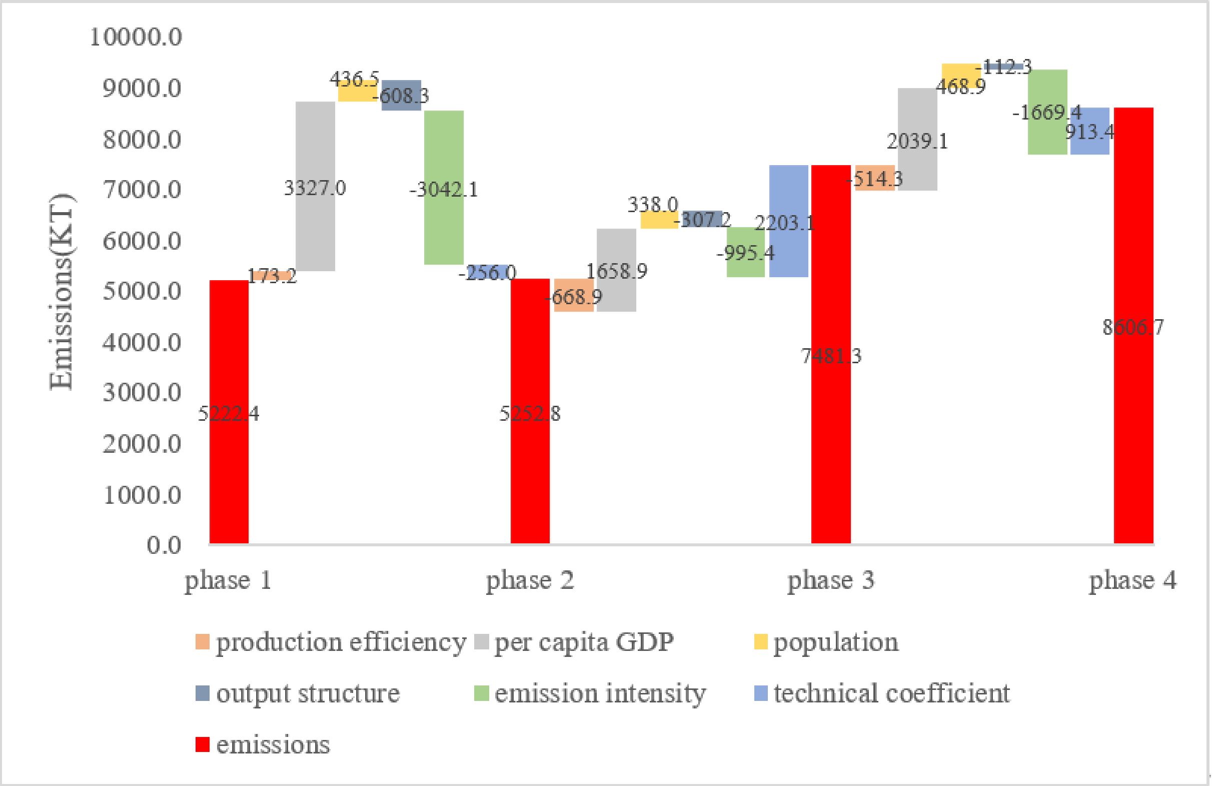
Fig. 3. Top 10 linkages by DOE (unit: KT) in key pathways across phases

DOE Results Analysis

- The sum of the DOE in the top 10 linkages account for around 45% of total DOE in the key pathways for each phase.
- These linkages were predominantly found in India, China, the United States, and Brazil, with the primary flows originating from the Agriculture, Primary Energy, and Waste sectors towards Other Manufacturing and Construction, Consumption, Petroleum Refining, and Metal Industry sectors.
- Notably, the DOE of the linkages from (China, Agriculture) to (China, Other Manufacturing and Construction) and from (India, Agriculture) to (India, Consumption) consistently occupied the top two positions throughout the four phases.

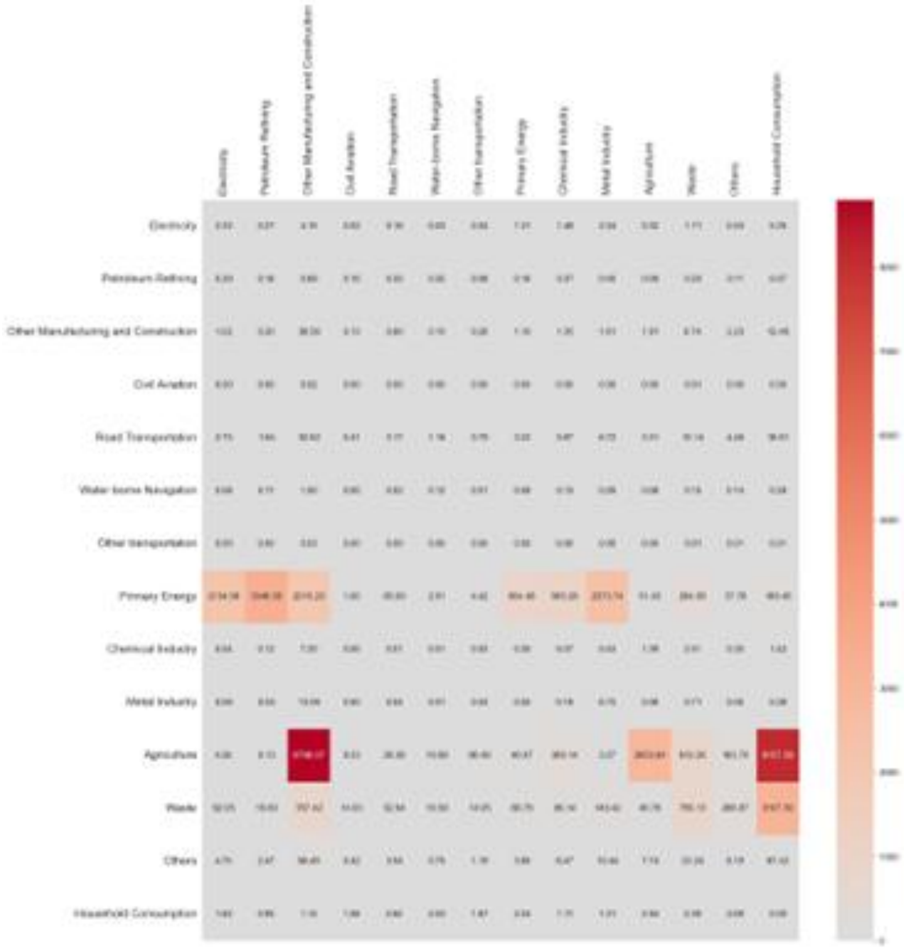


SDA results of (CHN, Agriculture) → (CHN, Other Manufacturing and Construction)

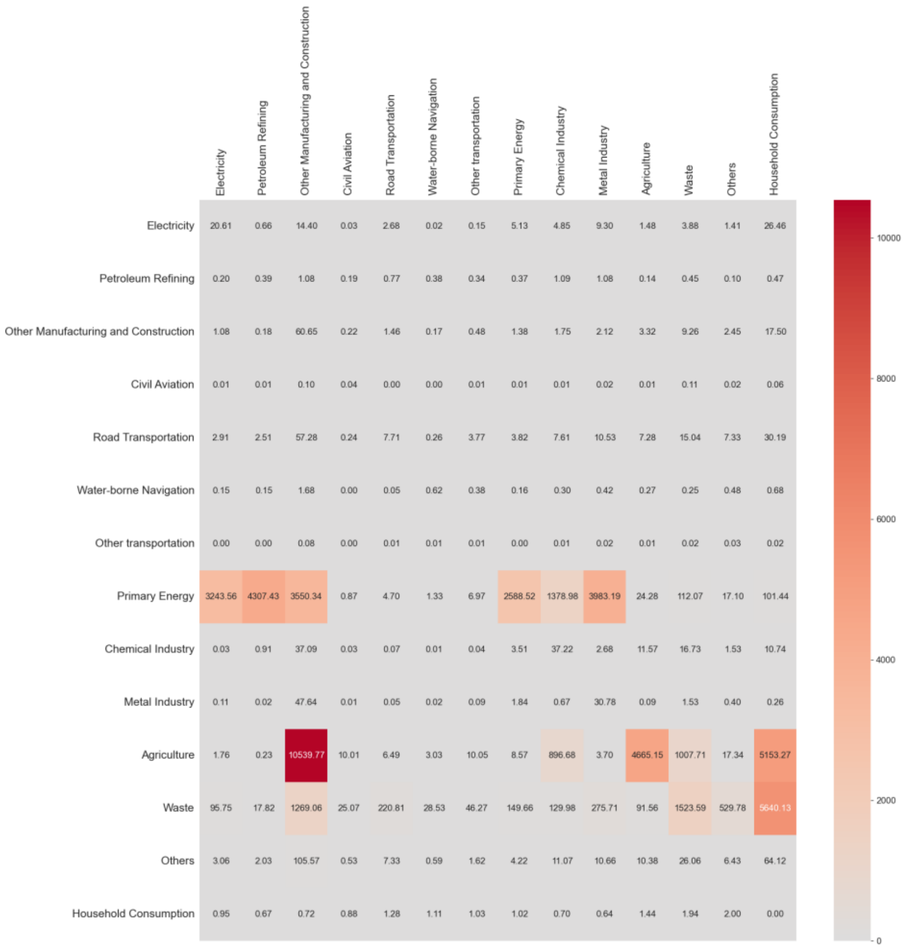


SDA results of (IND, Agriculture) → (IND, Consumption)

Note: In above figures, the number on each red column indicates the DOE of the linkage for each phase as specified in the subtitle, while the numbers between columns denote the contributions of six impacting factors to the reduction in the DOE between consecutive phases.



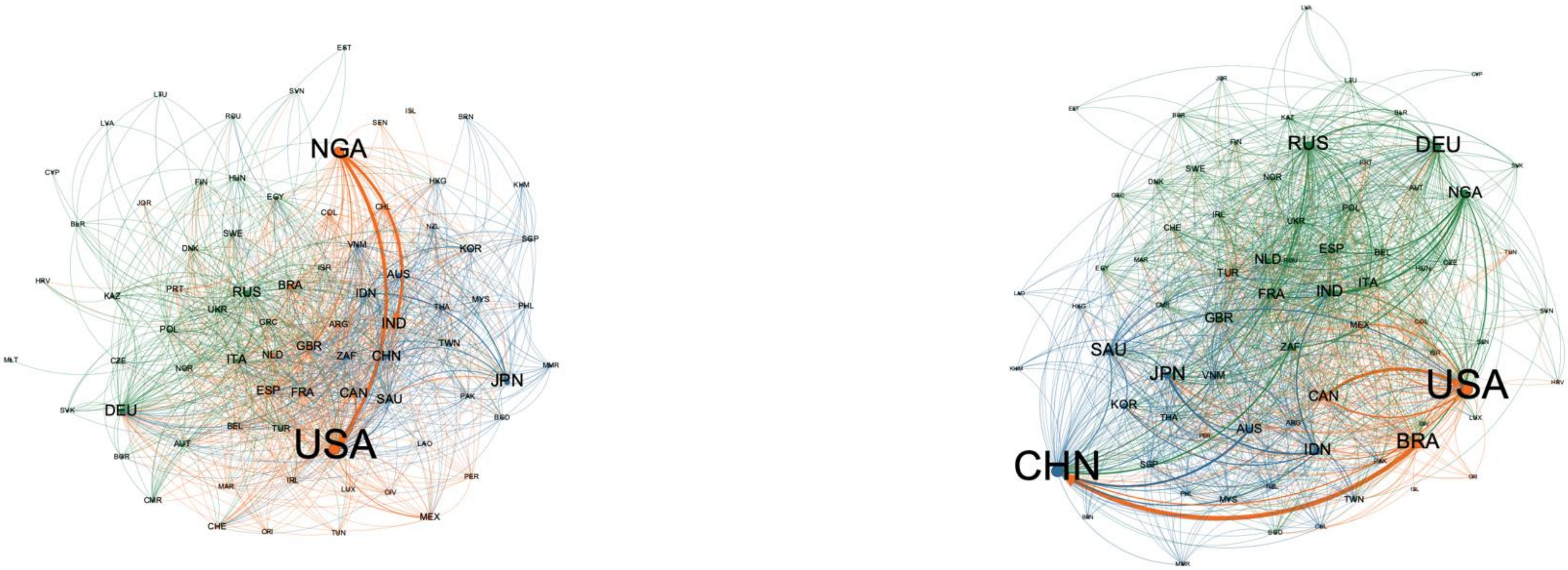
Phase 1



Phase 4

- The stability of the color depths reveals that the composition of DOE key pathways had been relatively stable in China, USA, and India throughout the 4 phases.

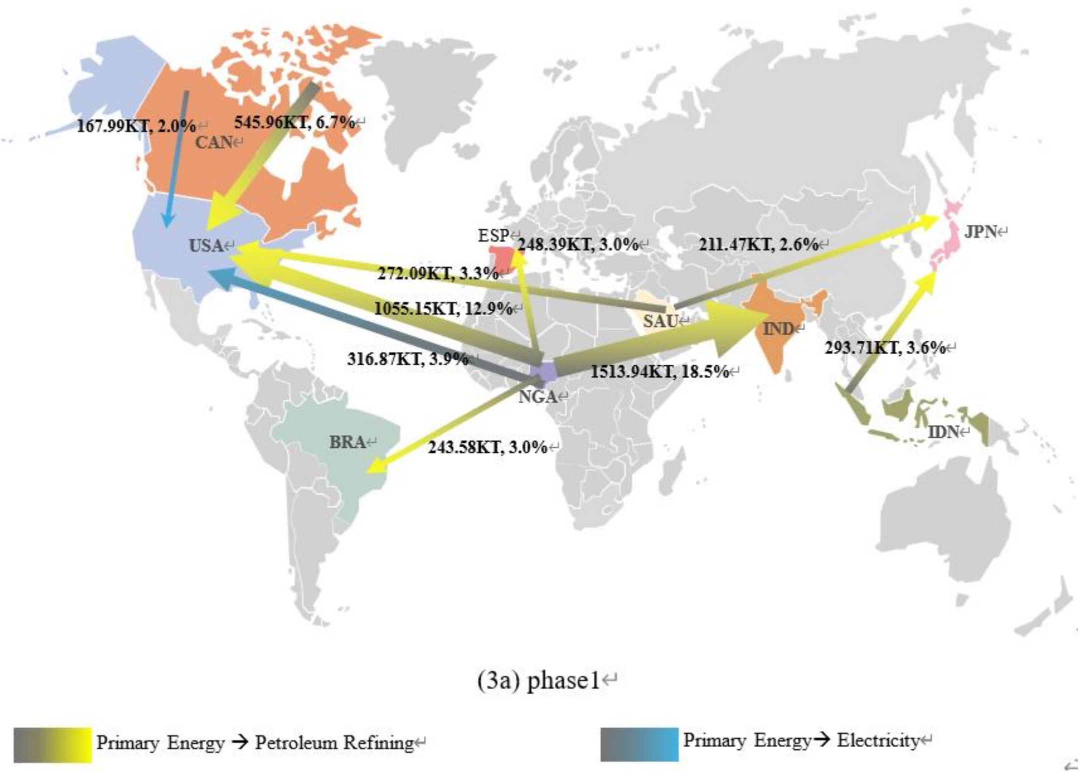
5.2 IME CH_4 emissions



Phase 1

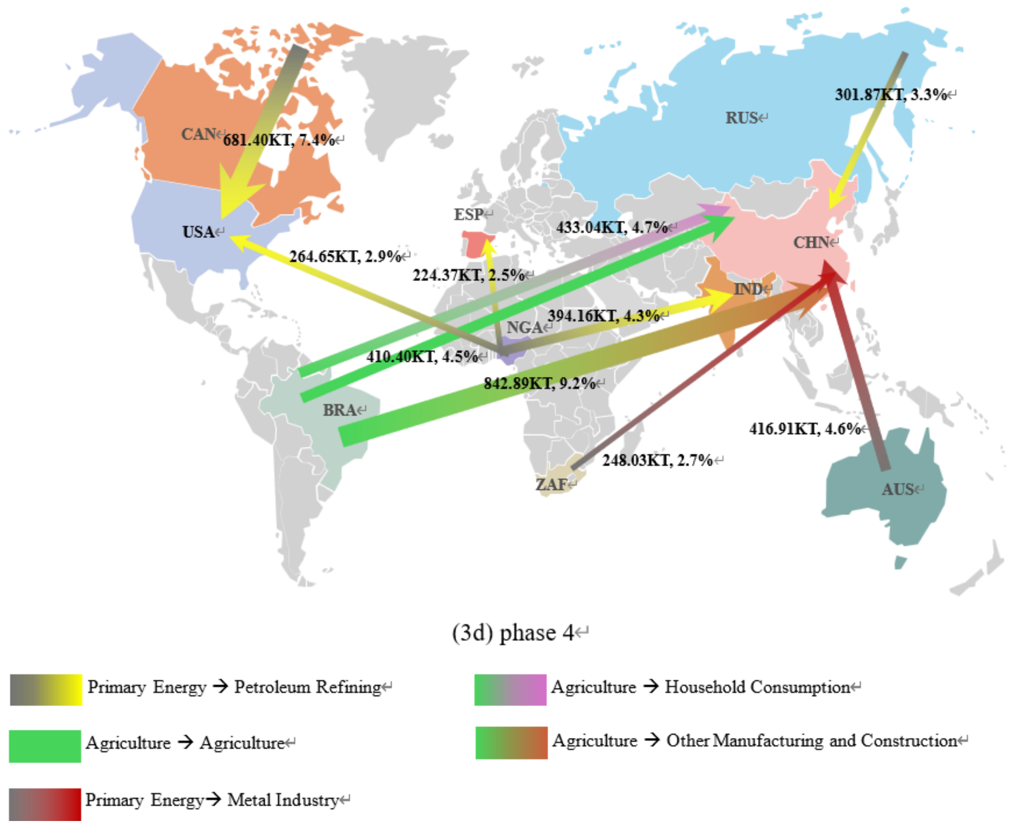
Phase 4

Fig. 4. Network combined by key pathways of IME among economies by phase



(3a) phase1

Phase 1



(3d) phase 4

Phase 4

Fig. 5. Top 10 linkages by IME (unit: KT) in the key pathways across phases

IME Results Analysis

- The key pathways of IME established emission communities with hub economies such as the USA, Russia and China at different stages.
- In the first stage, three emission communities were formed and centered around USA, Russia (RUS) and Japan (JPN).
- In phase 4, except China, Brazil (BRA) gradually took the outstanding position in the orange community, whose fourth phase IME accounting for 32.46% of the community’s IME. Conversely, the hub economy Germany in the European community experienced a 21.2% decrease in the IME by the fourth phase compared with the third phase.

Fig. 6. The decomposition in IME of (USA, Primary Energy) ⟶ (CAN, Primary Energy)

5.3 DOE and IME Reduction by 2025 in Two Scenarios

As we found emission intensity reduction and technical coefficient improvement were main contributors for the DOE and IME decrease, we predicted the methane emission intensity decrease (Table 3) and technological coefficients improvement of the input sectors in the key pathways in 2030, we estimated the methane mitigation potential through key pathways under scenario 1 (methane emission intensity reduction) and scenario 2 (technical coefficient improvement) in 2030.

Table 3. The reduction of DOE and IME in key linkages and corresponding cost in scenario 1 by emission intensity reduction

Origins	Targets	Emission Intensity in 2020	Predicted Emission Intensity in 2030	DOE/IME Reduction (KT)	Cost (billion $)
DOE related results					
('CHN', '11')	('CHN', '3')	0.0102	0.0017	8216.73	0.89
('IND', '11')	('IND', '14')	0.0362	0.0131	5872.72	0.58
('CHN', '12')	('CHN', '14')	0.0015	0.0002	5113.69	7.17
('CHN', '8')	('CHN', '2')	0.0203	0.0044	4578.19	0.33

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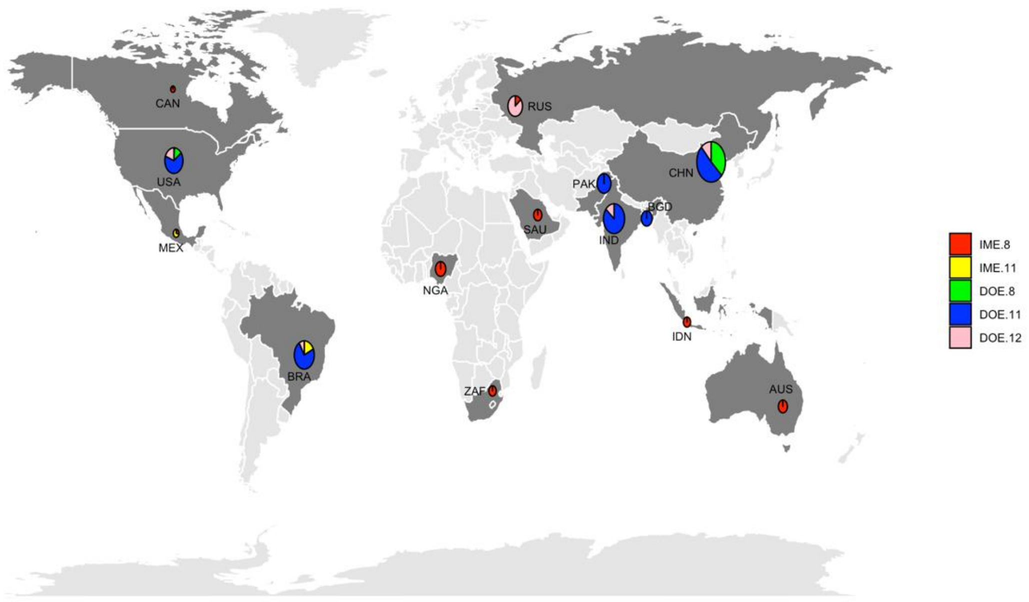
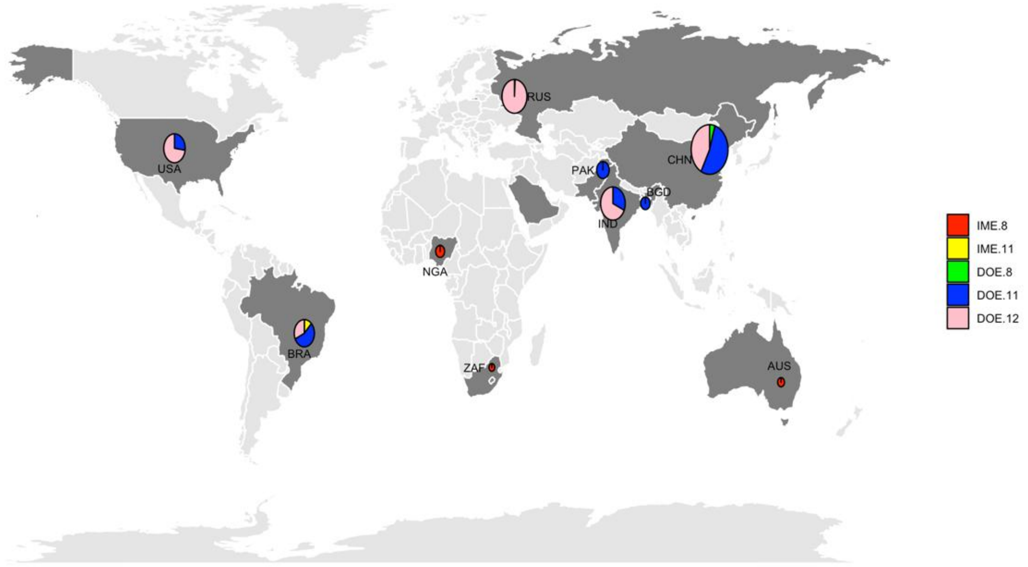


(6a) Proportion of methane emission reductions



(6b) Proportion of cost

(6c) The negative abatement cost proportion

Fig.6. Proportion of methane emission reductions and cost through emission intensity reduction of different sectors in key linkages in related economy

Findings in Scenario 1

- In Scenario 1, the combined reduction of DOE and IME in the key linkages identified represents 30.7% of global methane emissions recorded in 2020, indicating that the Global Methane Pledge by 2030 can be achieved.
- We conducted an extensive literatures review of methane emission reduction technologies widely applied up to January 2025, we then proposed detailed technological measures to reduce methane emission intensity for each key linkage's origin sector with optimal method. Under these measures, **the minimum total cost for achieving the emission reductions in Scenario 1 is estimated to be US$20.63 billion.**
- **The cost distribution is primarily concentrated** in DOE emissions from Sector 11 (Agriculture) in China (CHN), Brazil (BRA), Pakistan (PAK), and Bangladesh (BGD); DOE from Sector 12 (Waste) in Russia (RUS), India (IND), and China (CHN); and IME from Sector 8 (Primary Energy) in Nigeria (NGA), Australia (AUS), and South Africa (ZAF).
- **In contrast, negative abatement costs are predominantly observed in** DOE from Sector 8 (Primary Energy) in USA and IME from Sector 8 (Primary Energy) in Indonesia (IDN), Saudi Arabia (SAU), Canada (CAN), the United States (USA), and Mexico (MEX).
- These findings provide a practical pathway to achieve the Global Methane Pledge by 2030 through targeted interventions in the key linkages outlined in this study.

Scenario 2: Technical Coefficient Improvement

- The total reduction in DOE and IME emissions under scenario 2 amounts to 8,858.31 KT, constituting 4.5% of the global methane emissions in 2020.
- **In comparison, the combined reduction in DOE and IME across all key linkages in scenario 2 is substantially lower than that projected in scenario 1, with a shortfall of 66,907.72 KT.**
- **This marked difference underscores the critical importance of prioritizing the mitigation pathways outlined in scenario 1 to effectively fulfill the global commitment to reducing methane emissions.**

6. Conclusions

- This research developed an approach known as EDFM to identify key pathways within the intra-country and inter-country production networks that contribute the most to CH_4 emissions during the world production process.
- In contrast to previous studies, this research identified key pathways within intra-country and inter-country production and consumption networks across 76 main economies worldwide and their 14 industries, provided a practical way with emission intensity decrease through key pathways in scenario 1 to achieve the Global Methane Plague by 2030, reducing methane emissions 30.7% compared to 2020 level with the cost US$20.63 billion.
- Furthermore, the analysis of the DOE and IME key pathways assists major emitting countries in setting methane reduction actions and targets within their upcoming Nationally Determined Contributions (NDCs).
- Naturally, the proposed solution in this study is also applicable to the mitigation of other kind of greenhouse gas emissions.

7. Limitations and future research directions

- The low resolution of agricultural, coal mining industry etc. could cause uncertainty to the global analysis.
- The holistic analysis in this study lays the foundation for future studies, which will zoom in on specific industries within these pathways, such as Primary Energy and Waste Treatment.
- A more granular analysis will provide valuable insights into mitigation measures for the individual sector.

Thanks.

Your questions or suggestions please.

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